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9:10 (1A)-DDT 1

Simulating Deflagrations and Detonations with Detailed Chemistry

Florian ETTNER, Klaus G. VOLLMER, Thomas SATTELMAYER

When simulating detonations or the transition from a deflagration to a detonation (DDT), recent publications are often focused on high spatial resolution while chemistry is reduced to a one-step or two-step mechanism. This leads to good results when simulating established detonations, but in the case of DDT reaction parameters usually require a fit to the specific problem. Moreover, experiments have shown that quenching and reignition can play an important role for the onset of DDT. For this reason a reliable numerical tool for the investigation of DDT should include a chemical mechanism as accurate as possible. In the present paper a model including a detailed reaction mechanism is used to simulate clellayialions and detonations in tubes. The computational effort solving chemical reaction is minimized by an on-the-fly reaction mapping technique which can be combined with any reaction mechanism. It is demonstrated that this model is capable of qualitatively simulating both deflagrations and detonations and especially the transition between both regimes.

Deflagration to Detonation Transition in Binary Fuel H_2/CH_n with Air Mixtures

RemySORIN, Olivier BOZIER, Ratiba ZITOUN, Daniel DESBORDES The aim of the present study is to obtain deflagration to detonation transition data (LDDT) of *H//ICH*$_t$ - Air mixtures as a function of molar fraction x of H_2 into binary H_2/CH_4 fuel mixture, equivalent ratio **Φ** of the mixture and initial pressure P_0 at ambient temperature (T_0 = **293** K) A tentative of correlation between LDDT and detonation cell size *K* is done

Restructuring of a Flame due to a Preheated Zone as a Mechanism Underlying the Deflagration-to-Detonation Transition

Michael UBERMAN, Mike KUZNETSOV, Igor MATSUKOV, Anton IVANOV We present analytical, numerical and experimental studies of the mechanism underlying the deflagration-to-detonation transition (DDT). Insight into how, when, and where DDT occurs is obtained by analyzing analytically and by means of multidimensional numerical simulations dynamics of a flame accelerating in a tube with no-slip walls. It is shown that the deflagration-to-detonation transition exhibits three separate stages of evolution corroborating majority experimental observations. During the first stage flame accelerates and generates shocks far ahead of the flame front. During the second stage the flame slows down, shocks are formed in the immediate proximity of the flame front and the preheated zone ahead of the flame front is created. The third stage is self-restructuring of the steep temperature profile within the flame, formation of a reactivity gradient and the actual formation of the detonation wave itself. The mechanism for the detonation wave formation, given an appropriate formation of the preheated zone, seems to be universal and involves a reactivity gradient formed from the initially steep flame temperature profile in the presence ol the preheated zone The developed theory and numerical simulations are found to be well consistent with extensive experimental studies of the DDT in hydrogen-oxygen and ethylene-oxygen mixtures in tubes with smooth and rough walls.

Effect of Vortex Flow on Characteristics of Deflagration-to-Detonation Transition

Katsuo ASATO, Takeshi MIYASAKA, Yusuke KITOH, Yuta WATANABE The effects of rapid flame propagation and rotating velocity in the vortex flow (VF) on the characteristics of deflagration-to-detonation transition (DDT) were examined in order to control the DDT distance. A vortex flow field was established in the ignition and transition areas of the detonation tube using a VF-type injector to control the DDT distance, because the flame can propagate very rapidly depending on the rotating velocity in the VF. The distance for DDT was shortened by 15-56 %

when the VF injector was used, compared with that of a counterflow injector. The shortening effect becomes remarkable as the rotating velocity induced by the VF injector increases. However, the effect of the rotating velocity on shortening of DDT is deterred in the very strong turbulence due to the local extinction

9:10 (1B) - Modelling of Reactive System

POD/Galerkin Reduced Order Model of Tubular Reactor with Heat Recycle by Sampling of Chaotic Orbits

Katarzyna BIZON, Gaetano CONTINILLO

In this work, a POD/Galerkin method is applied to the 1D transient model of an autothermal tubular reactor with an external heat recycle, which generates complex oscillatory - periodic and chaotic - profiles of temperature and concentration. In the attempt of building an accurate reduced order model, a POD technique was applied to data sampled in the chaotic regime. The determined basis was then used to simulate the system's behavior by means of POD/Galerkin method for a wider range of the parameters i.e. far from the attractor of sampling. It was shown that the POD basis determined from the strange attractor, characterized by high spatio-temporal complexity, is able to capture correctly also periodic oscillatory profiles.

Predicting Flame Acceleration Using a Coherent Flame Model

Jennifer WEN, AH HEIDARI, Sergio FERRARIS, Vincent TAM

Flame acceleration is needed for the development of slow combustion front generating little overpressure to a severe gas explosion with a fast moving flame. A comprehensive review of the considerable volume of the work on this topic was recently given by Ciccarelli and Dorofeev with emphasis placed on experimental investigation It is well established through past experimental investigations that the presence of the obstacles would greatly increase flame speeds, overpressures, and could at high flame velocities a tendency for deflagration to detonation transition (DDT) compared to similar tests without obstacles. It was believed that turbulence in the unburned gas and the obstacles provide a powerful means of transferring mean flow kinetic energy into turbulent kinetic energy: Interaction of the flame with the obstacles promotes strong mixing and hence rapid combustion in the turbulent flame zone. Despite various attempt to numerically predict the dynamic three-way dynamic interaction of flame, turbulence and obstacles, there still lacks a robust code which can capture in detail this complex phenomena with accuracy. In the present study, a coherent flame model has been implemented into the large eddy simulation (LES) frame of the OPENFOAM code. Predictions are made between the predictions and the experimental data firstly for a spherical flame and then a rectangular shock tube. The reasonably good agreement achieved demonstrates the potential for the model to be further developed and extended towards predicting DDT.

Numerical Predictions of the Unburned Gas Flow Field Ahead of a Flame Propagating in an Obstructed Channel using Large Eddy Simulation

Craig JOHANSEN, Gaby CICCARELLI

Large Eddy Simulations of the unburned gas flow field ahead of a flame front propagating in an obstructed channel were undertaken. Rectangular obstacles were positioned on the channel top and bottom surfaces for the purpose of generating velocity gradients in the unburned gas flow field, promoting flame acceleration Simulation predictions are compared to a novel visualization technique developed to track the vortex that forms downstream of each obstacle. Good agreement was found between experimental results and numerical predictions for the initial vortex rollup period Results indicate that the vortex rollup is initially two dimensional. However, high levels of velocity at the inflow boundary result in large rates of strain near the obstacle leading edge causing three dimensional structures to form downstream Initial oscillations predicted in the centerline streamwise velocity account for the early oscillations of centerline flame velocity observed in the experiment.

Large Eddy Simulation of the Backdraft Phenomenon and its Mitigation in a Compartment Fire

Sergio FERRARIS, Ioana MAGDA, Jennifer WEN

In the present paper, a sub-grid scale model for partially premixed combustion has been implemented into a LES approach and applied to simulate a turbulent deflagration and its mitigation by water mist in a scaled-compartment with different open geometries. The present model is based on the coupling of independent approaches for non-premixed and premixed turbulent combustion. The flame index' concept was used to separate the two different combustion regimes. The simulations were conducted for the reduced scale tests of Weng and Fan. Reasonable

agreements have been obtained for parameters such as specie concentrations, total mass outflow and inflow, maximum pressure and likelihood of the occurrence of the fire ball outside the container. The numerical simulation has demonstrated the mitigation effect of water mist by reducing the laminar burning velocity of the mixture. Finally, important aspects of the deflagration depending on end opening geometries are commented

9:10 (1C) - Flames in 1C Engines

Evaluation of Morphological Effect on Behavior of Aggregated Particles by Thermophoresis

Sayaka SUZUKI, Kazunori KUWANA, Ritsu DOBASHI

Soot is a main pollutant emitted from combustion devises. It is important for appropriate emission control of combustion devises to understand the behavior of soot particles in combustion fields. If the size of a particle is very small, that is, as small as the mean free path of the ambient gas, the particle under a temperature gradient experiences a force toward the colder region. This phenomenon is called thermophoresis, a mass transfer phenomenon induced by the temperature gradient. Soot is a very small particle formed near a combustion field, where a very steep temperature gradient exists. In order to appropriately understand the soot formation process in a combustion field, the effect of thermophoresis must be taken into account. In this study, simultaneous measurements of the velocities and the sizes of aggregated carbon particles were performed to examine the effect of particle morphology on the thermophoretic velocity. Fourteen different samples of carbon black particles with well-defined aggregation characteristics were used to represent soot particles. However, thermophoretic coefficient, which corresponds to the slope of the graph, is different between samples This difference is thought to be affected by particle morphology of each sample. In this study, a new factor, dimensionless density, which is the ratio of the bulk density to the true density, is introduced as a morphological factor of aggregated particle The structure of particles is closer as the dimensionless density gets greater. Using the dimensionless density can realize to evaluate the morphological effect of aggregated particle on thermophoresis regardless of the types of the aggregated particles It shows that the higher the bulk density is, the smaller the thermophoretic coefficient is (i.e., the slower the thermophoretic velocity is). As the dimensionless density decreases, the thermophoretic coefficient seems to approach the value for the free-molecular regime, $K_{,h}$=0.55. This means the smaller dimensionless density leads the behavior of aggregated particle which is even in the continuum regime to be the similar to that of the small, primary particle which is in the free-molecular regime.

Two-Stage Combustion Mechanism in Gasoline Engine for CO_2 Emission Reduction

Hikmet ARSLANH. Rafig MEHDIYEV, Piotr WOLANSKI

Although internal combustion (1C) engines are not the only sources for $C0_2$ production, their contribution is significant. There is an agreement between European car manufacturers and European Community to reduce $C0_2$ emissions from new passenger cars to 120 g/km by 2012, meaning a 30% drop relative to 2000 emission level In 2012, manufacturers will have to pay a penalty of €20 for every g/km $C0_2$ emission exceeding 120 g/km, multiplied by the number of vehicles sold. This penalty rises to €95 as of 2015 Such a target creates a significant challenge to the automotive gasoline engine, which typically produces higher $C0_2$ emission than the diesel counterpart as a result of poor part-load efficiency and low compression ratio When all of these facts are taken into consideration it is obvious that $C0_2$ emission reduction in spark ignition engines is a challenging research area and a significant issue for global warming. Stratified charge engines have the characteristics of the two most popular forms of combustion used in 1C engines. A non-homogenous mixture is formed in the combustion chamber, like in diesel engines. Conventional gasoline engines have stoichiometric mixture in every part of the cylinder. However, stratified charge engines have rich mixture near the spark plug and lean mixture in the cylinder, globally. This non-homogenous mixture is obtained usually with the modification of the piston geometry. The geometry of the intake manifold can also be modified. Since there is a lean mixture in the combustion chamber globally, stratified charge engines have a lower knock tendency than the conventional gasoline engines. Due to this fact, the compression ratio of a stratified charge engine can be higher than the compression ratio of a conventional gasoline engine: higher then 12 is possible A higher compression ratio leads to a higher efficiency. Moreover, the existence of a lean mixture in the combustion chamber leads to lower fuel consumption. $C0_2$ emissions from automobiles are related to fuel consumption Improving the fuel efficiency of a vehicle leads to a decrease in $C0_2$ emission. As it is known, burning of stratified mixture could be a very effective way to increase the fuel economy and decrease $C0_2$ emissions in gasoline spark ignition engines. It was expected that stratified charge engines have a potential to attain 20% reduction in fuel consumption.

Numerical Analysis on the Interaction between Flames and Preflame Reactions under a Knocking Condition
Shinji KOJIMA, Yasuhiko OHTA
We investigate the interaction between laminar-flame and preflame reactions with an aid of numerical simulation of steady laminar flame propagation of various-grade partially reacted n-heptane/air mixtures laid under high temperature and high pressure condition where knocking may appear The results indicate the following:
1. The laminar burning velocity is changed by the interaction between flame propagation and preflame reactions
2. The preheat-zone structure of the laminar flame changes, by the introduction of intermediate species into the zone.
3. The influx composition of almost cool-flame appearance increases laminar burning velocity, presumably due to the radical pool introduced into the preheat zone.
4. The effect of active intermediates in the influx composition of after cool-flame occurrence is defeated probably by the decreased enthalpy of the composition.
More detailed chemical kinetic interpretation of these behaviors is currently being carried out.

Kinetics of Ion Formation in Gasoline Flames of Internal Combustion Engines -Numerical Investigation
Alexei MIGOUN, Andrey CHERNUKHO, Adam CENIAN
Electrical probes are used for diagnostics of combustion process in internal combustion engines. **A** wider application of this diagnostics techniques depends on the knowledge of ionization processes in gasoline flames. **A** modified kinetic mechanism of combustion in n-heptane/isooctane/air mixture is proposed. The approximation of OD adiabatic reactor of constant volume was used in order to simulate the combustion in internal combustion engine. Time evolution of gas temperature and main ions mole fractions are investigated at different equivalence ratios of gasoline/air mixture.

11:45 (2A)-DDT2

Deflagration-to-Detonation Transition in Obstructed Spaces
Vadim GAMEZO, Takanobu OGAWA, Elaine ORAN
We consider two-dimensional **(2D)** unconfined arrays of obstacles, and model the flame propagation through these obstructed **2D** spaces. For these configurations, the gas flow and wave propagation are only restricted by obstacles, but not by any external confinement Key mechanisms of flame acceleration and DDT are similar to that observed in channels with obstacles, though shock-shock interactions play a more important role for **2D** arrays.

Simulation of FA and DDT in a Channel with Repeated Obstacles with an Under-Resolved Mesh
Knut VAAGSAETHER, Dag BJERKETVEDT
This paper present results from simulations of flame acceleration and DDT in a channel with repeated obstacles. The computational mesh is under-resolved compared with flame or detonation front thickness. The results are compared with experimental findings. The simulation results show that the simulation method can reproduce the effects seen in experiments and it is possible to simulate different flame propagation regimes like choking regime and quasi detonations

DDT Test of Binary Fuel - Air Mixtures in an Obstructed Channel
Sergey MEDVEDEV, Alexey POLENOV, Sergey KHOMIK, Boris GELFAND The benefit of the hydrogen combustion is a reason for development of prospective fuel compositions. The use of binary mixture of hydrocarbons and hydrogen is one of the possibilities to extend kinetics and thermodynamics fuel properties The aim of the present work is experimental and theoretical investigation of the DDT in hydrogen-methane(propane)-air mixtures in channels with periodically placed obstacles. The results of experiments on deflagration-to-detonation transition in 54 mm tube were compared with the data gathered in 141 mm tube. It was shown that limits of DDT depend both on the relation between components in binary fuel hydrogen-methane(propane) mixture and scale of the setup. The peculiarities of the DDT process in binary fuel - air mixtures are determined by the behavior of detonation cell size.

11:45 (2B) - Jet Ignition

The Spontaneous Ignition of Under-Expanded Hydrogen Jets Released into Air
Brian MAXWELL, Matei RADULESCU

The present study addresses the ignatability of pressurized hydrogen jets. A sudden puncture in a high pressure fuel tank leads to a highly compressible jet release driving a strong shock. The high temperature induced by the shock wave can trigger ignition in regions behind the shock where the gases have mixed. A simple model was developed to predict whether ignition is possible, which takes into account the initial conditions of the |el and shock strength, the rate of expansion of the jet head, and the evolution of the chemical structure of the mixing layer. The mixing process is modeled through the homogenius mixing ignition model The critical point of ignition was found to depend on the competition between the heat addition due to chemical reactions, and cooling due to expansion The rate of expansion of the gas during the release is governed by the mass flow rate from the orifice. Finally, ignition was predicted in terms of critical orifice dimensions and storage pressures. The results were found in excellent agreement with existing experimental data.

Investigation of Hydrogen Ignition During Outflow into Atmosphere from High Pressure System

Pawel OLESZCZAK, Piotr WOLANSKI

The first investigations concerned with a problem of ignition of hydrogen during outflow from the high pressure installation were carried out nearly 40 years ago by Wolanski and Wojcicki. The research was concerned with a dramatic accident in Chorzow Chemical Plant "Azoty", where explosion of synthesis gas (hydrogen-nitrogen mixture, $3H_2$-N_2, 300°C, 30 MPa) had killed four people. After initial investigation, potential external sources of the ignition had been exluded and the main aim of the research was to determine the real source of the ignition. Hydrogen is regarded as a perspective fuel for various kinds of vehicles: fuel cell cars, trucks, buses etc. The crucial safety problems are concerned with storage of hydrogen at a very high pressure. High pressure of hydrogen storage causes potential risk of a sudden rapture of tank or of a high pressure installations which can lead to ignition and potential explosion. Mixing of the hydrogen and air heated up by the shock wave generated by expanding hydrogen can cause an ignition of produced combustible mixture. The aim of this research is the investiagtion of hydrogen ignition as a result of compression and heating of the air by shock wave generated by the discharge of hydrogen and also determination of critical pressure which can lead to ignition. The experimental tests have been conducted on a facility constructed in the Combustion Laboratory of the Institute of Heat Engineering, Warsaw University of Technology. Test with various configurations have been performed to determine critical conditions for high pressure hydrogen ignition to occure. The critical pressure for ignition depends mainly on geometrical configuration of an outflowing system (tube diameter) and presence of obstacles. To compare the experimental results with the theoretical analysis series of numerical calculations using Gambit 2.3 16 and Fluent 6.3.26 software were performed. The main aim of the calculations was to find a difference between experiments and numerical analyses to correct reaction mechanism used in the calculations. It was found that the use of simplified, one reaction mechanism gives unrealistic results and underestimates critical hydrogen pressure required for the ignition. The paper presents results of experimental and numerical investigations of the high pressure hydrogen outflow ignition.

Numerical Study on Auto-Ignition of a High Pressure Hydrogen Jet in a Tube Having a Gap

Naoki KITABAYASHI, Yamada EISUKE, A. Koichi HAYASHI. Nobuyuki TSUBOI In this study, a direct numerical simulation with a detailed chemical model is performed to clarify the ignition mechanism of high pressure hydrogen jet spouting from a tube having a gap at the inlet of the tube. A condition inside the tube is important when a hydrogen ignition is caused outside and inside the tube. The present calculation needs more to see an auto-ignition. The different gap system in the will be checked for the full paper, which may cause auto-ignition.

11:45 (2C) - Multiphase Reactive System 1

A study on the Molecular Aspects of ignition in Energetic Materials through Simplified Means

Frederick PAQUET, Hoi Dick NG

In order to fully model the combustion of energetic materials, the ignition process and condensed phase chemistry must be well understood. Molecular dynamics is currently the only way to study condensed phase combustion but this methodology involves highly complex calculations. In this work it is proposed to use spectroscopy data and statistical mechanics to compute the distribution of bonds with dissociation energy in a given energetic molecule. The advantage of the proposed technique is to use empirical data instead of the complex molecular dynamics calculations. Results obtained with the nitroguanidine molecule are shown to yield a sudden increase in the distribution curves at specific temperatures.

Reduced Order Dynamical Modeling of a Non-Isothermal Circulating Fluidized Bed Combustor

Katarzyna BIZON, Gaetano CONTINILLO

This work reports on the development of a 1-D dynamical model of circulating fluidized bed combustors, which integrate simplified hydrodynamics and fuel combustion. In order to emphasize the dynamical aspects, the model details are kept to a minimum. However, it is desirable to express the original model as a set of ordinary differential equations of the lowest possible order. Empirical reduction methods are interesting in that, in principle, they can incorporate information derived both from detailed model simulations and experiments In this work, in order to construct a light yet faithful reduced order dynamical model, a POD/Galerkin method has been illustrated and applied, based on full model simulation data. We have shown that, at least in the case of non-oscillatory regime, the system can be successfully projected onto just four POD modes, while retaining all qualitative features of the spatial distribution and, to engineering purposes, even quantitatively at steady-state. To provide accurate results in the transient, 24 modes are found to be sufficient. The introduction of the energy balance, leading to a non-isothermal system, is expected to exhibit more complex regimes, for which a larger number of modes are expected to be necessary to accurately reproduce the system dynamics.

Auto-ignition of Metal Particles in Oxygen Atmosphere

Vladimir LESCHEVICH, Vitaly MIRONOV, Oleg PENYAZKOV

Today metal powders, are widely used as fuel additives in various energetic materials such as propellents, explosives, and pyrotechnics due to its high volumetric and gravimetric combustion enthalpy. Recent numerous experimental studies were connected with the explosibility of metal dusts. With the view of determining conditions that can provoke spontaneous ignition of the metal dust we have conducted this research work. The Rapid compression machine was used in this study. The obtained data are useful for understanding the basics of multiphase media combustion, as well as for evaluating the explosion hazard. The auto-ignition was investigated at pressures ranged from 1,5 MPa and temperatures ranged from 800 K The different separated and not separated metal particles were studied

14:40 (3A) - Detonation Structure 1

Numerical Investigations of Spinning Detonations in a Circular Tube by One-step Reaction Model

Yuta SUGIYAMA, Akiko MATSUO

Spinning detonations propagating in a circular tube were numerically investigated with a one-step irreversible reaction model governed by Arrhenius kinetics by changing the activation energy and. The stability of spinning detonation in a circular tube depended not only on the activation energy but also on the diameter. In the case of D<Dcr, spinning detonation kept its propagation as unstable mode, and maximum pressure on the shock front oscillated, whereas, in the case of D>Dcr. spinning detonation kept its propagation as a stable pitch, and maximum pressure on the shock front keeps almost the same value.

Numerical Study of Three-dimensional Detonation Wave Dynamics in a Circular Tube

D.-R. CHO, Soo-Hee WON, Edward Jae-Ryul SHIN. Jeong-Yeol CHOI Three-dimensional structures of detonation wave propagating in circular tube was investigated using a parallel computational code developed previously. A series of parametric study for a circular tube of a fixed diameter gave the formation mechanism of the detonation cell structures depending on pre-exponential factor, k. The unsteady results in three-dimension showed the mechanisms of the multi-cell mode of detonation wave front structures same as the two, three, four and six cell mode. The detonation cell number was increased but cell width and length were decreased with increased pre-exponential factor k. In the all multi-cell mode, the detonation wave structure and smoked-foil records on the wall are made by the moving of transverse waves. The detonation wave front structures have the regular polygon and windmill shapes periodically.

Experimental Detonation Propagation Under High Loss Conditions

Scoft *JACKSON, Bok Jik LEE. Wei HUANG, Florian PINTGEN. Jim KARNESKY, Zhe LIANG, Joseph SHEPHERD*

In previous work, detonation propagation in tubes has been observed to occur at velocities well below the ideal Chapman-Jouguet velocity D. Such velocity deficits are thought to result from the presence of nonideal boundary conditions, which are not typically accounted for in theory The growth of viscous and thermal boundary layers serve to remove energy from the reacting flow through frictional dissipation and heat losses to the cooler tube wall. In situations where the reaction zone length is small relative to the tube radius, these losses have a limited effect on detonation, presumably because the sonic surface quickly isolates them from the chemically reacting gas driving the front. However, as mixture sensitivity decreases, the spacing between the shock front and the sonic surface grows and allows the loss mechanisms increased time to act on the reaction zone. The resulting decreased detonation velocities, termed "sub-CJ detonations," are observed in marginal conditions and range from 0.8**-1** 0D before failure of the detonation occurs But in extreme cases, "low velocity detonations" with average wave speeds as low as 0.5D have been recorded. Other researchers have used microwave interferometry to obtain instantaneous velocity measurements showing that these low velocities are actually due to a combination of highly unsteady stuttering or galloping waves However, due to the long wavelengths associated with these oscillatory modes, it is not clear if they are a persistent phenomena or simply a transient pathway to complete failure. Furthermore, the scaling of these modes is unknown since most measurements to date have been performed in tubes with identical 38-mm inner diameters. To address these issues, we have performed studies of detonation propagation in a variety of different conditions. Results are presented for detonations in propane and hydrogen mixtures with tube diameters ranging from **1**.27-6.35 mm and tube length-to-

diameter ratios ranging from 194-10,350. Average velocity measurements obtained from transducer transit times and high-resolution velocity measurements from a high-speed camera are reported. Velocity deficits as large as 0 5D were observed in propane mixtures when the induction zone length was large relative to the tube diameter. Such extreme deficits were not observed to occur with hydrogen mixtures, which exhibited no combustion waves slower than 0.8D. High-resolution velocity measurements showed that the deficits were not due to boundary layer displacement effects smoothly slowing the detonation to a constant velocity, but rather from the wave propagation oscillating between a detonation and a coupled shock-flame complex in a stuttering or galloping fashion. With decreasing mixture sensitivity, the coupled shock-flame mode became more prevalent, although the oscillations persisted right up until total failure of combustion in the tubes tested.

14:40 (3B) - Combustion Induced Vortex Breakdown 1

Prediction of CIVB Driven Flame Flashback for CH_4-H_2-Air Mixtures and Moderate Turbulence

Marco KONLE, Thomas SA TTELMA YER

Under certain conditions the reliability of swirl stabilized lean premixed gas turbine burners is limited by sudden flame flashback leading to overheat and severe damage. In former studies Combustion Induced Vortex Breakdown (CIVB) has been identified as one possible cause. This phenomenon is characterized by a formation of a closed recirculation bubble generated by production of negative azimuthal vorticity. Anchored at this bubble, the flame can start propagating upstream on the burner axis against high axial flow velocity with propagation speeds far beyond the turbulent flame speed. Especially burner systems without central bluff body and aerodynamic stabilization are prone to CIVB, but even for burners with a central obstacle flame propagation caused by CIVB can be observed. A numerical URANS study and new experimental investigations lead to the conclusions that the force driving the sudden flame propagation stems from the production of negative azimuthal vorticity and that its magnitude correlates well with the relative position of the flame with respect to the propagating recirculation bubble. On the basis of these findings an extended scaling law for the prediciton of CIVB driven flame propagation was proposed and published recently. It is shown there for natural gas that the model allows the calculation of the CIVB limits with high accuracy in the entire operation range covered in the study (22.000<Re<100.000) on the basis of one single reference measurement. In this paper an investigation concerning the extension and validation of this model for fuel mixtures containing up to 40% vol. hydrogen is presented. The successful coupling of this newly defined scaling law with the former model of Kroner et al. will be presented for CH_4-H_2-air mixtures in more detail at the conference.

Large-Eddy Simulation of Combustion-Induced Vortex Breakdown in an Unconfined Vortex

Eike TANGERMANN, Michael PFITZNER, Hannes KROGER, Egon HASSEL Combustion-induced vortex breakdown (CIVB) has been identified as a very complex mechanism for flame flashback in swirl stabilised lean premixed combustion. In the present study Large-Eddy-Simulations of the CIVB in an unconfined vortex have been performed. Two different approaches were used for the combustion modelling, one rather simple model based on an

analytic expression for the flame surface density and one more sophisticated presumed-PDF/ILDM approach. For different operating conditions flashback limits have been determined and compared to experimental data. A detailed analysis of the flame tip behaviour during the flashback could show the influence of the combustion model on the CIVB process.

Flashback Caused by CIVB in a Free Straight Vortex

Detlef WENDIG, Hannes KROGER, Nikolai KORNEV. Egon HASSEL

The paper presents experimental and numerical investigations of flame propagation in a free straight vortex which is formed by a moveable block swirl generation device. PIV was used to characterize the isothermal flow, high speed video films and LIF were used to gain informations on the flame propagation. Numerical simulations have been performed using the LES technique. It is shown that flame flashback is driven by Combustion Induced Vortex Breakdown.

14:40 (3C) - Diagnostics

Development of Chemiluminescence Sensor for Equivalence Ratio and Temperature Measurements in Turbulent Hydrocarbon Flames

Tsarng-Sheng CHENG, Y.-Y. CHENG, Y. -C. CHAO, Yueh-Heng LI. Chih-Yung WU The objective of this research is to develop a low cost, non-laser based optical sensor for simultaneous measurements of local equivalence ratio and temperature in turbulent premixed hydrocarbon flames. The measurement system consists of a Cassegrain optics coupled with an optical fiber and a monochromator. The developed optical sensor is calibrated in laminar premixed CH_n-air Bunsen flames operated at several equivalence ratios ranging from 0.85 to 1.5. The applicability of the sensor is demonstrated in stoichiometric and rich turbulent premixed flames. Experimental results indicate that the chemiluminescence sensor can simultaneously measure the local equivalence ratio and temperature in turbulent premixed hydrocarbon flames with reasonable accuracy.

Flame Imaging Using 3-D Electrical Capacitance Tomography

Piotr WOLANSKI, Gut ZBIGNIEW

Combustion processes have been traditionally monitored by optical means, using such techniques as Schlieren, shadow, interferometric, holographic or LIF ones. For flame visualization, high quality optical access to the area of interest is required. However, utilization of the above in industrial conditions is difficult. Combustion laboratories all over the world look for new techniques of visualization of flame. One of them is the Electrical Capacitance Tomography (ECT). The basic idea of ECT is to measure changes in the electrical capacitances between all possible combinations of electrodes that occur when a dielectric material is introduced into the measurement space At present, the main aim of Capacitance Tomography is to obtain the images of permittivity distribution in gas-flow flow systems, a dense pneumatic conveying system or a bubbling fluidization. But experimental studies have been carried out showing that this method can be applied to visualization of some types of combustion processes, especially stationary flames. When fuel is burnt, a large number of charged particles, ions and free electrons are generated The above charged particles may be formed as a result of chemical reactions, which are called chemi-ionization and thermal ionization. They will modify both the permittivity and conductivity of the reaction zone. So, the ECT is based on measurements of a variation of electrical properties of the flame, such as electrical permittivity and conductivity of the reaction zone. Signal level depends on the concentrations of various kinds of charged particles present during the combustions. Tomographic techniques have been widely accepted as a valuable tool for the process control and monitoring. The conventional tomographic approach is to reconstruct a 2D image of a process cross section. In this case, only one plane row electrodes with usually 12 or 16 electrodes is used. In the case of 3D capacitance tomography, the basic structure of the sensors and the measurement concept are the same as in 2D tomography. The difference lies in their layout. In 2D capacitance tomography, with its planar layout of electrodes, some inhomogeneities (i.e. objects) cannot be distinguished

and properly located in 3D space. In the case of 2D or 2.5D capacitance tomography, the measurements are made only for one or some cross sections. In the 3D capacitance tomography approach, the measurements are also performed between electrodes from different layers and therefore any inhomogeneity will certainly affect the measurement values and will be distinguished in the final image.

Photoemission Measurements of a Gas Temperature behind Reflected Shock Waves

Yauhen BARANYSHYN. Oleg PENYAZKOV, Kirill SEVROUK. Konstantin KASPAROV. Larisa BELAZIORAVA

There are objective difficulties in measurements of a gas temperature with a fast response time, especially, when chemical reactions occur between the different gas compounds. A photoemission method for gas temperature detection with 1 ps time resolution is presented in this report. The technique is applied for temperature measurements in reaction flows behind reflected shock waves. The object of research was the luminescence of reaction methane/hydrogen/air mixtures behind shock waves reflected from plain and conical walls Initial post-shock conditions were determined on the basis of incident shock wave velocity measurements from the 1-D shock relations assuming vibrational equilibrium and frozen chemistry Of the course of the studies the temperature histories were dermined during strong auto-ignitions of investigated gas mixtures. Results were compared with theoretical values of Chapman-Juguet temperature of combustion products TC-J. It was demonstrated that theoretically and experimentally determined temperatures are in good agreement.

16:20 (4A) - Detonation Structure 2

Propagation of Gaseous Detonations in Small Tubes

Alexandra CAMARGO. Hoi Dick NG, Jenny CHAO. John H.S. LEE

In this study, detonation limits in very small tubes are investigated to study the detonation propagation limit. Mixtures with highly argon dilution (stable) and without dilution (unstable) are used for the experiments. For stable mixture highly diluted with argon for which instabilities are not important and where failure is due to losses only, the limit obtained experimentally are in good agreement in comparison to that computed by the quasi-steady ZND theory with flow divergence or curvature term modeling the boundary layer effects. For unstable detonations in undiluted mixtures, regimes for different near-limit propagation modes of the detonation are studied. Different modes of detonation propagation will be observed in detail to investigate an operational criterion for the propagation limits.

Detonation Wave Propagation in Annular Channels

Su-Han LEE, D.-R. CHO. Jeong-Yeol CHOI

Present study examines the detonation wave propagation characteristics in annular channels. Numerical approaches used in the previous studies were extended with marching windows technique Parametric study has been carried out using a radius of curvature normalized by the channel width considered as unique geometric parameter. In the channels of small radius of curvature, detonation wave is unstable and the regular cell structure is not observed. There is a critical radius of curvature where cell structure can be sustained. The effect of curvature makes the pressure difference on inner and outer surfaces where the detonation wave is overdriven The results converge to that of straight channel as the radius of curvature gets larger, as expected. **Propagation Limits of Unstable Detonations in Thin Annular Channels** *Anne JESUTHASAN, Alexandra CAMARGO, Jean-Sebastien GRONDIN, Jenny Chao, Hoi Dick NG, John H.S. LEE*

In this study, the detonability limits of methane-oxygen mixtures in thin annular channels (w=2 2 and 4.3 mm) are investigated to elucidate the effect of losses and instabilities on the

failure mechanism. The experimental results are compared to theoretical limits computed using a quasi-steady ZND model with a flow divergence term to account for losses due to the curvature of the detonation front. It was found that the theoretical predictions did not agree well with the experimental results. Furthermore, the detonability limits could not be unambiguously determined for methane-oxygen. Near-limit galloping phenomenon where the detonation cycled between failure and reinitiation was observed beyond the detonability limit predicted by the ZND model. Complete failure of the detonation within the annular channel section was never observed for all the cases tested.

Detonation Diffraction from an Annular Channel

James *MEREDITH, Hoi Dick NG, John H.S. LEE*

In this study, gaseous detonation diffraction from an annular channel was investigated with a streak camera and the critical pressure for transmission of the detonation wave was obtained. The annular channel was used to approximate an infinite slot resulting in cylindrically expanding detonation waves. Two mixtures, stoichiometric acetylene-oxygen and stoichiometric acetylene-oxygen with 70% Ar dilution, were tested in a 4.3 and 14.3 mm channel width (W). The undiluted and diluted mixtures were found to have values of the critical channel thickness over the cell size around 3 and 12 respectively. Comparing these results to values of the critical diameter (D), in which a spherical detonation occurs, a value of critical D/W near 2 is observed for the highly diluted mixture. This value corresponds to the geometrical factor of the curvature term between a spherical and cylindrical diverging wave. Hence, the result is in support of Lee's proposed mechanism for failure due to diffraction based on curvature in stable mixtures.

16:20 (4B) - Combustion Induced Vortex Breakdown 2

Influence of Fuel Properties on Flashback in Turbulent Swirl Flows

Georg BLESINGER, Torsten VOIGT, Rainer KOCH, Hans-Jorg BAUER, Peter HABISREUTHER, Nikolaos ZARZALIS

The influence of fuel properties on the onset of flashback due to turbulent burning along the vortex axis (TBVA) and combustion induced vortex breakdown (CIVB) is investigated experimentally. The flashback mode is determined by capturing the flow field and flame position during flashback simultaneously. The stability limits of both flashback modes show differences for methane and propane that can be attributed to the fuel specific response of the burning velocity to stretch.

Experimental Investigation of Stability Limits and Upstream Flame Propagation in a Lean Premixed, Swirled Annular Slot Burner

Christof HEEGER, Robert GORDON, Jan BRUBACH, Andreas DREIZLER. Marco KONLE, Thomas SATTELMAYER, Mark TUMMERS

Lean premixed combustion offers the potential for low NO-emissions. In practical realizations, swirling premixed flames are usually stabilized by internal recirculation zones induced by vortex breakdown occurring when a critical geometry-dependent swirl number is exceeded. The development of precessing vortex cores (PVC) often precedes the vortex breakdown. The interaction between the flame and the turbulent flow field can enable the flame to propagate upstream into the nozzle causing serious problems

Numerical Simulations of Flashback in Lean Premixed Combustion Systems Using Probability Density Function Methods

Stefan UPP, Ulrich MAAS

In this paper we present a model to predict and investigate flashback phenomenas in turbulent lean premixed combustion systems numerically. The main focus is put on

flashback triggered by combustion induced vortex breakdown (CIVB) in swirling flames. The mathematical modeling of turbulent swirling flames is a difficult task due to the intense coupling between turbulent transport processes and chemical kinetics in particular for instationary processes like CIVB. The presented model consists of two parts. Chemical kinetics is taken into account with automatically reduced detained chemical reaction mechanisms which have been generated using the recently developed REDIM method ("Reaction-Diffusion Manifold"). The turbulence-chemistry interaction is modeled by solving the transport equation for the joint probability density function of velocity and scalars (JPDF). The modell is applied to a close-to-real combustion system.

Comparison of Different Combustion Models with Respect to the Simulation of Combustion Induced Vortex Breakdown

Torsten VOIGT, Marco KONLE, Eike TANGERMANN. Peter HABISREUTHER, Nikolaos ZARZALIS, Thomas SATTELMAYER, Michael PFITZNER

This work elucidates the numerical results of uRANS simulations of a premixed flame system for three different combustion models and compares the outcomes with experimental findings from literature. The investigated configuration exhibits an extraordinary transformation of the flame when a critical equivalence ratio is reached - the system shifts into an unstable condition. This phenomenon is known as "Combustion Induced Vortex Breakdown" (CIVB) and is associated with an unintended upstream propagation of the flame nearby the axis of rotation through the mixing pipe towards the swirler. This type of flashback is characterised by an intense interaction between the flow and the flame. Hence, the precise prediction of the local and time dependent distribution of heat release is necessary for the simulation of CIVB. The combustion model has to capture this challenging task which is even more sophisticated due to the restriction of the inherent processes to only a small volume around the axis of rotation. The combustion models that are assessed and compared to each other with respect to the appropriate simulation of the CIVB phenomenon are slightly modified versions of the approaches of Schmidt (1998), Lindstedt-Vaos (1999) and Hoffmann (2004). The combustion model originally introduced by Schmidt is based on the closure for the turbulent flame speed. The approaches of Lindstedt-Vaos and of Hoffmann are based on considerations for the flame surface density which in turn is determined by an algebraic formulation (Lindstedt-Vaos, 1999) or rather on a formulation for an additional transport equation (Hoffmann, 2004).

16:20 (4C)-Fires

A Study of Temperature Field with Fire Sources in a Tall Building

Takeshi TSURUDA. Takeshi SUZUKI

Tall building is constructed to accommodate large machinery of nuclear power plant for normal operation and maintenance works. The height of tall building of nuclear power plant is ten times higher than that of typical residential room. The role of the buoyancy force on the natural convection in this tall building becomes much larger than that in a typical residential room. A series of experiments in a toll building has been carried out with crib and flammable liquid fire sources by measuring vertical temperature distributions to investigate the vertical heat transfer mechanisms. Experiments have been carried out in an experimental chamber of 25 m (length) x 25 m (width) x 22m (height) with a 6.5 m (width) x 2 m (height) opening. The experimental chamber was vacuumed with a ventilation system at a rate of 90000 m/h. Two kinds of fire source were used in this experiment. One is an oil pan of 0.9 m x 0.9 m filled with 5 l of heptane, another is a crib of 0.73 m x 0.73 m cross section. A crib is constructed with Japanese #2 crib of 0.73 m x 0.73 m x 0.7 m. Two or three #2 cribs were stacked to increase heat release rate. A 21 m long thermocouple tree

was used to measure the vertical temperature distribution at 3 m, 6 m, and 12 m from the fire source. Thermocouple junctions were located at every one meter. Due to the mixing by the convection in the experimental chamber, the density of the fluid changes with time. The normalized density change velocity depends on the convection induced by fire source or water-cooling and the stability of the density layer. Experimental temperature distribution in a tall building was examined using the Brunt-Vaisala frequency plots. Excluding the initial heating period and the cooling period, the square of the Brunt-Vaisala frequency is positive, which indicates the formed density gradient is stable and the natural convection is suppressed. A crescent shape area of internal wave allowed area was found in the plot. The mixing rate of density layer was estimated from the normalized density change velocity plotted with the square of the Brunt-Vaisala frequency to see the effect of density layer stability. The convection dominating heat transfer is seen during the heating period.

Temperature Measurements in a Multiphase Fireball

David FROST, Samuel GOROSHIN, Malcolm CAIRNS, Robert RIPLEY, Fan ZHANG Detonation of a homogeneous high explosive charge generates high pressure and temperature combustion products and a propagating decaying blast wave. The combustion product gases rapidly cool as they expand adiabatically, whereas the shock heating of the atmosphere surrounding the combustion products generates a relatively long lasting zone of air at elevated temperatures. For oxygen deficient explosives, mixing and afterburning of the condensed carbon with this shock-heated air will result in condensed reacting carbon that may have a different temperature than nearby gases. The detonation of a heterogeneous high explosive containing reactive metal particles generates a multiphase fireball in which the particles and gas are, in general, not in thermal equilibrium. The temperature of the burning particles may be relatively constant whereas the temperature of the combustion product gases will vary rapidly In addition, the temperature of the air surrounding the combustion products will be augmented by heat transfer from the particles. In the near-field, instability of the combustion products interface as well as the particle cloud will result in large spatial variations in the gas and particle temperature fields. In the present work, in-situ temperature measurements are made within the near field of homogeneous (nitromethane, NM) and heterogeneous (NM with aluminum particles) explosive charges using fast-response thermocouples. The thermocouple temperature lags behind the local gas temperature, but when the thermocouple temperature reaches a maximum, the temperature is

approximately equal to the local instantaneous gas temperature. For a 1-kg charge of NM, the gas temperature at 3 locations (1.2, 1.5 and 1,9 m from charge) reached maximum temperatures of 800°C on times of 100's of milliseconds. In comparison, at the same time pyrometer measurements of the condensed explosion products (carbon) yielded solid temperatures of 1625±150°C. For the heterogeneous NM/Al charges, gas temperatures of over 1000°C were measured for long durations (over 100's ms). Pyrometer measurements of the temperature of the burning aluminum particles (over 10's ms) yielded values on the order of 2400°C.

Effect of Oxygen Concentration on the Combustion of Titanium Particles

Malcolm CAIRNS, David FROST, Samuel GOROSHIN

Previous investigators have studied titanium particle combustion using a variety of experimental techniques, including injection into a gas flame, droplet formation and ignition with a pulsed micro-arc, and particle levitation with laser ignition. The objective of the present study is to quantify the dependence of titanium particle burn time on initial diameter and oxygen concentration over a wide range of particle sizes. Two flames were studied, in which the oxygen concentration were varied. The power law curve fits to the present data for particles ranging from 50- 180 pm. The data in the present study indicate that the burn

time for Ti particles of size 15 - 180 pm in air follow a d^{15} scaling law. When the concentration of oxygen is increased, the burn time is reduced for particles over 100 pm, which agrees with the conclusion that gas-phase diffusion of oxygen is the rate-limiting step in Ti combustion for large particles.

Experimental Study of Inhibition of Premixed Flames

Pol HOORELBEKE, Kees van WINGERDEN

The present paper describes an experimental study investigating the effect of a number of flame inhibitors and mixtures thereof on premixed propane-air mixtures. One of the most important parameters describing premixed combustion is the laminar burning velocity. Hence in the present study study the effect the inhibitors have on the laminar burning velocity of propane-air is chosen to describe the effect of inhibitors on premixed flames. The laminar burning velocities were derived from pressure-time histories obtained in a 20-l sphere The inhibitors investigated were injected pneumatically. The injection process causes the mixture to be turbulent. Hence the presented approach implicitly assumes that the effect of the inhibitor is similar for turbulent and laminar flames All inhibitors investigated are solids and are introduced as fine particles

08:30 R. Soloukhin Memorial Session

Rem Soloukhin's Gold Hands in Shock and Detonation Phenomena Studies

Nikita FOMIN

My Recollections of Rem Soloukhin

Jonh LEE

The Scientific Legacy of Rem Soloukhin

Matei RADULESCU

Prevention of Hydrogen Self-Ignition at Technical Opening Via Replacement of One Orifice by Several Smaller Ones

Tatyana BAZHENOVA, Victor GOLUB, Igor LASKIN, Nikolay SEMIN In this work a 3D numerical modelling of a hydrogen jet behavior at its release in atmosphere has been done. Initial and boundary conditions that are sufficient for suppression of hydrogen diffusion self-ignition has been obtained.

Reconstruction of the Combustion Efficiency of Hydrogen-Air Mixtures from Experimental Data

Marten TOPCHIYAN

A reconstruction of the chemical composition in combustion of hydrogen-air and hydrogen-oxygen mixtures at the end of the scramjet duct and other combustors from incomplete experimental data (measured concentration of OH radicals and temperature) is analyzed. A closed algebraic system of equations including the concentration of OH radicals and the temperature as parameters is derived under the assumption of detailed chemical equilibrium of exchange reactions. A code for solving this system numerically is developed for determination of reaction completeness from the measured temperature and concentration of OH radicals. The model was tested by results of exact calculations of thermodynamic equilibrium at the Jouguet state and overdriven waves in a stoichiometric hydrogen-air mixture and various hydrogen-oxygen mixtures. For this purpose the temperature and concentration of OH radicals obtained in computation of equilibrium were substituted as parameters in derived equations. In the range of pressures of 0.2 to 500 atm and temperatures of 2500 to 3500 K, this method allows the molecular weight and heat release to be reconstructed with accuracy sufficient for gas-dynamic calculations (order of thermodynamical tables' accuracy).

11:45 (5A) - PDE and RDE 1

Optimization of the PDE Operating Regime

Ivan MANUYLOVICH, Vladimir LEVIN, Vladimir V. MARKOV

The interest that appeared to be arisen recently to problems of calculation of flows with propagating detonation waves could be explained by possible applications of obtained solutions at designing detonation engines that are quite perspective for propulsion. Since the detonation generates thrust on the walls of engine, then the question arises, whether it is possible to improve performance of such engine by defining special form of the walls. The given work examines pulse detonation engine (PDE) with axisymmetric nozzle form described by one arbitrary function. While calculating the flow in the channel the full two-dimensional non-steady pattern of the flow behind the detonation wave, distribution of velocity, density and pressure depending on coordinates and time is studied. Dependence of the average impulse and average specific impulse generated by the flow behind the detonation wave on the form of the channel is investigated. The aim of the investigation is to find optimal geometry of the channel that maximizes the thrust characteristics of pulse detonation engine. The axisymmetric channel previously filled by detonating mixture is considered. The initiated detonation wave propagates through the mixture and the flow

behind the wave generates thrust The channel has a closed end of fixed radius and the detonation wave is initiated near its whole surface and moves from left to right. The thrust is generated on the closed end of the channel and on the lateral wall. The form of the channel wall is given by function f(x) which can be chosen from some wide class, e.g. class of linear or parabolic functions. It's proposed that the detonation wave reaction zone has width much less than the channel diameter and, thus, we can rely on the model of infinitely thin detonation wave. The flow behind the detonation wave is described by the system of Euler equations.

The Influence of Heat-Transfer and Friction on the Impulse of a Single-Cycle Pulse Detonation Tube

Kou KAWANE, Satoshi SHIMADA, Jiro KASAHARA, Akiko MATSUO A Pulse detonation engine (PDE) has a higher theoretical thermal efficiency compared with conventional internal-combustion engines. However several experimental studies have shown that the measured thermal efficiency is less than the theoretical value. This is because in the actual flow fields, losses due to heat transfer and friction are generated. It is known that these losses increase with the PDE tube length We analyze the momentum of a PDE system by using a detonation tube as a ballistic pendulum, and estimate the losses of specific impulse caused by heat transfer and friction with a high degree of accuracy. The results are comparable with the numerical model solved by method of characteristics. It is shown that when the tube length divided by the tube diameter (L/D) is more than 103, heat losses is less than the calculated results. And frictional losses increase rapidly then and it becomes comparable to or more than heat losses.

Continuous spin and pulse detonation of hydrogen-air mixtures in a supersonic flow generated by a detonation wave

Fedor BYKOVSKII, Sergey ZHDAN, Evgenii VEDERNIKOV

Regimes of continuous spin detonation burning of acetylene in a subsonic oxygen flow were obtained and studied (Bykovskii FA, Vedernikov EF. (2003) Continuous detonation of a subsonic flow of a propellant. Combust., Expl., Shock Waves. 39 (3): 323). A question arises whether it is possible to burn the fuel in a supersonic oxidizer flow, which is of great practical importance for flying vehicles. The objective of the present work was to check the principal possibility of continuous detonation burning of hydrogen in a supersonic air flow in a flow-type combustor. Stable continuous regimes of spin and pulse detonation of a hydrogen-air mixture in a supersonic flow generated in the rarefaction wave of the detonation wave were realized for the first time.

11:45 (5B)-Fast Flames 1

The Physical Mechanism of Ultra-Fast Flame Acceleration

Vitaly BYCHKOV, Damir VALIEV, Lars-Erik ERIKSSON

We explain the physical mechanism of ultra-fast flame acceleration in obstructed channels used in modern experiments on detonation triggering. It is demonstrated that delayed burning between the obstacles creates a powerful jet-flow, driving the acceleration This mechanism is much stronger than the classical Shelkin scenario of flame acceleration due to non-slip at the channel walls. The mechanism under study is independent of the Reynolds number, with turbulence playing only a supplementary role. The flame front accelerates exponentially; the analytical formula for the growth rate is obtained. The theory is validated by extensive direct numerical simulations and comparison to previous experiments.

The Role of Shock-Flame Interactions on Flame Acceleration in an Obstacle Laden Channel

Craig JOHANSEN, Gaby CICCARELLI

The paper presents the results from an experimental investigation of flame acceleration in an obstacle laden square cross-section channel. The experiments have shown that there is a change in propagation mechanism as the flame accelerates up to a peak velocity on the order of 1000 m/s. Specifically, the later stage of flame acceleration is governed by shock-flame interactions, that along with flow contraction through the obstacle pair, are responsible for

the observed large flame tip velocity oscillations. The shock-flame interaction ultimately limits the final quasi-steady flame tip velocity which depends on the obstacle blockage ratio.

Lagrangian Modeling of Non-Premixed Turbulent Combustion in High Speed and Two-Phase Flows: Application to Rocket Engines Conditions

Jean-Francois IZARD, Arnaud MURA

The present work is devoted to the computational modeling of combustion between hydrogen and oxygen as it takes place in rocket engines conditions, for instance in the Space Shuttle main engine or in the Ariane engine.
Despite recent progresses, the multifaceted physical processes involved in such conditions still require great modeling efforts. The focus of the present study is on the development and the application of a Lagrangian model able to describe non-premixed and partially premixed turbulent combustion in the high speed flows encountered in such conditions. The proposed framework is applied to the simulation of different geometries, and, among others, (i) underexpanded supersonic coflowing reactive jets and (ii) the 10 bar MASCOTTE test bench. The obtained results display a fairly good agreement with both underlying physics and available experimental data.

11:45 (5C)-Soot

Shock Tube and Modeling Study of Soot Formation during the Pyrolysis of Propane and Propane/Toluene Mixtures

Pavel VLASOV, Gennadii AGAFONOV, Vladimir SMIRNOV

Propane is the simplest practical hydrocarbon fuel, with its thermochemical and combustion properties being closer to those of fuels more complex than methane and ethane Therefore, experimental and modeling studies of propane combustion with emphasis on its practical applications have drawn intense interest of researchers. To gain insights into the mechanism of soot formation during propane combustion, it seems profitable to examine its pyrolysis a constituent part of the overall oxidation accompanied by soot formation. The high temperature pyrolysis of propane was investigated using shock tube technique by a number of authors, notably Lifshitz and Frenklach. The main goal of the present work is to study soot formation during pyrolysis of propane and propane/toluene mixtures both experimentally and theoretically A further development of a detailed kinetic model of soot formation and the gas-phase mechanism of propane pyrolysis is conducted based on recently suggested concepts of PAH formation and growth, soot precursor nucleation, and the traditional surface HACA mechanism of soot particle growth.

Soot Formation in Hydrocarbon Pyrolysis behind Reflected Shock Waves

Kazuhiro ISHII, Nobumasa OHASHI, Atsushi TERAJI, Masaaki KUBO Soot formation process in pyrolysis of hydrocarbon fuels diluted with argon was studied using a shock tube. Soot yield was measured by the laser light extinction method. Time history of soot particles temperature was estimated based on spectral dependence c monochromatic emissive power of thermal radiation from the soot particles. The resul

show that the soot particle temperature, which differs substantially from the ambient temperature at pyrolysis starting behind the reflected shock wave and governs the final soot yield independent of the type of hydrocarbon fuels.

Modelling Soot Particle Composition and Structure Based on Detailed PAH Chemical _ Mechanism

Abhijeet RAJ, Markus SANDER. Matthew CELNIK, Markus KRAFT

A recently developed comprehensive model for soot formation and growth, named as, the aromatic site - primary particle (ARS - PP) model has been extended in this paper This model is based on the assumption that a soot particle is formed from planar PAH molecules. The basis for this assumption is the recent experimental findings of Vander Wal et al., in which stacks of planar PAH molecules were observed in high resolution transmission electron microscopy (HRTEM) images of soot particles from engines. For the growth of PAHs present in soot, a detailed chemical mechanism is used. The ARS-PP model is also able to track the size of primary particles constituting soot (primary particles are the spherical nanostructures forming chain-like aggregate structure of soot). With this detailed model, it is possible to obtain information about the composition (in terms of the number of C and H atoms) and the size distributions of soot particles in combustion devices. With the current reaction mechanism, the model has been shown previously to predict the C/H ratio of soot particles in between 1 and 2. However, the experiments predict this value in the range of 2 to 8, indicating that the present chemical mechanism over-predicts the number of H atoms in mature soot. This paper introduces new PAH processes in the chemical mechanism that can dehydrogenate mature soot particles (or PAHs). Furthermore, comparisons between the predicted particle size distributions with the observed ones for soot particles present in a premixed laminar flame and a PFR show that the model slightly over-predicts the particle diameter at lower residence times. To reduce the surface area of computed soot particles present in combustion devices, an effective sintering sub-model in the ARS-PP model is implemented. The interaction between PAH molecules to facilitate the formulation of sool nucleation sub-model is also studied

14:40 (6A) - PDE and RDE 2

Experimental Research on the Rotating Detonation in Gaseous Fuels-Oxygen Mixtures

Jan KINDRACKI, Piotr WOLANSKI, Zbigniew GUT

In the paper, experimental research on the rotating detonation carried out at Warsaw University of Technology will be presented. The research is focused on evaluation of the geometry and the conditions in which rotating detonation is propagating in cylindrical or cylindrical-conic channels for rich fuel-oxygen mixtures. Methane, ethane, propane as a fuel was used. Pressure - time history in the manifolds and in the chamber of those tests will be presented. Thrust-time profile and detonation velocity calculated from measured pressure peaks will be shown.

Thresholds of Detonation Limit in $H_2/0_2$ Rotating Detonation Engine

Takayuki YAMADA. A. Koichi HAYASHI, Eisuke YAMADA, Nobuyuki TSUBOI, Venkat E. TANGIRALA, Toshi FUJIWARA

The thresholds of rotating detonation at various inlet reservoir pressure and nozzle throat/exit area ratios are studied numerically using 2D compressible Euler equations with the full $H_2/0_2$ reaction mechanism. In the present case the inlet reservoir pressure of 2.7 MPa at is the threshold of detonation propagation for the nozzle throat/exit area ratio of 0.0657. In the full paper the further nozzle throat/exit area ratios will be shown. The reason for existence of such thresholds will be also discussed.

Numerical Study of Continuous Spin Detonation with a Supersonic Flow Velocity

Sergey ZHDAN, Aleksey RYBNIKOV

A possible alternative for conventional burning of fuels in a turbulent flame is fuel burning in a Pulse Detonation Engine (PDE) and in a Continuous Detonation Wave Engine (CDWE), which was first realized by Voitsekhovskii. By the moment, regimes with a continuous spin detonation wave in rocket-type annular combustors and in flow-type combustors have been obtained and studied [3] for several fuel-oxygen and fuel-air mixtures with a subsonic velocity of oxidizer supply. A question arose whether the principle of continuous spin detonation could be extended to ramjet-type combustors with a supersonic velocity of the incoming flow. A positive answer was given in [4], where numerical simulations of the process of burning of a hydrogen-oxygen mixture in an annular cylindrical combustor demonstrated for the first time that it is possible to obtain a regime with a continuous spin detonation wave in a supersonic incoming flow up to the flow Mach number $M_0 = 3$. In the present paper, the formulation of the problem [4] is extended to the case of pre-compression of the incoming supersonic flow in the diffuser. The influence of the degree of partial deceleration of the flow on the existence of the continuous detonation regime and the value of the specific impulse is studied numerically.

14:40 (6B) - Fast Flames 2

Turbulence-Flame Interaction and Formation of Distributed Flame

Alexei POLUDNENKO, Vadim GAMEZO, Elaine ORAN

We present results of detailed numerical and theoretical modeling of the interaction of flames in stoichiometric methane-air and hydrogen-air mixtures with turbulence of varying intensity and spectrum. We demonstrate the transition with increasing turbulent intensity from the laminar flame to the corrugated flamelet and finally to the distributed reaction zone. The latter represents a quasi-steady-state propagating burning front in which thermal conduction and species diffusion are mediated by turbulent transport. We discuss properties of such flames and their potential implications for deflagration-to-detonation transition both in confined and unconfined systems.

Structure of High Speed Turbulent Deflagrations

Guillaume SIMARD, Matei RADULESCU, Jean-Sebastien GRONDIN, John H.S. LEE The present study investigates the structure of high speed turbulent deflagrations generated downstream of a porous plate subsequent to the reflection of a detonation upstream. The deflagration is observed via high speed schlieren photography. Propane-oxygen and acetylene-oxygen-argon mixtures are investigated due to their differences in the cellular structure. Propane mixtures demonstrate a more irregular unstable structure (unstable) than high argon diluted acetylene-oxygen mixtures (stable). In the stable mixture, the transition to detonation is observed to occur either in the immediate vicinity of the perforated plate or decay with the complete decoupling of the precursor shock from the reaction zone. However, in the unstable propane mixture, the highly turbulent deflagration is observed to be able to maintain a more or less constant propagation speed for many tube diameters prior to transition back to detonation. The details of the photographs also reveal that the turbulent deflagration in the unstable mixture, in constrast with the stable one, remains highly scattered at distances from the plate where the plate induced turbulence would have

decayed. Its structure is composed of fine scale pockets of unreacted gas within reacted gases and scattered shocklets. The self-sustenance of the turbulent deflagration structure in

the unstable mixture was attributed to the ability of the exothermicity field to couple with the hydrodynamic instabilities of the turbulent deflagration, owing to the much higher sensitivity of reaction rates to temperature fluctuations in the unstable mixture. It is also observed that the deflagrations in the unstable mixture re-amplify back to a detonation in much less sensitive mixtures than for stable mixtures. This is in stark contrast with what would be expected from 1D ZND model of shock ignition. The present results thus show that the amplification of turbulent deflagrations and transition to detonation is linked with the ability of a mixture to sustain a turbulent deflagration rather than through global heating behind the leading shock.

Some Features of Oscillating Downward Propagation Flames Induced by External Laser Irradiation

*JuneSung PARK, Osamu FUJITA. Teruaki HONKO, Yuichiro YAMADA, Hiroyuki I*70, *Yuji NAKAMURA*

The presence of flame instabilities has been extensively discussed in recent years, because it is fundamental process of turbulent flames such as wrinkled flame surface, flame bulges and local flame extinction (flame holes). The propagation of premixed flames in a tube is widely used in order to investigate the genesis of flame front behaviors. Many researchers have reported that propagating flames in a tube show various types of flame shape along the direction of propagation (curved, flat, wrinkled, tulip and cellular shape). It was proposed that the formation of these shapes could be caused by the results from the combined effects of several factors such as non-slip condition at the wall surface, reverse flow in the vicinity of central part of flame, Darrieus-Landau instability and acoustic wave Under a certain condition, especially for downward propagation flames, it has been known that the burned gas flow generated in reaction zone could induce extreme acoustic waves excited in a combustion tube. Recently, Tsuchimoto et al. have conducted experimental studies to investigate oscillating phenomena by applying external laser heating. They controlled the convex curvature towards unburned mixture on freely propagating flame by C02 laser irradiation, where the flame could undergo positive flame stretch. This intentionally-formed flame surface could modify the subsequent flame propagation behaviors, such that the flame goes to show instability motions The external laser irradiation preheats the mixture locally along the path. As a result, the flame propagation velocity increases locally to give the deformed flame shape, which is sensitively subject to Lewis number effects. Although we have observed the complex instability motions by this system frequently, no transient to explosive stage. In this paper, we report the transient phenomena to tubulization of downward propagation flame triggered by $C0_2$ laser irradiation, in which the preheated mixture induces flame instability, then increased flame surface enhances the burning rates rather than stable flame. Due to the above-mentioned effects, burned gas flow behind reaction zone could be pronounced suddenly. Once the higher flow rate of burned gas in a tube is induced, the flame propagation is easily susceptible to being in acoustic influence.

14:40 (6C) - Flames 1

On Interaction of Centrally Ignited, Expanding Flame with Isotropic Turbulence at Elevated Pressure

Steven *SHY, Chien Chia LIU, Hsing Chung CHEN, Ming Wei PENG*

A new apparatus for the study of centrally ignited, outwardly propagating flames in quiescent and/or turbulent reactive environment of fuel-oxidizer mixtures, at atmospheric and elevated pressures, is proposed. The apparatus includes a high pressure, symmetrical cruciform fan-stirred premixed combustor, the inner chamber, which is resided in a very large pressure-absorbing safety chamber (the outer chamber). Both chambers are optically

accessible, allowing direct visualization and measurement of flame and turbulence interactions. The inner cruciform chamber is constructed by a large horizontal cylindrical vessel equipped with a pair of counter-rotating fans and perforated plates at each end capable of generating intense isotropic turbulence and a vertical cylindrical vessel The vertical vessel has four large sensitive pressure releasing valves installed symmetrically on its sides, so that the pressure difference between the inner and outer chambers at elevated pressure during explosion can be greatly minimized. Preliminary results, using lean methane-air mixtures at an equivalence ratio phi = **0.8** under both quiescent and turbulent conditions, show that turbulent flames seem to propagate more faster at elevated pressure than at atmospheric pressure. This is in opposition to laminar flames where their expanding speed decreases with increasing pressure. As the flame expands from the ignition kernel, cellular instability is observed for both laminar and turbulent flames, of which cellularity is promoted by the effect of elevated pressure and this influence is even more obvious for turbulent flames

Transient Inwardly Propagating Hydrogen-Air Ames Subject to Pressure Uctuations and Stretch

Nadeem MALIK

The response of premixed stoichiometric hydrogen-air flames propagating inwardly through moderately inhomogeneous fuel distributions and subjected to negative curvature and simultaneous pressure and equivalence ratio oscillations was explored computationally The pressure frequencies are in the range **100-1000HZ** which is the range where coupling with the flame structure has previously been observed. The impact of increasing curvature was investigated through the use of cylindrical and spherical geometries. The applied computational method is implicit and second order accurate in space and time and solves the fully compressible Eulerian balance equations with detailed chemistry and transport properties - the method resolves all the chemical and convective length and time scales in the chemically reacting flow system. The aim of these studies is to elucidate the underlying physics of fundamental thermoacoustic interactions at frequencies that may couple to the thermochemical structure of flames and the influence of curvature and stretch on these processes. In this paper, we use a comprehensive 9 species, 27 reaction H_2-air mechanism as reported in Malik & Lindstedt 2009 (under review, Combustion, Science & Technology). Individual chemical species show markedly different responses to the disturbances. Species formed in thin reaction zones (or layers), are generally not disturbed except with respect to their peak concentration. By contrast species with broader reaction zones (or layers) are generally significantly affected. In contrast to outwardly propagating curved hydrogen-air flames reported in Malik and Lindstedt 2009, the flame 'relaxation' time that the laminar flame takes to return to its mean stoichiometric value is much longer, by more than a factor of 2, for the inwardly propagating cylindrical and spherical flames. This highlights the impact of negative curvature and non-zero strain rate ahead of the flame and the influence of nonlinear molecular transport processes that couple to the flame.

Principal Strain Rates at Flame Front of Three-Dimensional Turbulent Premixed Flames

Yuki MINAMOTO, Yuzuru NADA, Mamoru TANAHASHI, Toshio MIYAUCHI The model of turbulent premixed flames has significant effects on accuracy of numerical prediction of combustors. Recently, many approaches have been attempted to develop high accuracy turbulent combustion model In these approaches, developed models are validated by using results of numerical simulation or experiments. Direct numerical simulation (DNS) with detailed kinetic mechanism is the most precise computational method. However, DNS requires large amount of computational resources and most of

them are limited to two dimension. In three-dimensional turbulence, it has been clarified that principal strain rate of the velocity gradient tensor have two positive and one negative eigen values on the average. This inherent nature of the strain field of turbulence is never represented by two-dimensional DNS. As for the modeling of turbulent flames, strain rates at the flame fronts have been frequently treated as an important property to describe the local characteristics of the flame element. Nevertheless, the response of the flame elements to the strain rate has been discussed based on two-dimensional DNS except for three-dimensional DNS with quite simple chemical reactions. As for experiments, simultaneous measurements of PIV and several PLIF may give detailed experimental information on the local flame structure. In general, however, experimental results obtained on two-dimensional cross section have been used to investigate the characteristic of local flame elements and confirm the various turbulent combustion models. Recently, even for experimental researches, few three-dimensional measurements have been proposed and conducted for turbulent premixed flameand for non-premixed flame, whereas these experimental techniques will require to be more sophisticated and to be applied for lots of combustion conditions. In general, local flame structure has been discussed based on the assumption that mean flow (or mean shear flow) scarcely affects the flame structure and local flame elements can be approximated as so-called flamelet The recent simultaneous measurement suggested that magnitude of the mean flow may change flame structure and its dynamics. These observations cause queries relating to conventional approaches for the investigation and modeling of turbulent combustion In this study, three-dimensional DNSs with detailed kinetic mechanism have been conducted for statistically-planer, freely-propagating turbulent flame and turbulent V-flame of hydrogen-air mixture. From the results of two type DNS. eigen values of strain field are evaluated to investigate modification of the strain field near the flame and alignment of the principal strain and flame.

17:00 (7A) - PDE and RDE 3

Three-Dimensional Modeling of The Rotating Detonation Engine

Arkadiusz KOBIERA, Michal FOLUSIAK, Kami SWIDERSKI, Jan KINDRACKI, Piotr WOLANSKI

A continuously rotating detonation was firstly reported in the early sixties of the last century by Voitsekhovskii et al. But only recently a significant interest has been focused on development of the Rotating Detonation Engine, known also as Continuous Detonation Wave Engine, since it offers significant improvements of the cycle efficiency and simultaneous simplification of the design. The work presents the results of three-dimensional simulations of a detonation propagating in continuously flowing gas. The simulations are based on the classical Euler equations describing the motion of a reacting inviscid gas. The model is implemented in a in-house code CFD-ZSL which works

on structural grids. The program utilizes HLLC-WAF, a second order in space and time solver, for the advective fluxes. The advective terms are integreted in time by use of the Runge Kuta 4th order scheme. The chemical source terms are integrated by the quasi-equilibrium solver Chemeq2. The results of the three dimensional simulation of the RDE have given some information about details of the structure of reactive flow with incorporated detonation wave. Performed computations have risen important questions about the role of deflagrative combustion in the region of mixing of the hot gases with the fresh mixture. The simulations have also shown that special attention must be paid to the interactions of the numerical diffusion and proper mechanism of the chemical reactions. Certainly, more advanced model of combustion at the contact surface will necessary in the future.

Numerical Investigations on the Three-dimensional Flow Patterns of the Continuous Rotation Detonation

Xiaohai JIANG, Baochun FAN, Mingyue GUI, Zhihua CHEN

Based on the three-dimensional Euler equations coupling with chemical reactions, the phenomena of the continuous spin detonation in an annular combustor were numerically studied by using high-resolution Roe scheme and MPICH2.0 parallel computing in the body-fitted coordinate system and wave structure in the flow field were discussed in detail according to the calculated results. Even the combustor are partly filled with the combustible gas, the spin detonation wave can propagate steadily in the layer of premixed gas. And detonation products rapidly move towards the ambient air, which lead to the possibility of self-sustaining supply of fresh mixture into the combustor.

Propulsive Performance Study of Rotational Detonation Engine

Tae-Hyeong YI, Jing Lou, Piotr WOLANSKI, Gary TURANGAN, Boo Cheong KHOO A detonation wave continuously rotating in an annular chamber is numerically simulated to investigate the effect of injection conditions on the propulsive performance of a novel detonation-based engine, called a rotational detonation engine (RDE). The RDE uses a single or multiple detonation waves propagating in the azimuthal direction of the annular chamber. The principle of the RDE is based on the creation of continuously propagating detonation in a ring-like combustion chamber. A fresh mixture is supplied from one side and combustion products are expanded from the other side of the chamber. Because of the inertia force of flowing-out burnt products, a rarefaction wave will be created inside the chamber, which significantly helps to evacuate the products from the chamber and refill the ring-like chamber. The expansion of the detonation products in the nozzle will produce the thrust, allowing the RDE to operate continuously. The frequency of chamber operation depends on the detonation velocity and the size of the combustion chamber, which is typically an order of 10 kHz. In this study, the comparison of a thrust and specific impulse with several different injection conditions is carried out in a two-dimensional chamber for the one-waved RDE. The injection conditions are chosen as the reservoir total pressure of 5, 10 and 15 atm at the fixed total temperature of 500 K and injector area ratio of 0.2. Moreover, an overall flowfield in the chamber is described with the injection conditions at the total pressure of 10 atm, the total temperature of 500 K and the injector ratio of 0.2.

16:20 (7B) - Ignition

Mathematical Modeling of Coniferous Tree Ignition by Ground Lightning Discharge Taking into Account Localization of Reactive Wood

Nikolay BARANOVSKY, Geniy KUZNETSOV

The mathematical models adequate to the real physical mechanism of tree ignition by ground lightning discharge have not created till now. Polarity, a peak current and voltage, and also duration of action are the basic characteristics of ground lightning discharges. The average peak current can reach: J=23.5 κA for the negative discharge and J=35.3 κA for the positive discharge. Essential structural heterogeneity is one of the important factors which among many should be considered at the analysis of conditions of real wood ignition. Nonuniform distribution of branches on length of a tree trunk should influence to conditions of discharge passage and accordingly, intensity of a warming up and reach of ignition conditions. For this reason modelling of process of coniferous tree trunk wood warming up under the influence of a lightning discharge in two-dimensional statement is expedient. The purpose of the present research is determination of coniferous tree ignition conditions by a ground lightning discharge depending on parameters of the discharge taking into account not one-dimensional process of heat distribution in a trunk.

Streamer Discharges Caused by High-Frequency Voltage Leading to Ignition of Hydrogen/Air Mixtures

Tim LANGER. Frank LIENESCH. Detlef MARKUS, Ulrich MAAS

In this work, the ignition of hydrogen/air mixtures by streamer discharges is examined experimentally. The electric field strength is calculated by a simulation of the rod/plane configuration used in the experimental set-up to compare the values of the electric field with values necessary for streamer formation at a positive and a negative rod. The results of the calculation in conjunction with an analysis of the streamer formation during one voltage cycle lead to a comprehension of the point of ignition.

Simulation of Deciduous Tree Ignition by Ground Lightning Discharge in Approximation of Large Vessels

Nikotay BARANOVSKY, Geniy KUZNETSOV

The electric current of a ground lightning discharge proceeds in a tree trunk in the zones sated with a moisture. There are two basic types of vessel allocation in wood of deciduous trees. If vessels have basically identical diameter and one are distributed in regular intervals in the year ring, wood is named scatter vesseled. Wood with vessels of unequal diameter, largest of which are concentrated in early wood, name ring vesseled. There are also various mediate between these two extreme types. Within these large types of allocation separate vessels can be isolated from each other or met bunches of the different dimensions and forms. Located bunches vessels have borders parallel to surfaces r=const and <p=const along a line of their contact with each other. Researches of conductivity at different kinds by means of radioactive phosphorus and dyes show, that at one kinds vessels are bound only within a ring layer whereas at others communication between separate layers of a ring is observed. The purpose of research is development of deciduous tree ignition physical and mathematical model in approximation of large vessels and analysis of moisture influence on formation of a temperature field taking into account water evaporation.

16:20 (7C) - Hydrocarbons Ignition and Combustion

Ion Formation in Methane/Air Flames - Effects of Species Diffusion

Alexei MIGOUN, Andrey CHERNUKHO, Adam CENIAN

The ionic composition of methane-flame plasma was already widely investigated. The calculated and experimental ionic mass-spectra agree quite well. However, the ion density spatial profiles show large difference in the spatial width of distribution. It was proposed that the main cause of the difference is related to light species (like hydrogen, CH or OH) diffusion. The distribution of these species significantly influence primary CHO* ion distribution, through the well known Calcote mechanism of ion formation. The paper presents progress in the investigations.

Ignition and Oxidation of Hydrocarbons by Pulsed Nanosecond Discharge

Ilya KOSAREV, Nickolay ALEKSANDROV. Nikolay ANIKIN. Andrey NIKIPELOV. Svetlana KINDUSHEVA, Svetlana STARIKOVSKAYA, Andrey STARIKOVSKIY The use of nonequilibrium plasma at temperatures close to autoignition temperature may give significant benefit in comparison with equilibrium heating. There are experimental papers where researchers report that they observe an ignition treating a gas with nonequilibrium plasma at ambient temperature. To prove possibility of nonequilibrium plasma to ignite gas mixtures at conditions where the autoignition is impossible and to analyze efficiency of nonequilibrium plasma in total, it is necessary to study detailed kinetics in combustible mixtures under the action of a discharge In this paper we give an example of experimental analysis of different combustible mixtures, based on saturated hydrocarbons,

staring from CH_4 up to $C_{10}H_{22}$, under the short pulsed volume discharge at ambient and elevated temperatures.

Diagnostics of Instantaneous Flow Structure in Swirling Premixed Flames by Optical Techniques

Sergey ALEKSEENKO, Vladimir DULIN, Yuriy KOZOREZOV, Dmitriy MARKOVICH, Sergey SHTORK

The present work is devoted to experimental study of flow/flame structure of premixed swirling jet flames at various combustion regimes. The swirl rate based on geometry of the swirlers was varied from 0 to 1.0. Stereo PIV technique combined with pressure probe was used for the measurements to investigate role of large-scale vortices in turbulent structure of the flames. Besides, chemiluminescence images were used to determine an average position of the flame front.

H. Edwards Memorial Session

08:30 *E. OR AN* **- Keynote**

Experiments with Flame Propagation in a Channel with One Obstacle and Premixed H_2-air

Andre GAATHAUG, Dag BJERKETVEDT. Knut VAAGSAETHER

This is a presentation of experimental results of flame propagation in a square channel with one obstacle The background was to study how a flame propagated when and after the flame inverted. H_2 concentrations from 15%vol to 40%vol were studied in the experiments Three different modes of pressure records was recorded. Mode a had a small first pressure peak and then a drop back to initial pressure. Mode b had a higher first peak but also a drop, but with oscillations. The last mode (mode c) had a continous pressure build up with oscillations. Perpendicular and angular Schlieren high speed film showed that experiments associated with mode b and c inverted while mode a experiments did not. Two types of ignition source was used, one point source and one distributed (line), but after the first pressure peak there was little difference between the two types of ignition.

An Experimental Study on Flame Acceleration and Deflagration-to-Detonation Transition in Narrow Tubes

Yao-Chung HSU, Y.-C. CHAO

Recently, the prevailing of the microelectronic mechanical systems (MEMS) has attracted intensive and extensive research attention on the micro energy and power generation devices with significantly higher energy and power density than current lithium batteries can provide. Among the many possible power generation sources, combustion is still the most reliable and feasible method with specifically high energy and power density output for the micro power generation system However, some problems will be encountered when the scale is decreased to micro scale, such as low temperature reaction and quench due to the enhanced heat loss Nevertheless, if we consider a flame propagation system with a very high-speed reaction front, the heat loss from flame to the wall will be reduced to a minimum so that the existence of detonation wave propagation in the micro-scale systems may not be a question. Besides, the constant-volume combustion process provides higher efficiency. In general, the detonation wave can be generated by several ways including direct initiation, shock induced detonation transition (SDT), and deflagration-to-detonation transition (DDT). For practical consideration, the direct initiation and SDT methods need very high energy to obtain the detonation waves, so they are not appropriate for small tubes. However, DDT only needs a weak energy of ignition to generate a low speed deflagration and then with proper flame acceleration the flame may transit to detonation. The overall process may include flame acceleration, instabilities, high speed turbulent flame, shock pre-conditioning and finally a local explosion occurs

Experimental Study of the Preheated Zone Formation and Deflagration-to-Detonation Transition

Mike KUZNETSOV. Michael LIBERMAN. Ivan MATSUKOV

Experimental investigation of DDT in stoichiometric hydrogen-oxygen and ethylene-oxygen mixtures in channel geometry at temperature 20°C and pressures 50+750 mbar have been performed. The study was focused on key characteristics of the DDT such as: flame acceleration and flame velocity, strength and location of shock waves, produced by the accelerating flame, formation of the preheated zone, and critical parameters of the preheated zone capable to trigger transition to detonation. A mechanism of advancing shock generation connected with flame acceleration law and formation of preheated zone

ahead of the flame as result of shock wave amplification was investigated. It was found that critical temperature of preheated zone, its minimum width and strength of advancing shock waves are dependent on the mixture reactivity and overall reaction order.

Experimental Investigation of Gradient Mechanism of Detonation Initiation

Aleksandr RAKITIN, Andrei STARIKOVSKII

An experimental study of detonation initiation by high-voltage nanosecond gas discharges has been performed in a smooth detonation tube with four-cell discharge chamber designed to realize a gradient initiation mechanism The chambers were constructed on the basis of our previous studies and introduced analogous cell geometries The gradient mechanism of deflagration to detonation transition has been proposed and confirmed experimentally. The governing parameters have been established and a significantly higher efficiency in terms of detonation initiation has been achieved due to the enhanced geometry. Successful DDTs have been observed in a stoichiometric propane-oxygen mixture diluted with 40% of nitrogen under energy inputs as low as 200 mJ at initial pressures of 0.8 bar and higher. The run-up distance is within 80 mm, the DDT time is below 0.5 ms. A technique for detonation initiation in fuel-air mixtures in smooth detonation tubes can now be elaborated

11:45 (8A) - Detonation Structure 3

Numerical Study of a Highly Unstable Detonation with Viscosity and Turbulent Effects

Edward Jae-Ryul SHIN, Kiha KANG, D-R. CHO, Jeong-Yeol CHOI

Highly unstable detonation is occurred when the activation energy of detonable mixture is very high It is though that that the irregularity and instability of the highly unstable detonation wave is affected by turbulence. Present study is aimed to examine the effect of turbulence on the characteristics of the highly unstable detonation by using Monotone Integrated Large Eddy Simulation (MILES). Compressible fluid dynamics equations and species conservation equation with one-step Arrhenius reaction model are solved simultaneously by 4th-order classical Runge-Kutta method for time integration and 5th-order MUSCL TVD scheme for calculating numerical fluxes. A series of numerical studies are carried out based on Favre-filtered Navier-Stokes equation including deliberate formulations of heat transfer and viscosity term with high activation energy and on fine grid system. The computational results are investigated by comparing the results from inviscid Euler equations, Reynolds Averaged Navier-Stokes (RANS) equations, and Monotone Integrated Large Eddy Simulations (MILES).

Numerical Simulation on Two-Dimensional Detonation with Boundary Layer

Nobuyuki TSUBOI, A. Koichi HAYASHI, Mitsuo KOSHI

Two-dimensional full Navier-Stokes simulations on the detonations are presented in order to estimate the boundary layer development behind the front. The multi-zone grid system is applied to simulate the detonation front and the boundary layer. The results show that the boundary layer thickness behind the front is approximately 10% of the channel width for the adiabatic wall and 20% for the isothermal wall The detonation velocities are also affected by the wall boundary due to the boundary layer thickness.

Numerical Analysis on the Correlation between Transverse Wave Strength and Detonation Velocity

Kuninori TOGAI, Nobuyuki TSUBOI, A. Koichi HAYASHI, Yamada EISUKE Two-dimensional numerical analysis is performed on H_2/Air detonation. Using Euler euqations as the governing equations of the simulation, velocity deficits are observed in

cases with initial pressures varying from 0.1 atm to 1.0 atm. The comarison of the detonation velocity deficit with the strength of the transverse wave implied a correlation between them.

11:45 (8B) - Detonation Initiation 1

Nonclassical Detonation and Deflagration Transmissions into Half-limited Space

Pavel KRIVOSHEYEV. Oleg PENYAZKOV

Point explosion by different energy sources (high explosive materials, laser radiation, high-voltage discharge, etc.) and detonation transmission from the smaller-diameter various cross-sections tube are usually considered as standard means of detonation initiation in the half-limited space. Theoretical and empirical correlations, in particular, for direct detonation initiations and transmissions are proposed in the literature for estimation of the critical energy of direct initiation and conditions for successful transmission events. The mentioned initiation means require the using of high-energy initiation source or already formed nonmarginal detonation with a cell size at least one order of magnitude smaller than the diameter of initiating tube. At the same time, for a number of applications the significant reducing of critical energies, tube diameter and mixture sensitivities are required for improving the overall effectiveness of system. One of the probable scenario is the onset of detonation in volume is a consequence of the deflagration to detonation transition (DDT) event in the vicinity of output from smaller tube to the volume. The objective of this work was to elucidate the effectiveness of transmission of shock wave - deflagration for detonation initiation in a half-limited space. It was found that the transmission of a nonstationary complex of a shock wave followed by deflagration into a semi-confined area could essentially facilitate the following detonation re-ignition and reduce the sensitivity and requirement for driver tube mixtures. The transmission of such a complex (also as transmission of overdriven detonation) could produce the successful detonation initiation in a large volume, at least, three times lower initial pressure than for the classical direct detonation transmission case.

Numerical and Experimental Investigation of Detonation Initiation in Profiled Tubes

Ilya SEMENOV, Pavel UTKIN, Vladimir MARKOV, Sergey FROLOV, Victor AKSENOV The computational and experimental studies of shock to detonation transition in a round tube with profiled wall have been performed Proper shaping of wall profile (parabolic contraction and conic expansion with smoothed or sinusoidal wall) was shown to promote shock to detonation transition.

Detonation Initiation by Charges of Intermediate Symmetry

Anatoly VASIUEV

The experimental results devoted to initiation of detonation wave by initiator of intermediate symmetry are presented. The criteria for classification of initiator form and sizes from point of view of symmetry types was proposed

11:45 (8C) - Numerical Simulation 1

A Numerical Study on the Effects of $C0_2$/N_2/Ar Addition on Liftoff of a Laminar CH_4/Air Diffusion Flame

Hongsheng GUO. Jiesheng MIN. Cedric GALIZZI, Dany ESCUDIE, Frangoise BAILLOT A numerical study on the effects of different additives to air on the liftoff of a laminar ChWair diffusion flame has been carried out. Detailed reaction scheme and complex thermal and transport properties have been employed Three different additives were investigated Results show that the addition of N_2 affects the flame liftoff due to the sole dilution effect.

For CO_2 addition, it causes flame liftoff due to the dilution, thermal and chemical effects, with the dilution effect being the most significant one, followed by the thermal effect. All these three effects tend to reduces combustion intensity and cause flame to be lifted. The radiation and transport property effects are negligible. For Ar, its addition to air causes flame liftoff due to the dilution effect. This dilution effect is countered by the thermal and transport property effects, because of the lower thermal conductivity and specific heat of Ar than those of Air.

Strouhal Number Influence on Methane-Air Jet Diffusion Flames

Mario SANCHEZ-SANZ, Beth BENNETT, Mitchel SMOOKE, A. LINAN In this study, we investigate computationally the effect of the variation of the oscillation frequency of the fuel inlet velocity on laminar methane-air jet diffusion flames. We have solved the transient equations for the conservation of mass, momentum, energy and species mass with detailed transport and finite-rate chemistry submodels (15 species and 42 reactions steps). The equations are made non-dimensional by using the characteristics values of all variables at the jet exit (density p_F, viscosity u_F, thermal conductivity A_f, mass diffusivity D_F and temperature T_F), the jet radius a and the characteristic velocity U_F. The unsteadiness introduced by the velocity modulation affects both the fluid dynamic and the chemistry of the problem. The pulsation induced the creation of outer vortices that interact with the flame perturbing not only its shape but also its chemical structure. The changes in the concentration of the different species depends strongly on the frequency of oscillation, being observed differences over 50% for the mass fraction of CH_4, CO and $C0_2$ for Strouhal numbers S = 0.5 when compared with the steady solution.

Turbulence-Flame Interactions in Premixed Lean Hydrogen Flames

Andrew ASPDEN, Marc DAY, John BELL

Several studies have shown that premixed methane flames are unable to survive at sufficiently high turbulence levels However, a recent study (Aspden et al. ApJ, 689, 2008) of a supernova flame at a Karlovitz number of approximately 230 found that the flame speed was enhanced by turbulence, and global extinction was not observed. In this paper, we take a similar approach to investigate turbulence-flame interactions in premixed lean hydrogen flames (small Lewis number) at a variety of Karlovitz numbers using high-resolution three-dimensional numerical simulations with detailed chemistry. We show that for these flames, even at a Karlovitz number of approximately 1500, global extinction is not observed, the overall flame speed is greatly enhanced by the turbulence, and that a transition similar to that observed in the supernova flame does not occur due to the persistence hydrogen diffusion.

A.K. Oppenheim Memorial Lecture

08:30 **Oppenheim's Gasdynamic Perspective of Combustion and Explosion Phenomena**
Allen KUHL, Piotr WOLANSKI

9:20 (9A) - Detonation Structure 4

Concentration Limits of Detonation Re-Initiation behind a Multi-Orifice Plate

Sergey KHOMIK, Bernard VEYSSIERE, Sergey MEDVEDEV. Vincent MONTASSIER, Herbert OLIVIER

The experimental investigation was performed to establish the dependence of concentration limits of detonation re-initiation behind the multi-orifice plate on mixture composition and initial pressure for hydrogen-air mixtures. The experiments were carried out in detonation tubes of 106 mm and 141 mm inner diameters separated by multi-orifice plate into two sections. Tubes were equipped by pressure gauges, ionization probes and semi cylindrical smoked plate. It is shown that initial pressure has strong influence on the value of concentration limit, especially for lean hydrogen-air mixtures. On the base of soot records it can be supposed that re-initiation occurs due to the collision of shock waves emerging from the neighboring holes.

The Origin of Shock Bifurcations in Cellular Detonations

Mate! RADULESCU, Andrea PAPI, James QUIRK. Philip MACH. Brian MAXWELL Recent numerical simulations of the structure of cellular detonations have revealed that shock bifurcations may be present on the front of detonations, accounting for part of the cellular sub-structure. This bifurcation manifests itself as a distinctive kink on the Mach shock In order to determine its origin and role in detonations, we have conducted detailed numerical simulations of the shock reflection process in inert and reactive gases. The present study determined that the shock bifurcations previously observed stem from inert shock reflection hydrodynamics occurring after the triple shock collisions. These bifurcations couple with the chemical reaction fields and give rise to finite strength secondary modes on the detonation structure. They are promoted for mixtures with lower specific heat ratios and larger shock strengths.

Steadiness of Oblique Detonation Waves around Spherical Projectiles

Akane UEMICHI. Sinpei KATO, Jim KASAHARA, Akiko MATSUO

Many researchers have studied oblique detonation waves as a part of oblique detonation engines. However, the steadiness of oblique detonation waves have not been discussed experimentally, enough. The oblique detonation waves around spherical projectiles were visualized by shadowgraph and recorded by using a high speed camera. The inter-frame time of this camera is 1 (is and multi-flame picture of spherical projectile accelerated to 1.4 km/sec and 2.2 km/sec have been captured. As the experimental result, stabilized oblique detonation waves were observed. From

multi-flame pictures, the detonation wave velocities were almost constant, 1.1 km/sec in all experimental conditions In addition, the quasi C-J detonation waves were observed within results. The steadiness of oblique detonation waves from multi-flame pictures has been discussed and we confirmed the steadiness of this oblique detonation structure shown in the past study.

Plastic Deformation of Tubes due to Detonation

Jim KARNESKY, Jason DAMAZO, Joseph SHEPHERD

A series of experiments were performed in the Explosion Dynamics Laboratory at Caltech on thin-walled steel tubes to obtain data on the plastic deformation resulting from propagating and reflected detonations. The experiments were performed with stoichiometric C_2H_4-O_2 at pressures varying from 0.8 bar to 3 bar. As we increased the pressure, we saw three regimes: For low pressures, there was no plastic deformation. Mid-range pressures saw plastic deformation on the reflected wave only. At high pressures, plastic deformation was observed on both the incident and the reflected waves. Tube deformation and movement measurements were obtained with strain gauges, a displacement gauge, and a high-speed camera. It is the goal of these experiments to obtain a guideline such that, given an initial pressure, one may predict whether plastic deformation occurs and, if plastic deformation does occur, to what extent. Experimental results were compared with a single degree of freedom plasticity model.

9:20 (9B) - Explosions 1

Effect of Instabilities and Acoustics on Pressure Generated in Vented Propane-Air Explosions

Regis BAUWENS, Jeff CHAFFEE, Sergey DOROFEEV

A series of parametric vented explosion experiments have been performed for stoichiometric propane mixtures with air in FM Global's 64 m^3 explosion test chamber. The objective of the present work is to analyze the data and to further investigate the effect of flame instabilities and acoustics on pressure generation in vented explosions. This was accomplished by frequency analysis of the pressure data, comparison of the pressure data with higher speed videos, and by numerical simulation of various aspects of the explosion process and flame structure interactions. Hydrodynamic, Taylor and flame acoustic instabilities were found to be of key importance in modeling vented explosions and computational models and neglecting these phenomena failed to reproduce correct pressure time history profiles. Results of several attempts to model the flame instabilities are presented and the strengths and limitations of these models are discussed.

Effect of Ignition Location, Vent Size and Obstacles on Vented Explosion Over-Pressures in Propane-Air Mixtures

C. *Regis BAUWENS, Jeff CHAFFEE, Sergey DOROFEEV*

Venting is a method commonly used to prevent or minimize damage to an enclosure by relieving the pressure generated within the volume during a combustion process. Due to the limited reliability of the current methods for prediction of pressure generation during vented explosions, a detail experimental study was conducted to generate a set of experimental data focusing on the effects of mixture composition, ignition location, vent size, obstacles and scale on vented explosion overpressures. Results of tests on vented explosion obtained in a room-size enclosure with and without obstacles for stoichiometric propane-air mixtures are presented and the dependence of maximum pressure generated on experimental parameters are studied. A comparison is made with available engineering guidelines for vent sizing.

Al-Air Combustion in Unconfined SDF Explosions

Allen KUHL, John BELL, Vincent BECKNER

We study the flow fields created by un-confined SDF explosions at the 10-kg scale. In particular, we consider an SDF charge consisting of 3.6-kg spherical C4 booster surrounded by 6.4-kg of flake Al powder. The charge was detonated 122 cm above a concrete pad

instrumented with static pressure gages. Described here are numerical simulations of the explosion field performed with our three-dimensional (3D) Adaptive Mesh Refinement (AMR) code. The Combustion Model treats the flow field as a dilute heterogeneous continuum - with separate conservation laws each phase - and interaction terms that allow the phases to exchange mass, momentum and energy via phenomenological laws. A unique feature of the Model is that a high-order Godunov algorithm is used not only for the gas phase, but also for the particle phase. This provides an accurate solution of the governing hyperbolic conservation laws that is devoid of artificial effects of numerical diffusion. The system of equations is closed by a Quadratic EOS model that specifies the thermodynamic states of the combustion fields. Results of the AMR code simulations of the **10** kg-SDF explosions will be described and compared with experimental results.

Investigation on the Explosion-Driven Dispersion and Combustion of Aluminium Particles

Yann GREGOIRE, Michel STURTZER, Boris KHASAINOV, Bernard VEYSSIERE Shock wave dispersion and ignition of solid combustible particles is a fundamental problem of great importance for various applications. For example, metallized explosives are designed and produced to generate specific effects different from those obtained with homogeneous ones, such as delayed energy release; but their exact working mechanism remains roughly known. Previous studies at ISL were carried out on cylindrical charges made of a mixture of liquid explosive saturated with aluminium particles, which were exploded in a semi-confined area, simulation the explosion of thermobaric charges in an urban environment. Depending on particle size, different reactive characteristics were observed using high speed imaging and spectroscopy recording the evolution of the aluminium oxide specific emission inside the fireball. Aluminium particles, on account of their particular physical and chemical properties are a privileged candidate for this domain of applications The purpose of the present work is to get a better understanding of the mechanisms of particle dispersion and ignition by an explosive in a simplified one-dimensional spherical configuration.

9:20 (9C) - Multiphase Combustion

Deformation of Liquid Layer under the Cool Flame Propagation

Oleg SHARYPOV, Pavel KUIBIN

Experimental study of gravitational flow of thin liquid film with local heating shows the existence of steady-state regimes with two- or three-dimensional flow structure. Film deformations are caused by thermocapillary effect. Film thickness increases and liquid flow is slowed down in the region where the temperature distribution at the surface is non-homogeneous. If the power of immovable local heater is lower some critical value, then a steady-state 2-D liquid flow takes place. 2-D flow structure is unstable at high power of heating. The flow becomes 3-D with periodic structure in transverse direction. Such a structure (like "fingers") was observed for the case of combustion wave propagating along immovable thin layer of liquid fuel. The power of heat release in usual combustion wave is high, so 3-D structure only is observed in these experiments. We suppose that 2-D flow structure in thin liquid layer also could exist if power of heat release is low (for example in cool-flame combustion). The paper is devoted to theoretical study of effect of combustion with low heat release on the structure of thin horizontal liquid layer. The liquid is locally heated by a planar cool-flame wave propagating in gas along the layer. The temperature gradient at the free surface is not high. The used model temperature distribution is nonmonotone, describing heating and subsequent cooling down of the liquid. The previous results show that 2-D steady-state flow regime in thin horizontal layer can exist if the heat source is moving and its power doesn't exceed certain critical level. These conditions provide the existence of 2-D steady-state (in the frame moving together with heat source) flow without dry spot formation even in microgravity. The equation for layer deformation is derived and solved numerically. Distributions of the pressure, velocity components and stream lines are calculated. 2-D steady-state flow structure with vortex is described.

Three-dimensional Numerical Simulation of Spray Flame in Laminar Counterflow

Junichi FUKUI, Jun HAYASHI, Fumiteru AKAMATSU

The three-dimensional DNS was applied to spray flames formed in the counterflow, and detail structure of spray flames was investigated. The Langmuir-Knudsen evaporation model and a global 1-step reaction model are used to simulate droplets evaporation and a chemical reaction for n-Decane, respectively. A computation result of 1-g spray flame location showed good agreement with the experimental observation of flame location. The 1-g spray flame was classified in two regimes; the diffusion-like flame and the premixed-like flame. In the diffusion-like combustion region, a group combustion phenomenon was observed. A heat transfer between gaseous phase and dispersed phase that cause temperature rising and evaporation of droplets leads to decrease of gas temperature (evaporative cooling effect). The premixed-like combustion region wad generated by pre-vaporization of fuel droplets as a result of heat supply from downstream diffusion-like flame. In the 0-g condition, the decrease of fuel mass fraction in group combustion region, the flame position shift to upstream of conterflow, and the increase of peak value of flame temperature were observed by comparison with the 1-g condition. These phenomena can be explained through consideration of decrease in droplets velocity at upstream of counterflow due to reduction of gravity acceleration.

Modeling Smolder Combustion and Transition to Flaming

Amanda DODD, Chris LAUTENBERGER, Carlos FERNANDEZ-PELLO Smoldering combustion and transition to flaming in polyurethane foam is examined using a two-dimensional numerical formulation that includes an eight-step reaction mechanism. The numerical model includes the effects of heat, mass, species, and momentum transfer of the porous solid and gas phase. The reaction mechanism includes heterogeneous and homogeneous reactions The reaction model is capable of simulating both forward and opposed smolder. The current study examines the transition to flaming in normal gravity. Model results qualitatively agree with experimental data and

observations. For example, during a simulation, forward smolder is initiated by an igniter. Later in time, the oxygen concentration is increased. Then, the secondary char oxidation reaction propagates in the opposite direction of the smolder front, followed by a localized sharp increase in temperature where the gas phase reaction begins thermal runaway The details of the temperature, species, reaction, porosity and permeability profiles are examined qualitatively and quantitatively. The gas phase temperature profiles are reported in the extended abstract. To the authors' knowledge, this is the first time a model has been capable of replicating experimental observations seen when transition to flaming occurs. Furthermore, the model is capable of addressing additional factors such as heat losses, sample size, ambient oxygen concentrations, fuel types, and both normal and microgravity.

Experimental Study of Single Wall Flame Quenching at High Pressures

Maxime KARRER, Sergei LABUDA, Julien SOTTON, Marc BELLENOUE It is well known that in vicinity of wall, the thermal heat losses become large enough to slow down chemical reactions, to stop flame propagation and to quench the flame. When the flame reaches the wall, the wall heat flux strongly increases. At the instant of the flame quenching, the wall heat flux gets its maximum. The implementation of new combustion

technologies, such as Homogeneous Charge Compression Ignition (HCCI) or high pressure combustion (HPC), is directly related to the detailed information on the heat exchange processes during the flame/wall quenching at elevated pressures. The experimental difficulties of the flame quenching study are underlined in literature. These difficulties explain the lack of data for a high pressure range (higher than 1MPa). Therefore new experimental data characterizing the single wall flame quenching at high pressures are required. Previous works showed that both ion current and wall heat flux diagnostics allow an estimation of flame quenching distance. The results were validated for a pressure range of 0.08-0.35MPa. Measurements of wall heat flux and ionization current were carried out in a Rapid Compression Machine (RCM) with stoichiometric methane-air mixture in laminar head-on quenching configuration for the pressure range of 0.8-16MPa. It was found that wall heat flux grows with pressure increase as P^{05}. However the dimensionless wall heat flux decreases with a pressure rise. Thus in our experimental conditions we could deduce that wall heat losses less than 10% of flame power are high enough to quench the flame. It is experimentally founded that quenching distance values evaluated from wall heat flux and electrical probe current decrease with a pressure rise. These independent methods give the same result in the pressure range of 0.8-16MPa Minimal value of quenching distance obtained at the pressure 15MPa is about 30pm. Pressure evolution of quenching distance would be fitted by the power polynomial 5, - $P^{\circ 5}$. Taking into account good correlations of quenching distance evaluated with heat flux and electrical probe tecnniques the value of maximal wall heat flux would be determined from ionization current measurements at known pressure.

11:45 (10A) - Detonation Initiation 2

Direct Initiation of Acetylene-Oxygen Mixture Using Laser Ablation

Hidefumi KATAOKA, Hiroyuki K A TO, Kazuhiro ISHII

Laser ablation is expected to achieve direct initiation with a smaller amount of energy as compared to laser breakdown. In the present work, the critical energy of direct initiation using laser ablation of an acetylene-oxygen mixture was experimentally studied with various distances between the focal point of the laser beam and the target surface used as target material. The experimental results show that the critical energy in laser ablation is obviously smaller than that in laser breakdown and that the critical energy has a complex dependence on the distance between surface of the target and the focal point.

Study of Cell Width and Shock Pressure in Directly Initiated Spherical Detonation

Tomofumi ICHIKAWA. Akiko MATSUO

The directly initiated spherical detonation was numerically simulated with two-dimensional Euler equations under the axis symmetric assumption by one-step chemical reaction model to clarify the mechanism on the change of cell width in directly initiated spherical detonation. The grid refinement study was done with the grid resolution of **2, 4, 10, 30** and **50** pts in the half-reaction length, L_{K_2} In all simulated results, the number of cell was almost constant for each grid resolution before **400Li,2,** and linearly increased after that. Therefore, the width of cell linearly increased before **400Li,2** and converged on the constant width after that. As for quantitative consideration, the resolution more than **10** pts would be required for the scientific discussion. Furthermore, the simulated results revealed that the time lag between the lowest pressure region and location of the maximum width of detonation cell came from the one cell-length around the lowest pressure region. The effects of the initiation energy were also examined, and the relation between the averaged maximum pressure history and the maximum width of detonation cell were clarified.

Measurement of Critical Energy for Direct Initiation of Spherical Detonations in High-Pressure H_2-O_2 Mixtures

Vsevolods KAMENSKIHS, Hoi Dick NG, John H.S. LEE

In this study, the critical energy for direct initiation of spherical detonations in high-pressure hydrogen-oxygen mixtures are measured and investigated to look at the effect of explosion limits on the detonation sensitivity. Experiments are carried out in a spherical bomb and direct initiation is achieved via a high voltage capacitor discharge Different methods to obtain a good estimate of the correct amount of energy deposited into the mixture used to initiate the detonation, including the calorimeter method and current method, are discussed. Results obtained from experiments are compared with those predicted from some simple correlation models.

11:45 (1 OB) - Explosions 2

Flammable Plumes Dynamics Resulting from the Convective Dispersion of a Fixed Mass of a Gaseous Fuel into Air, Comparison of 3D versus 2D Models Comparison

Ghazi KARIM, Sina FARDISI

An important source of fire, explosion and toxic hazards is due to releases of fuel vapour within fuel installations or during various industrial operations. The mixing of fuel vapour with the overlaying air produces flammable regions that grow with time and gradually decay as the fuel dissipates into the outside atmosphere. Any source of ignition such as a spark or a sufficiently hot spot within the flammable region can then ignite the mixture to produce a flame that could cause serious economic or environmental damage. Moreover, the exposure of a fuel to the overlaying air also can be a major source of environmental pollution. Improvement to our understanding of the mechanism of the processes of gas emissions and dispersion will help in developing better guidelines to detect and mitigate hazardous vapour dispersion.

Venting of Gaseous Explosions: Influence of Flame Transmission Mechanisms at the Vessel Exit

Bernard VEYSSIERE, Bogdan PONIZY, Nicolas HENNETON

Evacuation of gases out of a closed vessel during an accidental explosion is a crucial problem to prevent increasing of the internal pressure beyond values non compatible with the mechanical resistance of equipments One of the most simple and often used method consist in designing relief vents of appropriate size at the vessel walls. However, progress toward a more reliable modelling of the venting process is limited by the insufficient knowledge of flame transmission mechanisms from the vessel to the discharge opening Here, results of recent experiments performed to investigate the flame evolution and behaviour at the vessel exit and its influence on the process of pressure discharge are presented. Experiments were performed in a cylindrical plexiglas transparent vessel. When a circular hole is fitted at the end of the chamber to simulate a vent, different flame behaviours are observed, following the size of the orifice. Two modes of transmission are identified, depending on the vent area - chamber volume ratio. These marked differences in the flame front transmission from the chamber to the exterior result in dissimilar evolution of the overpressure inside the chamber

Observation of Wire Ignition Phenomena at Excess Electric Current Application in Reduced Gravity

Yasuhiro KIDO, Osamu Fujita, Takeshi Kyono, Hiroyuki Ito, *Yuji Nakamura*

A most potential cause of fire in space is combustion of wire harness in spacecraft, which is generally started with short circuit or overloading of electric wire. Therefore it is important to know the ignition characteristics of overloaded wire in microgravity to improve fire safety in space. In the future space exploration missions, the activities on the Moon and Mars will be included and the fire safety issues under partial gravity condition should be added to the researches on fire safety in space In the previous researches, authors reported that dramatic extension of ignition limit in terms of supplied electric current in microgravity. Then comparison of ignition processes between microgravity and normal gravity were reported. Meanwhile information on the effect of gravity level change, partial gravity effect in other words, on wire ignition can not be found in the literatures. In the present work, therefore, wire ignition experiments with excess electric current were performed under partial gravity condition attained by aircraft parabolic flight. In this study, overloaded wire exposed to reduced gravity condition was observed and determined if ignition occurs Ignition map showing ignition condition in terms of electric current and gravity conditions is drawn. Behavior of degradation gas motion was also observed by optical method in reduced gravity to discuss relationship between degradation gas motion and wire ignition.

11:45 (1 OC) - Chemical Kinetics 1

Autoignition of Methyl Butanoate as a Biodiesel Surrogate

Benjamin Akin KUMGEH, Jeffrey BERGTHORSON

Biodiesel is increasingly employed as an alternative fuel or fuel additive. In order to better understand its combustion properties and assess the associated emission benefits, fundamental research is needed. Because of the difficulties in modelling the long chain methyl esters that make up biodiesel, the chemical kinetic modelling of methyl ester

oxidation is best approached by considering shorter chain methyl esters as surrogate fuels, such as methyl butanoate. This approach is analogous to the central role of hydrogen and methane chemistry in the kinetic modelling of larger hydrocarbons. A model has been proposed for methyl butanoate and through experimental and theoretical investgations. modifications have been suggested to enhance its applicability to a wider range of combustion conditions Since the ignition properties of a fuel is central to its choice for specific combustion engine applications, one of the combustion characteristics employed in chemical kinetic mechanism validation is the ignition delay of homogeneous gas-phase mixtures, often measured behind reflected shock waves. Relatively few shock tube ignition studies of biodiesel surrogate ignition are available for performing the necessary validation, as compared to traditional hydrocarbon fuels. The ignition data by Metcalfe et al.were performed at pressures of 1 atm and 4 atm at rich, stoichiometric and lean compositions in an argon bath. Low temperature data at higher pressures have been reported. Herein we report experimental data at average pressures of 4 atm and 10 atm. Post reflected shock temperatures range from 1190 K to about 1750 K. These experimental data further provide insight both into the oxidation of methyl esters with regards to the effect of pressure and equivalence ratio on ignition.

Low Temperature Oxidation of Hexane with In-Situ Fuel and Oxygen Concentration Measurements

Philipp BOETTCHER, Joseph SHEPHERD, Raza AKBAR

A concern for the commercial aviation industry is the ignition of fuel in the fuel tank or surrounding flammable leakage zones due to heated elements such as pipes carrying hot gas. Ignition may occur at any altitude and therefore a range of pressure and compositions needs to be investigated. Additionally, a better understanding of the applicability of the 225°C auto-ignition temperature for kerosene is sought. In the current study laser based concentration measurements are used to observe the composition changes leading to and during the autoignition process.

Vibrational Nonequilibrium of HO_z Radical in a Model of Chain Branching in Hydrogen-Oxygen Reaction

O/eg *SKREBKOV, Sergey KARKACH*

The mechanism of the reaction of hydrogen with oxygen is considered now as the most studied one (in contrast, for example, to hydrocarbon oxidation). However, all the kinetic calculations executed for interpretation of experiments was based on use of the assumption about an availability of equilibrium on the internal and external degrees of freedom of molecules and radicals. Comparative (from the practical standpoint) successes of kinetic descriptions in terms of the equilibrium approach have been achieved owing to considerable variations of the rate coefficients of important processes.

14:40 (11 A) - Detonation Initiation 3

Initiation of Detonation by Conical Projectiles

Jimmy VERREAULT, Patrick BATCHELOR, Andrew HIGGINS

Initiation of a detonation by a hypersonic conical projectile launched into a stoichiometric acetylene/oxygen mixture with 80% argon dilution at an initial pressure ranging from 0.67 to 1.3-atm is investigated Projectiles are launched from a single stage, combustion driven gas gun using hydrogen and oxygen as propellant. Velocities up to 2.3~km/s are achieved. Pictures of the projectiles are taken via self-luminous high-speed photography. An energetic and a kinetic limit are proposed to predict the conditions required to initiate a detonation. These two limits show excellent agreement with experimental results.

Shock-initiated Ignition

Josue MELGUIZO-GA VILANES, Nika REZAEYAN, Luc BAUWENS Shock-initiated ignition is closely related to deflagration to detonation transition. The scenario whereby a shock moves over a slow flame, enhancing kinetics in unburnt mixture ahead of the flame can be reduced to the problem of ignition between a shock and a contact surface separating burnt (or inert) fluid from combustible mixture. This problem only lends itself to analysis under fairly restrictive conditions. Numerically, this is a difficult problem because of the singular nature of the initial conditions. Indeed, initially, as the shock starts moving into the shocked reactive mixture, the region of interest has zero thickness. Thus, if the problem is resolved on a usual spatial grid, the domain in which the hot spot will appear and ignition will take place does not exist initially In the absence of chemistry, the inert problem is a Riemann problem that admit the usual self-similar solution, and initially, chemistry is very slow. Thus initially the solution to the reactive problem departs from that inert solution very slowly. The difficulty associated with the singular nature of the initial conditions is eliminated when transforming the problem from using physical space x and time t as the independent variables to x/t and t, assuming that the origin x=0 corresponds to the initial location of both shock and contact surface. This approach yields a finite domain initially, and provides for a well resolved problem at early times and less computationally intensive simulations. The transformed problem is solved numerically using an essentially non oscillatory algorithm. Preliminary results are in good agreement with results in the literature, obtained using grid refinement. The current model yields not only the initially slow hot spot formation, but the entire process, including rapid growth of the hot spot, shock formation, retonation and the appearance of a detonation wave.

Detonation Wave Initiated by Explosive Condensation of Supersaturated Carbon Vapor

Alexander EREMIN, Alexander EMELIANOV, Vladimir FORTOV, Alexander MAKEICH, Helga JANDER, Heitz Georg WAGNER, Joachim DEPPE

It is known, that the detonation of most gaseous hydrocarbon fuels is accompanied by the formation of condensed carbon particles and the process of condensation, just as the

oxidation reactions, is characterized by the essential heat release. In the recent paper the process of carbon cluster formation behind detonation waves in acetylene-air and acetylene-oxygen mixtures has been studied, however the quantitative input of condensation energy to the detonation wave was not discussed in details On the other hand the rightful question is the possibility of realization of conditions for the generation of a detonation wave driven only by the heat release of condensation. Recently, the phenomenon of considerable heating of reacting mixture, caused by the condensation of carbon vapor formed during the shock wave pyrolysis of carbon suboxide C_30_2. was for the first time observed Carbon suboxide is rather unstable volatile compound and under heating up to 1400 - 1600 K its molecules decompose to carbon atom and two CO molecules. A complete transformation: C_30_2 -> *CO + carbon nanoparticles* in the mixtures containing only 3% C_30_2 in Ar resulted in the additional temperature rise up to 300 K. An important peculiarity of this process is that a bottleneck of condensed particle growth is the reaction of carbon vapor formation, exponentially accelerating with the temperature rise [3]. At the temperatures 1800 - 2500 K and pressures 3 - 3 0 bar a stage of cluster growth up to the sizes 10^3–10^4 atoms, which is accompanied by the active heat release, lasts at about 1-10 us. Therefore one can assume that at appropriate conditions the process of condensation and energy liberation can proceed in a heat explosion regime and form a detonation wave.

14:40 (11B)- Flame Instabilities 1

Dynamical Motion of Flame Flickering under Swirling Flow

Hiroshi GOTODA, Yuta ASANO. Keng CHUAH, Genichiro KUSHIDA The dynamical motion of the flickering flame under swirling flow produced by a rotating cylinder burner has been experimentally investigated from the viewpoint of nonlinear dynamics based on chaos theory. As the rotational Reynolds number Rer exceeds 312 (Swirl number S=1.4), irregular fluctuations of the flame front begin to be produced with the onset of a spiral flame. The trajectory of the attractor change's from a limit cycle to a complicated structure, and the correlation dimension Dc becomes a noninteger value. This result demonstrates that the dynamical motion of the flickering flame changes from a periodic oscillation to a chaotic oscillation with increasing rotational Reynolds number. The flow visualization shows that the vortex motions generated by centrifugal instability associated with a rotating Taylor-Couette flow have a significant effect on the induction of the chaotic oscillation of the flame front.

The Effect of C02/02 Co-flow on Methane Jet Flame

Yung-Sheng LIEN, Yueh-Heng LI, Yei-Chin CHAO

In the few decades, the pollution of burning fossil fuel will getting worse There are warnings from developed countries, the emission of carbon dioxide will be increased significantly more than 60% in 2020[1][2] Carbon dioxide is one of the main causes for greenhouse effect Burning fossil fuel could be the main source of carbon dioxide emission Even the development of renewable energy is going to fast, the consuming of fossil fuel still the main power for growing up the economy in the next 50 years. Considering about the cost and modern technology, the fossil fuel will still play the main role inevitably. For reducing the global warming impact , there are several ways: increasing the efficiency of using energy, using low-carbon fuel and developing reliable renewables. All of those methods have the same purpose that is to down-size the amount of carbon dioxide emission But the effect is not obvious so far. In modern technology, zero-carbon emission may be proceeded by those technilogies: post-combustion capture, pre-combuston capture,oxy-fuel combustion or in-situ capture and conversion in combustion system [3-7]. Those technologies were

developed from two decaes ago. **All** of technologies have the same purpose: to separate and store carbon dioxide It is different from traditional burning model that is oxy-fuel burning model. When the oxy-fuel burning is proceeding, the carbon dioxide will be leaded back to combustor at the same time not only to low down the temperature of combustor but also to save the cost of recycling carbon dioxide. For Energy-saving and zero-carbon emission, it demanded immediate attention to further research on those technologies

New Properties of High Velocity Regime of Filtration Gas Combustion

Yaroslav KOZLOV, Valerii ZAMASCHIKOV, Aleksei KORZHAVIN, Viatcheslav BABKIN Filtration gas combustion (FGC) as the process of gas phase combustion in an inert porous medium includes a number of steady-state regimes of combustion waves propagation. They are Low Velocity Regime (LVR), u~10^ m/s; High Velocity Regime - HVR, u-1-10 m/s; Sonic Velocity Regime - SVR, u-100 m/s; regime of Low Velocity Detonation and Normal Detonation with heat and momentum losses - LVD, D-800 m/s; ND, D~(1-0.9)$D_{c.j}$ [1]. Some aspects of FGC are studied in detail. However a number of principal problems are unclear [2]. One of them is the problem of effect of forced flow of combustible gas on combustion characteristics in HVR, which is characterized with absence of baric wave in the combustion zone and characteristic size of the channel of a porous medium d more than critical diameter $d_{„}$. To clarify the role and mechanism of participation of forced flow at FGC in HVR there was carried out an

experimental investigation of the combustion character, steady and nonsteady processes, regimes transitions, the characteristic of counterflow, stabilized and coflow combustion waves under variation of filtration velocity.

14:40 (11C) - Numerical Simulations 2

Simulation of the Combustion of Kerosene Vapors by a Multi-Physics Model

Jean Marc PASCAUD, Philippe GILLARD, Nicolas GASCOIN

Over the last past years, there has been a considerable effort to precise the characteristics of the combustion of kerosene which has received much recent attention because of its importance in power-generating equipment, especially in high output military aircraft propulsion systems. The aim of this work is to present a simple multi-physics simulation able to describe the combustion of kerosene vapors in a closed vessel with subsequent applications to vent openings. The initial characteristics of the gaseous mixture are known (pressure, temperature) or may be calculated like the concentrations in a rich or a lean mixture. The evolution of the thermodynamical variables is obtained by the resolution of a system of partial differential equations (PDE) taking into account heat and transport phenomena and the flow in the vessel. Simulated predictions have been compared with experimental results available for a special kind of kerosene (F.34) which has been studied as part of a contract between the laboratory and the Ministry of Defence (DGA)

Statistical Analysis of Displacement Speed in Partially Premixed Flames using Direct Numerical Simulation

Sean MALKESON, Nilanjan CHAKRABORTY

The statistical behaviour of local flame propagation plays a key role in the Flame surface density (FSD) and level-set based modelling methodologies for turbulent partially premixed flames. It is possible to define a reaction progress variable c in terms of fuel mass fraction YF so that c increases monotonically from zero to unity from unburned gases to fully burned products. The speed at which a c isosurface moves normal to itself with respect to an initially coincident material surface is referred to as the displacement speed S_d. Although the statistical behaviour of S_a has been studied extensively for perfectly premixed flames, relatively less attention is given to S_a statistics in partially premixed flames. In the present

study, the statistics of S_d for globally fuel-lean and stoichiometric (i.e. <<p>=0.7 and 1.0) partially premixed flames have been studied using 3D compressible DNS data. The displacement speed statistics have been analysed in terms of its components (i.e. $Sd=S_r + Sn + S_t + St$), which are, namely - the reaction rate component S, , the component due to flame normal molecular diffusion rate $S_„$, the tangential component S_t and the contribution arising from the reactant inhomogeneity S.. For the configuration studied in this paper, the species inhomogeneity is introduced in the unburned gas side in the form of sinusoidal equivalence ratio variation ahead of an initially planar laminar premixed flame Following this, a homogeneous isotropic turbulent velocity field is superimposed on the species distribution and the flame is allowed to interact with the turbulent flow field and upstream reactant inhomogeneity. It has been found that the magnitude of the component of displacement speed due to reactant inhomogeneity S= remains negligible in comparison to the magnitudes of S_r, $S_„$ and $S_,$. The pdfs of S_d show probabilities of finding negative values but the probability of finding positive values overcome that of finding negative values to result in a net positive mean value of S_d. The local displacement speed $S_„$ is found to be negatively correlated with curvature, principally due to negative $S_,$-curvature correlation. The negative correlation between tangential strain rate and curvature gives rise to a positive correlation between S_t and tangential strain rate which opposes the negative correlation between $(S,+S_„)$ and tangential strain rate to yield a weak So-tangential strain rate correlation. These strain rate and curvature dependence of S_d are required to be taken into account while modelling turbulent partially premixed flames using both FSD and level-set methods of reaction rate closure.

Numerical Investigation of Edge Flame Propagation behaviour in an Igniting Turbulent Planar Jet

Henrik HESSE, Nilanjan CHAKRABORTY, Epaminondas MASTORAKOS Many engineering applications, such as the Direct Injection (DI) engines and the relight of gas turbines in high altitudes, involve localised forced ignition of imperfectly mixed reactants. It has been found that the resulting flame from localised forced ignition in inhomogeneous reactants exhibits edge flame structure, where premixed flames are formed on both the fuel-rich and fuel-lean sides and the edge between these two branches propagate on the stoichiometric mixture fraction isosurface. The speed at which the fuel mass fraction isosurface at the edge moves normal to itself relative to an initially coincident material surface is known as the edge flame displacement speed Sd*, which is important for understanding the propagation characteristics of partially premixed flames. Several previous experimental and Direct Numerical Simulation (DNS) studies addressed different aspects of edge flame propagation. However, previous DNS studies on edge flame propagation in the context of localised ignition of turbulent inhomogeneous mixtures were carried out in planar mixing layers without any mean flow and in the absence of any mean shear rate. To account for

some of the above limitations, in the present study the edge flame propagation has been analysed in terms of density-weighted edge flame displacement speed Sd* statistics for an igniting turbulent co-flowing planar jet using 3D compressible DNS data. The edge flame displacement speed Sd* is found to be negatively correlated to Sd*; the correlation between Sd* and tangential strain rate shows both positive and negative correlating trends but the positive correlating trend is found to be dominant at later stages of flame propagation; and the probability of finding negative Sd* is not zero, although the mean value of Sd* remains positive. The above information plays an important role in modelling the propagation of turbulent edge flames.

16:20 (12A) - Detonation Structure 5

Study on Propagation Characteristics of the Shock Waves Driven by Gaseous Detonation Waves

Kou KA WANE, Satoshi SHIMADA, Jiro KASAHARA, Akiko MATSUO We experimentally investigated propagation characteristics of the shock wave driven by a gaseous detonation wave. In general, shock waves are considered to be generated by solid explosives or shock tubes Although solid explosives are possible to generate shock waves even in unconfined space, it can not generate repeatedly. And, although shock tubes are relatively easy-to-use, it is also not capable of generating shock waves repeatedly. In the present research, we generate shock waves repeatedly in free space using the technology for gaseous detonation wave which is one of combustion waves and propagates at from 2 to 3 km/s. Generally, a gaseous detonation wave can be generated with a cylindrical tube filled with combustible gas, where one side is closed and the other side is open. The detonation wave begins to propagate from the closed end to the open end right after high-energy ignition. The detonation wave diffracts at the open end, and burned-pressurized gas as a piston pushes atmospheric air and creates a shock wave. Moreover, it has become possible to operate this cycle periodically at higher frequency. These mean that we could easily create finite pressure waves repeatedly in arbitrary space and arbitrary intensity at high frequency using recent pulse detonation engine (PDE) technology. In order to utilize the shock wave, its characteristics of propagation should be investigated. As for previous studies, there has been a few investigations about propagation characteristics in far field from a source of the shock wave while there has been a lot of investigations about that especially in vicinity region of a source. In the present study, we carried out optical visualization in vicinity region of the end of detonation tube. In far field (200 m far from the end of the tubes), we conducted fixed-point observations using piezo pressure transducers in order to obtain overpressure time-histories of the shock and pressure waves in the axial direction of the detonation tubes.

Accurate Direct Numerical Computation of Detonation Instability

Asian KASIMOV. Brian TAYLOR, Scott STEWART

In this paper we discuss a new shock fitting algorithm that is based on numerical integration of the reactive Euler equations in the frame attached to the lead shock. A local system of hyperbolic partial differential equations on the shock coupled to the reactive Euler equations inside the reaction zone is derived and used as part of a numerical algorithm. Widely used shock-capturing methods suffer from numerical shock smearing and Gibbs oscillations at the shock and are thus difficult to use in verification of stability results. In contrast, our method almost completely eliminates such numerical errors and allows for a very sensitive calculation of the growth of instability. Using high-order time- and space discretizations, we compute the growth of linear instability into non-linear cellular detonation regime and perform detailed verification of the results of detonation stability theory in two dimensions. Our approach is ideally suited for testing detonation stability theory as well as nonlinear asymptotic theories.

Detonation Analogues

Asian KASIMOV

We present several examples from fluid mechanics that are closely related to the phenomenon of detonation and can be considered as its analogues In particular, it will be shown that a structure consisting of a lead shock followed by a transonic flow is quite common in other areas of fluid dynamics. Such phenomena as hydraulic jumps in shallow water flow, traffic jams in vehicle traffic, and others can be described by a theory similar to

the ZND theory of detonation. Both experimental and theoretical advantages of using the analogues will be discussed.

Experiments on Structure of Laser-Driven Detonations

Takuma ENDO. Naohito SUWA, Tomohisa HONDA, Shiro TAKI, Hiroyuki SHI RAG A, Keisuke SHIGEMORI, Mayuko KOGA

Laser-driven detonations were generated in nitrogen gas. In the experiments, self-emission images of the detonations were observed edge-on with a streak camera, and Schlieren images of them were observed edge-on with a gate camera. By dividing the optical path to the gate camera into two and making their path lengths different, two gated images at different times were simultaneously observed When a corrugated detonation front was driven by

nonuniform laser irradiation, the front seemed to be stable. It was found out that the laser heating of the gas began prior to the shock heating and the longitudinal structure of the laser-driven detonations markedly depended on the initial pressure of the nitrogen gas.

16:20 (12B) - Micro and Mesoscale Combustion

Experimental and Numerical Study on Methane/Air Combustion in a Micro Swiss-Roll Combustor

Junwei LI, Beijing ZHONG, Ningfei WANG, Zhijun WEI

To understand working characteristics of a micro Swiss-roll combustor, combustion of premixed CH_4/air was conducted in a micro Swiss-roll combustor. Flammable limits of the combustor at different methane flow rates were obtained, and effects of heat recirculating on the limits were studied.The results showed that when the methane flow rate lies in the range of 0.4-2.3mg/s, stable combustion of the premixed gas can be achieved in the combustor and the flame is kept in the center of the combustor. But the fuel-lean limit and fuel-rich limit are not symmetrical about the equivalence ratio equal to 1. The fuel-lean limit is much larger and stable combustion can be sustained in the combustor at a large air flow rate. Meanwhile, the combustor was numerically simulated. The results revealed that there was a recirculating zone in the center of the combustor, which stabilized the flame at a larger air flow rate.The highest outside wall temperature occurs in the combustor center when air excess coefficient is a little larger than 1. In addition, if air excess coefficient is larger than 1, CH_4 can be completely oxidized. Otherwise, if air excess coefficient is less than 1, excess CH_4 is converted into CO and H_2, and combustion heat release is decreased, which makes the combustion unstable.

Performance of a Miniature Combustor Applied in a Portable TPV System

Yueh-Heng LI, Hong-Yuan LI. Derek Rankin, Y. -C. CHAO

In view of the fact that traditional batteries fail to satisfy the rapidly growing trend towards miniaturization of both mechanical and electromechanical engineering devices, the need for micro or miniaturized power sources with significantly higher energy/power density becomes an emergent issue A small-scale power system has been regarded as a liable solution and alternative power source. In the process of the miniaturization, however, with increasing surface-to-volume ratio (S/V) it inevitably leads to some apparent obstacles including incomplete combustion and flame instability [1-2]. Some logistical strategies have been developed to overcome these challenges. Among these novel and viable small-scale power source designs, the thermophotovoltaic (TPV) power system promises to be a very clean and quiet source of electrical power generation with no moving parts and yielding high power density, using a wide variety of fuels [3-6] In general, the small-TPV power system mainly consists of a combustor with its wall served as an emitter and a PV array. The system is simple yet effective. However, the most obvious drawbacks of the TPV power

devices are their low conversion efficiency and low throughput The overall efficiency of a conventional thermophotovoltaic power system is the product of the efficiencies of the PV cells, and the radiation source, consisting of the combustor and the emitter. In particular, technological improvements in the fields of selective emitter and low band gap PV cells have opened up a renewed page in TPV generation of electricity [7-10]. Despite material limits on the PV cells, both combustor and emitter are key components in the design of a successful small-scale TPV power device. The emitter is usually the wall of the combustor and it functions to convert heat from the combustion into radiation by emitting photons. As regards to a small-scale combustor, it is highly constrained by inadequate residence time for complete combustion and high rates of heat loss from the combustor wall. Therefore, the major challenge in the small-scale combustor design is to keep an optimum balance between sustaining combustion and maximizing the specific electricity output. A high surface-to-volume ratio is very favorable to the surface power output per unit volume. On the contrary, a high heat loss through wall may influence the stable combustion in the small-scale combustor. This is because heat loss through the wall of the combustor increase drastically when miniaturized, which tends to suppress ignition and quench the reaction in high S/V ratio device. Therefore, the problems often encountered in the small-scale TPV combustors are those associated with incomplete combustion, flame instability and nonuniform emitter illumination. In the design of the miniaturized TPV, one should carefully consider the delicate coupling and balance among the fluid dynamics, heat transfer, and chemical kinetics [11]. In this paper, a novel design of the miniature TPV combustor with a reverse tube and a porous medium injector is proposed to remedy the above-mentioned obstacles. Consequently, the overall efficiencies of the miniature TPV system in different combustor configurations are tested and discussed

A Study on the High-luminescence-Flame Thermophotovoltaic Power System

Yueh-Heng LI, Chin-Yung WU, Y.-C. CHAO

Present photovoltaic material has good quentum effieicncy in the range of visible wavelength but emitting spectrun of combustion-driven TPV locates in the near-infrared wavelength. This spectrum mismatch leads to develop the

narrow-band photovoltaic cells and selective emitters all over the world in order to enhance the overall efficiency of TPV power system. In general, flames emission mainly locates within visible wavelength range Therefore, a new concept of developing a high-luminscence-flame TPV system is proposed to enhance the overall efficiency instead of material improvements. This high-luminscence-flame TPV system has a broad emitting spectrum due to combining the visible wavelength range from flames and the near-infrared wavelength range from the emitter. In this manner, utilizing conventional, broad-band photovoltaic cells in TPV power system can obtain well radiant-to-electricity conversion rate. It helps cost down the manufacture expense and increase the material flexibility of PV cells.

A Mesoscale Syngas-Burning Multilayer Catalytic-Mesh Combustor

Yueh-Heng LI, Hung-Wei HSU, Yei-Chin CHAO

In the present study, a multilayer catalytic-mesh combustor was designed and tested. The main subjective is to ignite the syngas by the minimum energy input, and simultaneously to stabilize combustion in fuel-lean condition. Wire-mesh catalysts combine the excellent mass and heat transfer performance of a pellet-type catalyst with the low pressure drop of a monolith. The effects of pore diffusion during combustion are relatively small due to the shell like design of the catalyst layer. Thus the catalyst efficiency is considerably improved compared with pellet or monolith catalysts. Therefore, catalyst configurations (honeycomb and wire-mesh) were compared and some parameters were also examined such as layer number and distance D between catalytic meshes. Concept, design and preliminarily results are addressed in this paper.

16:20 (12C) - Flames 2

Study on the Blowout Mechanism of Turbulent Lifted Jet Flames

Teresa LEUNG, Ida WIERZBA

A method is proposed for predicting the blowout limits of lifted non-premixed jet flames in a co-flowing air stream. Based on the premixed combustion theory, the velocity at the base of a lifted flame at the blowout location is balanced by the turbulent burning velocity. The turbulent burning velocity was estimated using Bray's model. Flow parameters needed to calculate the turbulent burning velocity were determined using a RANS model. Calculations show that at the experimental blowout conditions, the local jet velocity is approximately equal to that estimated. This method allows the blowout limits to be predicted through an iterative procedure for a variety of operating conditions. It was shown that there is good agreement between calculated and experimental blowout limits.

The two-dimensional velocity field at the lifted flame base was measured at the near blowout conditions using the new high-speed particle image velocimetry (high-speed PIV) technique. This system allows for both accurate time and space resolution at the flame base, from which the mean velocity and turbulence characteristics can be derived. The present experimental data can be used to assess the validity of the premixed flame theory.

Global Reaction Mechanism for Ethylene Flames with Preferential Diffusion

Terese LOVAS, Nadeem MALIK, Fabian MAUSS

New challenges for predictive simulations are related to the yet unknown behaviour of alternative clean fuels, such as bio-fuels. Hence, further development of reliable and practical chemical models that can be implemented into modern computational tools are strongly needed from an industrial point of view The formation of particles is located in fuel rich regions during non-premixed combustion such as in diesel engines, or in small fuel rich pockets due to inhomogeneities during combustion e.g. In petrol engines, in particular when running in direct injection mode. In the transition between laminar to turbulent conditions will preferential diffusion effects play a crucial role on the soot formation layer, and this in turn will highly affect the amount of particle formation and growth We have studied this effect using an unsteady flamelet approach We have furthermore proposed a reduced 8 step ethylene mechanism for implementation into complex flow codes for the prediction of this effect.

The Response of Transient Inhomogeneous Methane-Air Ames Subject to Pressure Fluctuations and Stretch

Nadeem MALIK, Peter LINDSTEDT

Stoichiometric planar and outwardly propagating cylindrical and spherical methane-air flames are studied with the aim of shedding light on the coupling of the thermochemical flame structure to thermoacoustic oscillations in the context of inhomogeneous fuel distribution and for different levels of curvature and stretch. The flame-pressure interactions are explored In the limit of high Karlovich number, Ka>1, when the convective scales penetrate into the internal structure of the flame. Hydrogen-air systems have been investigated by Malik & Lindstedt 2009 (under review, Combustion, Science & Technology) and Malik 2009 (ICDERS 2009, this issue), and it is of great interest to compare the response of hydrocarbon flames to hydrogen-air flames, especially in view of the differences in molecular transport processes and Lewis numbers which could alter the thermoacoustic coupling with the flame structure. The recent progress in computer technology makes it possible to explore this important regime of

combustion in considerable detail. Malik & Lindstedt 2009, Malik 2009 have developed an implicit Eulerian method with full pressure velocity coupling in compressible flow and coupled also to comprehensive chemical

mechanisms. The method is features the capability of resolving all the convective and chemical length and time scales in a chemically reacting system which is essential for resolving such highly stiff reacting flows. In this paper, we use a 30 species, 148 reaction set that contains up to two carbon atoms per species, the mechanism is due to Lindstedt and co-workers.

Modeling Ignition Using One-Step Chemistry

Sally BANE, Jack ZIEGLER, Joseph SHEPHERD, Sergey DOROFEEV, Carl BAUWENS Determining the risk of accidental ignition of flammable mixtures is a topic of tremendous importance in industry and aviation safety. The concept of minimum ignition energy (MIE) has traditionally formed the basis for studying ignition hazards of fuels. Standard test methods for determining the MIE use a capacitive spark discharge as the ignition source, and there have been extensive experimental studies to determine the minimum ignition energies of many different flammable mixtures. Work has been done on the numerical modeling of the hydrodynamic evolution following a spark discharge in a non-reactive gas and on spark ignition in reactive mixtures using various models for the flame and spark discharge. However, due to the complexity of modeling the ignition process, predicting ignition remains primarily an experimental issue. The objective of this work is to develop a numerical model of the spark ignition process that accurately captures both the chemistry and the fluid dynamics over a range of physical scales. We use the AMROC (Adaptive Mesh Refinement in Object-Oriented C++) software package to solve the non-reactive and reactive Euler and Navier-Stokes equations including mass diffusion with high resolution. Preliminary 2D cylindrical computations of the flow field evolving from a spark discharge in a non-reactive gas have been completed. To perform reactive simulations in an efficient manner we need to use simplified chemistry, for which we choose a one-step reaction model. We have developed methods based on thermal explosion theory for extracting physically reasonable effective activation energies and reaction orders for one-step models. We first implemented the one-step models into a steady 1D laminar flame code and validated the models by comparing the flame properties with those calculated using the full chemical mechanism. We then implemented our one-step model for a stoichiometric hydrogen-air mixture into the AMROC software to perform a preliminary simulation of a 1D laminar flame. The flame simulations in AMROC were validated using the flame calculations from Cantera, and the one-step model chemistry will be extended to non steady and multidimensional simulations.

8:55 (13A) - Detonation Structure and Chemical Reaction

Numerical Study **of** the Structure **of** Detonation in Very Lean Hydrogen-Nitrous Oxide Mixtures

Remy *MEVEL, Dmitry DA VIDENKO, Gabrielle DUPRE, Claude-Etienne PAILLARD* Detonation soot records sometimes show sub-structures that appear inside the main cell pattern. For nitromethane-based mixtures and mixtures with $N0_2/N_20_4$ as oxidant, the substructures have been correlated with a two-step energy release in the ZND structure. The double structure in H_2-$N0_2/N_20_4$ mixtures has been reproduced in 2-D simulations using a two reactions kinetic scheme Recent studies have shown that very lean H_2-N_20 mixtures also feature a double cellular structure and a non-monotonous energy release. The present study aims at investigating detonation in very lean H_2-N_20 mixtures through numerical simulations, using realistic chemistry. The ZND structure has been simulated and explained using a detailed kinetic model. Two reduced models have been obtained and used to performed 2-D Euler simulations. The first model reproduces the two-step energy release whereas the second presents a single maximum. No significant differences have been observed between simulations with both models: (i) soot foils exhibit a double cellular structure but somehow different than in H_2-$N0_2/N_20_4$ mixtures, (ii) Schlieren pictures and temperature fields show large pockets of unburnt gases downstream of the detonation front. A comparison with the ZND structure of H_2-$N0_2/N_20_4$ mixtures seems to indicate that some critical conditions are required for the thermicity profile to generate "nitromethane-like" sub-structures.

Effect of Losses on Detonation Propagation in 2-step/2-cell Mixtures

Florent VIROT, Boris KHASAINOV, Daniel DESBORDES, Henri-Noel PRESLES In usual $H_2/0_2$ or $C_nH_m/0_2$ mixtures, the detonation front instabilities draw a single cellular pattern on smoked foils, the detonation cells, whose characteristic size lambda is linked to chemical induction length. Nevertheless some mixtures like gaseous nitromethane or rich mixtures composed of H_2 or C_nH_m with $N0_2$ exhibit a double cellular structure since chemical energy is released in two global successive steps of very different characteristic time. We call these mixtures 2-step/2-cell mixtures. Different experimental investigations in $H_2/N0_2$ 2-step/2-cell mixtures diluted or not by Ar clearly show two different detonation regimes in a tube of inner diameter d. When larger cells become of the order of d, the classical quasi-CJ detonation regime turns into a low velocity detonation regime. This bifurcation can be attributed to the effects of losses on the second detonation energetic step which vanishes. 2-step/2-cell mixtures

were first simulated in a flat channel by Guilty et al. and recently in 3D in a round detonation tube by the authors. Up to now, no losses were taken into account in numerical simulations and no velocity deficit relative to CJ values could be seen. That is why we numerically study the effect of losses on detonation structure and regime for these kind of mixtures.

Diaphragm Effect on Detonation Wave Transmission from Propane/Oxygen to Propane/ Air

Лин-Ming LI, Kung-Ming CHUNG, Yao-Chung HSU, Ken-Chin CHANG, Frank K. LU This study examined the effect of diaphragms of different thicknesses and with a slide valve on the detonation wave propagation from a propane/oxygen mixture to a propane/air mixture. The use of diaphragm thicknesses included 9, 25, 38, and 100 micro meter. Wave speed measurement and smoked foil technique were used to observe the detonation wave transmission. The results showed that failure, reinitiation, and attenuation of the transmitted detonation wave were observed whether a diaphragm is used or not. The failure of the transmitted detonation wave is attributed to the concentration discontinuity even though a

diaphragm is used. The post-transmission cell sizes obtained using thin diaphragms (equal to and smaller than 38 micro meter) were smaller and showed a gentler rate of increase compared with those obtained with the slide valve These results may be attributed to a stronger incident detonation wave induced due to the use of the diaphragm, which leads to a stronger transmitted detonation wave than when no diaphragm is present.

Low-velocity Thermonuclear Curved Detonations in Type-Ia Supernovae with a Detailed Nuclear Network

Abdelmalek El MESSOUDI, Pierre VIDAL, Yves BUSEGNIES

A Type-Ia supernova (SNIa) is now described as the result of the thermonuclear explosion of a compact and dense Carbon-Oxygen star called "white dwarf". However, the ignition stage and the propagation mode of the combustion wave are not identified yet. Thus, the considered mechanisms are a pure deflagration or a deflagration-to-detonation transition process. In terrestrial explosives, the dynamical detonation behaviours result from a very strong hydrodynamics-chemical kinetics interplay. For example, in homogeneous gases, these are the cellular structures characterizing the intrinsic local instability of the reaction zone or the very sudden extinctions and transverse reignitions observed in the limiting initiation by point-source energy release or in the transmission from a tube to a large volume. These behaviours are determined by the number and the relative importance of the energy-release steps : the head of the release wave - the "sonic surface" - that partly or fully limits the reaction zone of the self-sustained detonation can thus be located at the end of the last step or of an intermediate one, depending on whether the flow divergence is weak or strong The former case defines CJ (Chapman-Jouguet) or quasi-CJ regimes and the latter defines the so-called low-velocity detonation regimes, because only a limited amount of the available energy sustains the shock. As a rule, each step is associated with a cell size and an existence condition such as the ignition energy, the transmission diameter or the detonation radius. Indeed, the characteristic lengths of these phenomena are strongly correlated to that of the energy-release process in one-dimensional steady detonation. The simulations can represent these dynamics only if all cellular levels are simultaneously accounted for because, for example, a local re-ignition results from the unsteady, three-dimensional flow prior to extinction. To our knowledge, such simulations have not been performed yet in the astrophysical context Since no spontaneous ignition mechanism (e.g., TDD or point-source explosion) is able to generate a planar flow, we here study existence conditions for the self-sustained (sonic) detonation regime in Type-Ia supernovae by means of a curved detonation model. We consider a weakly-curved detonation that propagates with a speed D that increases to the planar value limit when its curvature decreases if the latter is smaller than a maximum (critical) value. Often discussed for gaseous terrestrial detonations, this model provides a good average of the behavior of a curved cellular detonation before relaxation to the planar regime because experiments show that cell sizes are small compared to the curvature radius

8:55 (13B) - Electric and Magnetic Effects

Response of Counterflow Diffusion Flames to Low Frequency AC Electric Fields

Byung Chul CHOI, H.K. KIM, M.K. KIM, J.H. CHOI, Suk Ho CHUNG The effect of electric fields on the response of diffusion flames in a counterflow has been investigated experimentally by varying the voltage and frequency of AC. The result showed that the flame was stationary with high frequency above the threshold frequency. Below the threshold frequency, the flame oscillated by exhibiting near sinusoidal or complex behaviour. This oscillation can be attributed to the ionic wind effect by the generation of

bulk flow, arising from the momentum transfer between neutral molecules and ions, where the ions in the flame were accelerated by the Lorentz force.

Methane/Air Laminar Diffusion Flames in Magnetic Gradients

Pascale GILLON, Jean-Noel BLANCHARD, May CHAHINE, Virginie GUARD We present an experimental study of the behavior of a laminar diffusion flame from a coaxial burner submitted to a magnetic field. Measurements of the lift height and flame length are reported versus the ratio of velocities of air and methane at two positons of the burner inside the magnetic field. It is shown that the lift height is decreased in the positive magnetic gradient whereas it is increased in the negative one. The flame length is found to be increased by the magnetic field whatever the position of the burner versus the magnetic field distribution. Interpretation is based on the direct magnetic force acting on the paramagnetic oxygen but also on the thermomagnetic convection driven by the magnetic force along the flame due to the heat release.

A Numerical Study of the Magnetic Influence on Coaxial Jets Flow

Pascale GILLON, Brahim SARH, Thomas DELMAERE

We present a numerical investigation of the laminar flow issuing from a methane/air coaxial burner submitted to a magnetic field. The study intends to understand the mechanisms involved in the magnetic stabilization of the lifted flames. The model is based on the coupled equations of conservation of mass, species and momentum in which the magnetic force acting on paramagnetic oxygen is introduced in the source term. A classical CFD code is used to solve the steady state equations in an axisymmetric domain. Magnetic effects are deduced from a comparison of the flow behavior with and without magnetic field. Air jet velocity is shown to be decreased locally in front of the magnetic gradient. Calculation of the stoechiometric radius reveals a lateral displacement of the stoechiometric line when the magnetic force is applied. These magnetic effects on the flow can explain the observed reduction of the lift height of flames under magnetic gradient.

Energy Input Areas Initiated by Electric Discharge in Supersonic Flow of Reactive Gases

Boris POSTNIKOV, Vasilii FOMIN, Konstantin LOMANOVICH

Electric discharges allows intensify fuel-air mixtures ignition, reduce ignition induction time, ignition temperature. These parameters are strongly important in research and development of advanced plasmochemical technology and in a row of gasdynamics applications. In present paper volumetric electric discharge in supersonic expanding flow of reactive gases (methane, air, and methane-oxygen mixture) is under consideration. Atermic ignition reaction initiated by diffusive electric discharge discussed. Gasdynamics parameters for diffusive discharge initiation in methane-oxygen and methane-air mixtures were investigated as well as volt-ampere characteristics, flow visualization in the reactor acceleration section. In some experiments external magnetic-field was applied to discharge area. Supersonic channel geometry responsible for volumetric electric discharge keep up in reactive mixtures was optimized. Experiments aimed to understand impulse-periodic discharge frequency influence to energy input area were carried out. The research was made as a framework for supersonic natural gas pyrolysis reactor development. In frequency energy input mode it was obtained that the discharge frequency control gives an opportunity to adjust selectivity of methane conversion end-products in sub- and supersonic reactors.

8:55 (13C) - Flames in Channels

Effects of Configuration of Chamber on Flames Propagating through a Narrow Channel

Jifeng DU, Teruo YOSHIHASHI, Tetsuro OBARA, Shigeharu OHYAGI Experiments were conducted in order to understand behaviour of the hydrogen-air premixed flame passing through a narrow channel, which connected two rectangular combustion chambers. The behaviour of the flame was observed by two pressure transducers equipped on each chamber and the events were visualized by using Schlieren optical technique with an aid of high-speed video camera. Mixtures tested in this study are hydrogen-air and methane-air An equivalence ratio, initial pressure, and a width of the channel were varied in order to investigate effects of these parameters on characteristics of the flame propagation in the narrow channel. As a result, the behaviour of the flame was classified into two categories, i.e. (i) the flame was quenched inside the narrow channel and combustion wave was arrested to propagate, (ii) the flame was propagated through the channel without quenching, which produced a rapid pressure rise in acceptor chambers. Effects of configurations on the quenching distance will be discussed

Computational Study of the external shock-wave impact on the combustion regime

Alexey KIVERIN, Mikhail IVANOV, Viktor GALBURT

It is known, that deflagration-to-detonation transition (DDT) in gaseous combustible mixtures accelerates sufficiently in presence of external impact. It induces studies of the combustion processes sensibility to external influences. Most prevalent of such influences is a shock-wave impact. Under certain physical conditions such an impact causes DDT acceleration. Shock interaction with the developing flame launches non-linear gasdynamic processes. Evolution of these non-linear processes strongly affects flame evolution. As a result a highly perturbed flame structure is generated, energy-release rate increases, flame accelerates and transition to the detonation regime occurs This paper examines shock-flame interaction by the means of two-dimensional numerical simulations. The problem

corresponds to the conditions of the shock-tube experiments. A flame is ignited at a distance from a reflecting wall. A shock is released at the opposite end of the tube (open end). Shock-flame interaction distorts flame surface, increasing the energy-release rate in the system and accelerating the combustion. Consequence of the interaction is determined by the characteristics of the shock wave and the flame. This paper examines scenario of the system evolution due to the shock-flame interaction in hydrogen bearing mixtures. The main results are related to the less intensive ("slow") and more intensive ("fast") regimes that are realized in the hydrogen-air and hydrogen-oxygen mixtures correspondingly. The characteristic velocities (normal velocities of the laminar flames) of these regimes differ approximately on the order. Consequently, flame acceleration and DDT caused by shock interaction with the "slow" flame are determined mainly by the non-linear processes of hydrodynamic mixing. It differs from the shock interaction with the "fast" flame. In this variant the impact of the same intensity may cause DDT already behind the incident shock. Computer simulations of the combustion process, shock-flame interaction and DDT is based on gasdynamic model of hydrogen combustion. The model includes gasdynamic transport of viscous gas, oxidation kinetics of hydrogen, multi-component diffusion and heat conduction. For multi-component mixture and combustion products the equations of state for real gases were used. The reduced model of chemical kinetics includes nine reactions and describes process sufficiently detail. Paper's results give relatively detailed description of the shock-flame interaction in confined volumes. Depending on shock wave and flame characteristics DDT may take place. These characteristics are related mainly to the dynamics of flame and shock wave (velocities, shape e. t. a). In both variants (hydrogen-

oxygen amd hydrogen-air mixtures), as the shock interacts with the flame surface, the nonlinear gasdynamic effects are triggered by the curvature of the flame. These effects are more intensive than the flame front instability (Darieus-Landau instability). The highly perturbed flame is generated. Besides the pressure increase plays its role. And as a result DDT takes place earlier than in absence of any extrinsic factors.

Dynamics of Premixed Flames in a Narrow Channel with a Step-Wise All Temperature

Vadim Kurdyumov. Gianmarco Pizza, Christos Frouzakis, Ioannis Mantzaras The effect of the inflow velocity and wall temperature on the dynamics and stability of unity Lewis number premixed flames in channels with specified wall temperature is studied with the help of steady and transient calculations with a two-dimensional thermo-diffusive model. The simplified model is capable of capturing many of the transitions and the combustion modes observed experimentally and in direct numerical simulations of hydrogen/air flame in micro- and meso-scale channels, and indicates that the thermal flame/wall interaction is the mechanism leading to the observed flame instabilities.

Experimental Study of the Initial Flame Propagation of Premixed H_2-air Explosion in a Channel

Kanchan RAI, Dag BJERKETVEDT. Ole Kristian SOMMERSEL

Experiment with release of hydrogen inside a channel, 1.7 m long, 0.1 m wide and 0.1 m high was carried out. The objective of the present work is to study the initial phase of the flame propagation in inhomogeneous mixtures. The Schlieren technique was used in combination with a high speed camera was used to study the process. Experiment with homogeneous mixture of hydrogen air was carried out to get better understanding of the initial phase of explosion and to remove the complexity of the inhomogenity. The flame stretch rate was calculated and the time of onset of flame instability was observed from the high speed video. The onset of instability occurred between 3.8 ms - 6 ms for all the experiments. The critical Peclet number was estimated for the homogeneous mixture of hydrogen air at 1 atm, which agreed with the data from Joomas et al for 5 atm for equivalent ratio less than 1. Above 1 the crtical radius for calculating the Peclet number became larger compare to the cross section of the channel. It was also seen that there was an increase of flame speed due to the flame instability. There was an increase of approx. 50 % and 100 % increase of flame speed due to the instability in the axial direction for equivalent ratios of 0.52 and 0.75 respectively. This increase is about the same for lean hydrocarbon-air mixtures (1.6-1.8 times the laminar flame speed) observed by Lind and Whitson. However the increase in the flame speed may be affected by the walls also. Further experiments will be carried out in a setup with large cross section to reduce the wall effect. Similar flame propagation behavior was observed in the lean hydrogen-air cloud experiments.

11:00 (14A) - Detonation Multiphase 1

One- and Two-Dimensional Analysis on Jet A/Air Two-Phase Detonation

Naomichi MASUDA, A. Koichi HAYASHI, Venkat TANGIRALA

There are few data for Jet A/air or Jet A/0_2 detonations. The present extended abstract shows the detail numerical analysis of Jet A/air comparing with the equilibrium data and JP10/air data. Since this abstract provides only gaseous detonation cases, the cell size of Jet A/air detonation is quite small, but the two-phase detonation case will give us a

larger cell or non-detonation case. The data will give us the important information for detonation devises such as two-phase PDE.

Numerical Simulation of Detonation on the Basis of Harten Scheme

Sergey MARTYUSHOV, Tov ELPERIN

The mathematical model corresponding simplified model of two-phase chemical reaction, including the induction period and the subsequent reaction period was used for numerical simulation of detonation in gas mixes oxygen-hydrogen. Gas was assumed ideal and non viscous. Two problems have been calculated: cycle of the pulse detonation engine and a spontaneous detonation of an air-hydrogen mix under a protective environment of a nuclear reactor.

Combustion of Poly-Dispersed Reactive Systems

Nickolay SMIRNOV, Valerii NIKITIN, Evgeniy SHEMYAKIN, Veronika YANUSHKEVICH The paper presents the results of theoretical investigations of combustion and detonation initiation in heterogeneous polydispersed mixtures. A mathematical model for ignition and turbulent combustion of polydispersed mixtures incorporating solid dust and liquid droplets in cylindrical vessel is developed. The equations of motions for particles consider the influence of random turbulence pulsations in gas flow. Thermal destruction of dust particles, vent of volatiles, chemical reactions in the gas phase, carbon skeleton heterogeneous oxidation by $C0_2$, and chemical reaction with H_20 are the processes essential for describing dust and particulate phases. The problems of liquid droplets atomization, evaporation and combustion being the key factors for ignition delays and shock waves attenuation evaluation in heterogeneous mixtures and the non-equilibrium effects in droplets atomization and phase transitions were taken into account. The effects of droplets size non-uniformity and spatial distribution non-uniformity on mixture ignition and flame acceleration were investigated. Dispersed mixtures having been formed by different pulverizers could not be spatially uniform. However, in most experimental and theoretical investigations the ignition characteristics of uniformly distributed in space mixtures were studied. To achieve uniform droplet distribution and to avoid gravitational separation of the mixture having been formed investigations under microgravity conditions are performed. The goal of the present research was, however, to investigate sensitivity of detonation onset to mixture parameters non-uniformity (spatial non-uniformity of dispersed phase, size distribution function, etc.).

11:00 (14B) - Flame Instabilities 2

Influence of External Noise on Dynamics of Expanding Flames

Roman FURSENKO, Sergey MINAEV

The dynamics of outward propagating cylindrical flames has been studied in terms of exact solutions of the Sivashinsky equation with a random force term. The force term models the computational round-off errors or a variety of perturbations of physical origins. In contrast to noiseless conditions, the number of poles in the system does not conserve and new poles appear due to the external forcing. It was found that modification of the pole solutions taking into account the appearance of new poles captures the features typical for the hydrodynamically unstable flames, which cannot be detected by the pole solutions with a fixed number of poles. Investigations based on the pole solutions make it possible to exclude the uncontrolled numerical noise that is always present in direct computations of the Sivashinsky equation, and to examine the interplay between noises and hydrodynamic instability. The study clearly demonstrates that the presence of noises is a necessary condition for flame acceleration.

Model of the Flame Front Evolution with Inertial Effects

Sergey MINAEV, Roman FURSENKO

The non-stationary behavior of near-limit premixed flame propagating in a micro channel of variable area and nonuniform temperature distribution in the channel wall was theoretically investigated. 1D nonlinear evolutionary equation of the flame front was obtained. The nonlinear model outlined the flame stabilization, nonlinear flame oscillations and periodical flame extinction and ignition processes that were observed in experiments.

Impact of $C0_2$/N_2/Ar Addition on the Internal Structure and Stability of Non-Premixed CH4/Air Flames at Liftoff

Jiesheng MIN, Aurelie WYZGOLIK. Frangoise BAILLOT, Eric DOMINGUES, Martine TALBAUT. Beatrice PATTE-ROULAND. Dany Escudie. Cedric Galizzi, Frederic ANDRE, Olivier GICQUEL

The present study is focused on the influence of carbon dioxide added to the air on the transition from an attached flame to a lifted flame issued from a coaxial jet (inner methane and outer air). As known, main effects due to a diluent are induced not only by pure dilution, but also by thermal and chemical actions. In order to find features able to discriminate between them, two other diluents had also been investigated: nitrogen, thermally inert and argon,

chemically inert. Firstly flame stability was analyzed; results show that flame lifting can always occur such that it is essentially controlled by the critical flow ratio, (QrIIuenl/QsirIMing even though aerodynamics from inner jet structure does also influence it. Attached flames can stabilize with dilution at a higher position, Ha Ha-evolution is dictated by the normalized parameter (QdtamlQairMQdIluent/QlIirWting for the three diluents, leading to a unique curve under given aerodynamic conditions Modifications in inner flame structure (OH-zone) are totally different when lifting results from pure aerodynamics (no dilution) or from a diluted configuration. But for all the three diluents, effects on flame OH-zone are identical when lifting occurs.

Instability of Flames in Cylindrical Tubes

Victor V. VOLKOV

Instability of planar flame spreading in an inviscid, incompressible medium was proved by Landau. Viscosity is the main factor stabilizing the process of normal burning. The account of viscosity requires simultaneous consideration of the finite thickness of the flame zone. Changing of the flame thickness plays an essential role in stabilizing laminar flame propagation in viscous gas mixtures as well. Compressibility of medium is also a stabilizing factor, although much less considerable than viscosity But all those conclusions concern only combustions in the open space. The main aim of this investigation is to research stability of flames propagating in cylindrical tubes. Three different cases are considered:

1) the case of the infinite tube;
2) the case of the cylindrical tube (combustor) with the closed end and the open end;
3) the case of the tube with both closed ends

The spectrum of eigenvalues satisfying boundary conditions is discrete. **Self-oscillating**

Laminar Lift-off Flames

SungHwan YOON. Jeong PARK, Oh KWON, Jin YUN. Sang KEEL

Characteristics of lift-off propane flames diluted with nitrogen have been investigated experimentally to elucidate the existence of a self-oscillation and effects of flame curvature. Flame stability maps are compared for the fuel tube diameters of 0.1 and 1.0mm to clarify the effects of flame curvature in flame stability and flame oscillation. Flame oscillation modes are classified into three: a pure self-oscillation, a combined form of self-oscillation

and buoyancy-induced oscillation, and a combined form of self-oscillation and diffusive-thermal instability. It is shown that the pure self-oscillation is not relevant to a diffusive-thermal instability and a hydrodynamic instability caused by buoyancy, and appears at all lifted flame conditions irrespective of fuel Lewis number. These experimental evidences are displayed through the analysis of power spectrum for temporal variation of lift-off height. The possible scenario of self-oscillation mechanism is also addressed.

11:00 (14C) - Chemical Kinetics 2

Performances and Limitations of the Detailed Kinetic Models of Low-Temperature Oxidation of Alkanes

Frederique BATTIN-LECLERC

The increasing concern for environmental issues and for energy conservation has led academic and industrial researchers to devote many effort to develop more and more sophisticated detailed chemical kinetic models, based on a large number of elementary reactions, for a large and widening variety of model fuels. The purpose of this paper is to summarize the conclusions which can be derived from a review of the gas-phase detailed kinetic models which have been recently developed to model the oxidation and autoignition of alkanes and alkenes.

Global Analysis of Chemical Kinetic Mechanisms

Viatcheslav BYKOV, Ulrich MA AS

In the present work a novel method of global analysis of detailed and skeletal chemical kinetics mechanisms is presented. The method is applied to a number of detailed models of low hydrocarbon combustion. The main idea of the approach is to describe explicitly the decomposition into fast and slow motions that typically present in the combustion system. Exploration of this internal hierarchy of chemical mechanisms allows description of the thermo-chemical state of the system by a low-dimensional manifold Hence, the result of the analysis can be used for model reduction purposes. In this way, the model reduction shrinks to an identification problem of such manifolds. It is well known, that most existing methods (sensitivity analysis, CSP, ILDM etc.) of the chemical kinetic model analysis have a local character, i.e. they are based on the analysis of the system Jacobian. Therefore, they are limited in the applications and interpretation of results to a neighbourhood of a particular system state. Questions of how the system dynamics can be decomposed and what is a global hierarchy of the system are still open. In the current work, the gap between a local and global analysis is narrowed by considering the so-called global

linearization procedure that can efficiently be applied to model reduction as well as to comparative analysis of the detailed mechanisms and study their properties.

A Skeletal Mechanism for the Oxidation of *n*-Heptane / iso-Octane generated by the Chemistry Guided Reduction Approach

Lars SEIDEL, Frida BRUHN, Sayeed S. AHMED, Gladys MO RE AC, Thomas ZEUCH, Fabian MAUli

We apply to the primary reference fuels n-heptane and iso-octane the chemistry-guided reduction (CGR) formalism for generating kinetic hydrocarbon oxidation models. The approach is based on chemical lumping and species removal with the necessity analysis method, a combined reaction flow and sensitivity analysis. A defined sequence of simplification steps, consisting of the compilation of a compact detailed chemical model, the application of linear chemical lumping, and finally species removal based on species necessity values, allows a significantly increased degree of reduction compared to the simple application of the necessity analysis, previously published species, or reaction

removal methods. The CGR approach provides a lumping concept that allows for a very compact description of the isomerization reactions of peroxy-radicals that is intrinsically independent of the fuel size. We previously described in detail this lumping method for linear peroxy isomers produced during the oxidation of n-heptane. In the present study we demonstrate that the lumping technique can be applied to the branched peroxy radical isomers formed by iso-octane oxidation with minor modifications.

Predictive Modeling of the Chemical Kinetics in Jet-A/Air for High-Temperature Combustion and Gas Phase Detonations: Multi-scale Approach

Marina STRELKOVA, Igor KIRILLOV, Ivan ZAEV. Mikhail OKUN, Stanislav UMANSKII. Boris POTAPKIN, Venkat TANGIRALA, Anthony DEAN, Adrian TENTNER In the present paper the hybrid multi-scale first-principle based approach for the development of predictive kinetic mechanisms for the combustion and detonation is presented. Utilizing this approach the kinetic mechanisms for Jet A/air detonative combustion were developed: detailed mechanism (417 reversible reactions, 71 components), reduced mechanism (38 reactions, 24 species), overall mechanism (11 forward reactions, 10 species) These mechanisms were validated upon the available experimental data.

Intensification of Shock-induced Combustion by Electricaldischarge-excited Oxygen Molecules

Alexander STARIK, Boris LOUKHOVITSKI, Nataliya TITOVA. Leonid BEZGIN, Valery KOPCHENOV

Combustion intensification mechanisms in a supersonic flow behind the oblique shock wave front as well as the features of detonation wave formation over a sharp wedge in a supersonic H_2-0_2 reactive flow are investigated when vibrational and electronic states of 0_2 molecule are excited by an electrical discharge. The novel thermal nonequilibrium model of chemical kinetics for the analysis of the influence of the delayed excitation of the molecular vibrations of reagents behind the primary oblique shock wave front forming over the wedge on the ignition and combustion structure in the flow downstream from the oblique shock was developed. The presence of vibrationally and electronically excited 0_2 molecules in the oxygen plasma allows to intensify the chain mechanism in the H_2-0_2 mixture and to significantly decrease the ignition zone length and the length of the oblique detonation wave formation in a supersonic flow. It makes possible to stabilize the detonation wave at a short distance (-1-2 m) from the wedge apex for low initial temperature of the supersonic flow (-400-500 K) and for small specific energy deposited to molecular oxygen in the discharge region (-0 01-0.003 J/cm3). It was shown that the activation of 0_2 molecules by electrical discharge should be organized in a limited near axis region in front of the wedge Excitation of 0_2 molecules is more efficient for acceleration of oxygen-hydrogen mixture combustion than mere heating of the gas by an electrical discharge

14:40 (15A) - Detonation Multiphase 2

Cellular Detonation Diffraction in Gas - Particle Mixtures

Yulia KRATOVA, Alexander FEDOROV, Tatyana KHMEL

The work focuses on investigation of propagation of the cellular detonation in gas suspensions in channels with an abrupt expansion of the cross-section. The purpose of the work is the analysis of cellular detonation diffraction in aluminum particles oxygen suspension on the backward step: 1) determination of scenarios of detonation propagation after the passage of the channel cross-sectional breakdown; 2) the analysis of influence of

the size of particles of a monodisperse suspension and geometrical parameters of the channel on the flow development in various propagation regimes.

Modelling of Detonation Cellular Structure in Aluminium Suspensions

Arnaud BRIAND, Bernard VEYSSIERE, Boris KHASAINOV

Heterogeneous detonations involving aluminium suspensions have been studied for many years due to their interest in industrial safety policies, military applications or propulsion applications. As for gaseous detonations, the cellular detonation structure was established to exist in aluminium suspensions in oxidizing atmosphere, but its characteristic size is larger due to slower chemistry of heterogeneous burning of particles. The numerical two-step model previously developed by the authors was able to simulate the detonation cell structure, and the calculated cell sizes agree with the few experimental results available for suspensions of aluminium particles in air or oxygen. It also displays major differences between heterogeneous and gaseous detonations in the mechanisms of ignition. For both aluminium - air and aluminium - oxygen mixtures, the detonation cell size was found to be proportional to the particle diameter to the power 1.4. Moreover, a linear relationship was found between the detonation cell size and the induction length while no obvious correlation was found between the cell size and the combustion zone length. In the present work we improve the predictive ability of our model by incorporating a hybrid model of aluminium combustion similar to that proposed by Zhang et al. and examine correlations between the detonation cell size and the particle diameter. Results obtained with this new model are close to the former ones and our preceding conclusions are corroborated

The Dynamics of "Dark Waves" in Homogeneous Liquid Nitromethane

David MACK, Andrew HIGGINS

This investigation develops a new technique to permit the long duration dynamics of dark waves (regions of local detonation failure) in liquid nitromethane to be recorded and analyzed. The technique uses a plate on the edge of the charge (witness plate) to record failure marking patterns. Regions where detonation occurs are recorded by an indentation of the plate, while regions of failure leave the plate unchanged. While this technique is simple and yields a wealth of information, it is limited by the aspect ratio of the charge used. To eliminate this effect, the charge can be rolled into an annulus, effectively creating periodic boundary conditions on the edges of the charge. The central rod now becomes the recording surface for the failure markings. Rods recovered from experiments are laser-scanned and then analyzed for the failure wave dynamics. The results of this investigation demonstrate that failure of an unstable homogeneous liquid explosive like nitromethane is governed by a complex dynamics of dark waves that can persist for many hundreds of characteristic charge dimensions before failure or may continue indefinitely This study identified a qualitative difference between high impedance confinement (aluminum) and low impedance confinement (PVC) in regards to the dynamics of the dark waves

14:40 (15B) - Flame Instabilities 3

Experimental Study on Flame Structure in Methane-air Diffusion Flames

DaeGeun PARK, Jeong PARK, Jin YUN, Sang KEEL

Experiments have been conducted to clarify impacts of curtain flow and velocity ratio on low strain rate flame extinction, and to further display transition of shrinking flame disk to flame-hole. Critical mole fractions at flame extinction are examined in terms of velocity ratio, global strain rate, and nitrogen curtain flow rate. It is shown that multi-dimensional effects at low strain rate flames through global strain rate, velocity ratio, and curtain flowrate dominantly contribute to flame extinction and transition of shrinking flame disk to flame

hole. Our concerns are particularly focused on the dynamic behavior of an edge flame in shrinking flame disk.

Fluid-dynamical Characteristics of Bifurcating Jet inside Diffusion Flame under Transverse Acoustic Excitation

Suzuki MAS A TARO, Tomohiro HAMATANI, Tohru UMEDA. Wataru MASUDA Measurement of velocity profile of a fuel jet bifurcating inside a diffusion flame under acoustic excitation is conducted by means of particle tracking velocimetry. It is confirmed prior to the detailed examination that the addition of particles to the fuel gas has negligible effect on the behavior of the jet, and that the measured velocity by this method is reasonably accurate. The results indicate that the velocity profile is not altered by the acoustic forcing in the region in which shadowgraphy shows the jet going straight before meandering. This infers that the bifurcating behavior is originated from not the effect of steady streaming but that of linear instability. On the other hand, the velocity profile oscillates synchronically with the acoustic forcing in the region in which the shadowgraphy shows the jet meandering. A qualitative explanation of the bifurcation of the jet is successfully obtained by considering the probability density distribution of the oscillating fuel jet based on the interpretation of the experimental results.

Influence of Tube Diameter on Lean Limit Flame Propagating upward in Methane/Air Mixture

JozefJAROSINSKI, Grzegorz GORECKI, Yuriy SHOSHIN, Tadeusz FODEMSKI It is known that flammability limits of premixed flame are influenced by coupled effect of flame stretch and preferential diffusion [1]. Preferential diffusion depends on Lewis number for the deficient reactant (Le=a/D). Positively stretched flames are

characterized by increased flame temperature and extended flammability limits for mixtures with Le<1, and reduced flame temperature and narrowed down flammability limits for mixtures with Le>1.

14:40 (15C) - Various Topics 1

Thermal Explosion Characteristics in the Presence of an Additional Heat Source

Suraju AJADI, Vladimir GOL'DSHTEIN

The present work is focussed on the analysis of the thermal explosion characteristics associated with an additional source of heat released due to forces of internal friction(mechanical heat source), which is important in connection with the motion of highly viscous reactive system.

By using the quasi-stationary state procedure, an approximate criterion was derived for a finite activation energy. We used some experimental data to determine the extent contributions of this additional heat source on the criterion of thermal explosion by comparing with known results.

Dynamics of Combustion Products Flow in Ring Nozzle with Semienclosed Cavity

Vladimir LEVIN, Nataliy AFONINA, Valeriy GROMOV, Gennadiy SMEKHOV, Aleksander KHMELEVSKY, Vladimir MARKOV

In the paper are represented the results of the comprehensive experimental-design study of the thrust characteristics of the model of end device of the jet engine, which works on the products of the equilibrium combustion of the acetylene of air mixtures, that make it possible to conduct the verification of mathematical models through the results of the comparison of experimental data with the calculated. The calculations of flow taking into account viscosity were performed with the use of a computer complex, which includes the programs of the numerical integration of Navie-Stokes equations for different models of gaseous medium. Flow in the inviscid approximation was described by the system of

equations of Euler, augmented by the equations of chemical kinetics. Experiments on the testing of model in wind tunnel of end devices were executed in the laboratory pulse aerodynamic installation.

Boundary Layer Control Using Surface Discharges

Irina ZNAMENSKAYA, Denis ORLOV, Oleg PENYAZKOV, Pavel KHRAMTSOV, Maryna CHERNIK

In present work two types of surface discharges are tested for boundary layer control purposes. Investigations of local energy deposition were conducted. Nanosecond pulse surface discharge ("plasma sheet") efficiency and flow control mechanism are compared to those of HF barrier discharge. Plasma sheet can be used for creation of nonequilibrium energy deposition area in thin layer near wall. Pulse-periodic energy supply in boundary layer including shock wave interference area using plasma sheet is one of the effective ways to correct the flow . In the HF barrier discharge a directed gas flow appears, which forms a turbulent boundary layer. The use of high frequency surface barrier discharge allows achieving profile drag coefficient decrease on 3 - 7 % in velocity range of incident flow up to 10 m/sec.

16:20 (16A) - Detonation Multiphase 3

Secondary Combustion of Detonation Products with Surrounding Air Experimental Characterization of Fireball Dynamics

Laurent MUNIER, Emmanuel LAPEBIE, Gerard BAUDIN

This article focuses on the secondary order phenomenan in time, occuring when a condensed high explosive detonates. To be more precise, we focused on turbulent combustion betwenn detonation products and air. The problem under consideration there is the turbuelent mixing in a fireball induced by a very large density ratio across the fireball interface. The paper presents also a new non intrusive temperature measurment device used to record average temperature at the fireball surface

Unconfined Hybrid Detonation Waves

Fan ZHANG, Akio YOSHINAKA, Robert RIPLEY

Unconfined hybrid detonation studies are conducted in free field conditions in order to investigate the self-maintenance of the hybrid detonation wave propagation without the influence of tube confinement. Hybrid detonation in an unconfined large-scale aluminum-liquid fuel spray suspended in air has been experimentally demonstrated in which the energy release of aluminum particles within the detonation zone of the liquid fuel spray reduces the cell size and enhances the detonation. This phenomenon is in agreement with that observed in the previous confined tube studies and referred as a strong solution of hybrid detonation in the analysis. The impulse of unconfined hybrid detonation scales with the cubic root of aluminum-liquid fuel mass observed over a wide range of fuel masses from 3 kg to 1000 kg. In contrast to the laboratory tube observation, the double-shock weak detonation

solutions have not been apparent in the unconfined experiments when increasing the aluminum particle size in a range from 1.6 to 13.2 micrometer mean diameter by number or 3 to 36 micrometer mean diameter by mass In order to examine the conditions for possible solutions of unconfined hybrid detonation, spherical numerical simulations are conducted using a full two-phase fluid dynamics model and the results will be reported in the final paper.

Detonation Propagation as a System of Randomized Discrete Energy Sources

Andrew HIGGINS

Detonation waves in gaseous and homogeneous liquid explosives are known to be inherently unstable, with the detonation front comprised of an ensemble of interacting

wavelets. The dynamics of detonation waves in heterogeneous explosives with large-scale heterogeneities is dominated by the random nature of the discrete media. In order to investigate the dynamics of these systems, this paper considers a "model problem" of detonation propagation in a cloud of randomly positioned, point-like energy release centers embedded in an inert media. The blast waves from the sources are treated using point-blast theory and the pressure fields generated are linearly superimposed. If the blast pressures are sufficient to trigger new sources, a mechanism of continued wave propagation exists. The results of this simple model capture the behavior observed in unstable gaseous and liquid explosives and highly heterogeneous explosives in predicting a ratio of critical charge diameter to critical thickness of 3.5:1, in agreement with the gas-phase detonation experiments of Benedick et al. and the recent experimental study of heterogeneous explosives by Petel et al. It appears that the stochastic nature of energy release in the detonation front (or in the media itself) permits the wave to propagate in much thinner two-dimensional slabs than would be predicted by scaling cylindrical charge results using front curvature theory

16:20 (16C) - Various Topics 2

Mechanochemical Method of Increasing of Reaction Ability of Mixtures of Aluminum and Magnesium with Oxidizers

Alexander DOLGOBORODOV, Andrew STRELETSKII, Igor KOLBANEV, Michael MAKHOV

The paper considers the rules of formation, the structure and reactivity of metal oxidizers composites (Me=Al, Mg; Ox=Teflon, $Mo0_3$), prepared by mechanochemical method. Under mechanical treatment the following stages were separated: (i) independent grinding and mixing of reagents, (ii) formation of molecular-dense composites consisted from nanosized Metal particles and matrix of second component, (iii) chemical interaction of components and (iv) crystallization of products. Formation of nanosizes Me/Ox composites (stage ii) leads to the great increase of reactivity For example, for system Al/MoO_3 combustion rate increases from 1 to 400 m/s, for Al/Teflon was observed detonation-like regime with the velocity up to 1300 m/s, etc. Metal-oxidizer nanocomposites prepared by the mechanochemical method may be used for the development of various energetic materials, materials for hydrogen power systems, etc. Formation of nanocomposites is the intermediate stage of the mechanochemical synthesis, and, depending on the formulated problem, one can prepare the specimens with different properties.

Existence and Uniqueness of Travelling Front in Premixed Combustion in Porous Media

Natalia KRAPIVNIK, Vladimir GOL'DSHTEIN

We consider a phenomenon of combustion wave driven by a local pressure elevation through the inert solid skeleton filled with combustible gaseous mixture. We focus on the traveling wave solutions arising in the adiabatic models of this phenomenon. Existence and uniqueness were proved for the sub-sonic traveling wave solution for model which includes a quadratic dependence of the friction force on the velocity of the gaseous mixture.

Mechanocomposites $Si0_2$/Al for SHS Preparation of Composites Si/Al_20_3

Tatiana GRIGORYEVA, Tatiana TALAKO, Marat SHARAFUTDINOV, Yuri KAMINSKIY, Irina VORSINA, Antonina BARINOVA, Klaus BECKER, Vladimir SEPELAK, Nikolai LYAKHOV

The process of mechanochemical interaction of Si02 with Al was studied. The mechanical activation of the $Si0_2$/Al mixture results in a decrease of the temperature of chemical interaction of $Si0_2$ with Al from 1100 C to about 600 C. The mechanochemically prepared

$Si0_2$/Al may serve as a precursor for Si/Al_20_3 composites formed by subsequent self-propagating high-temperature synthesis (SHS). For the first time, the SHS process (reduction of SiO_2 by Al) was followed in-situ by the time-resolved X-ray synchrotron diffraction.

Numerical Simulation of a Turbulent Diffusion Flame

Tohid DARVISHZADEH

In this paper, we have numerically investigated the properties of a diffusion turbulent flame inside a model combustor. Our aim is to compare different numerical methods with the results from experimental data to understand the underlying physics of turbulent diffusion flames. We have first simulated non-reactive flow of air inside a pipe to appreciate the properties of the turbulence independent of combustion. We have then extended the problem to a reactive flow, in which a nonpremixed turbulent diffusion flame is formed It is found that the "species transport" and the "K-e" are the best models to resemble combustion and turbulent processes, respectively, through comparison to experimental data. The accuracy of the results compared to the experimental data indicates the correctness of the models and the simulation used, which was not acquired with any of the recently done researches.

Partitioning Effect on a Dust Explosion

Jean Marc PASCAUD

The aim of this work is to verify the partitioning effect on the chain propagation of a dust explosion and the formation of overpressures inside a partitioned vessel. A calculation methodology, particularly interesting in the field of the risk assessment is developed to simulate the transmission of the explosion from one compartment to another adjacent compartment by the means of the hot flow through the shared orifice and finally to generalise this methodology to a complex multi-partitioned structure. The basic characteristics of the model have been developed for the ignition and the combustion of propulsive powders and adapted to dust suspensions with appropriate parameters linked to simplified kinetics. A simple representation of the combustion phenomena based on energy transfers and the action of specific molecular species is presented. The model allows the study of various parameters such as the initial thermodynamical conditions, the size of the inner openings or the vent areas and finally the location of the ignition energy and of overpressures inside the structure. The calculations have been compared with experimental data available for usual dust suspensions and indicate correct preliminary tendencies

Dynamic Behaviors of Fuel Dusts through the Flame Propagation in Combustion Chamber

Mehdi BIDABADI, Ramin KHALILINEZHAD

At present research physics and dynamics of fuel particles according to a particle free body diagram in combustion chamber crossing the flame zones have been studied. Gravity forces, drag force from gas and thermopherotic force are these forces on a fuel particle. By existing of these forces on a particle, acceleration will be inducted to a particle in flame zones. By solving the differential equation of dynamic equation for a particle with continues boundary condition in velocity curve of the fuel dusts versus the distance from the flame, it has been estimated across the flame propagation Considering the mass continues law in combustion chamber, concentration profile of fuel dusts has been derived across the flame zones. Theoretical estimation of velocity and concentration profiles in this study has been compared to an experimental study on velocity and concentration profiles of iron particles (diameters are distributed from **1**//m to *5fim* and concentration is *^.05kglm^3)* across the upward flame propagation through the particles cloud in (Iron-Air) suspensions.

Oscillatory Propagation of a Rich Premixed Spray Flame

Leonid KAGAN. Barry GREENBERG, Gregory SIVASHINSKY

The present work is a continuation of a previous study in which it was found that the rich premixed spray flame propagates in steady manner and. depending on the operating

conditions, the reaction fronts are eventually either plane or curved. Before a flame reaches its final steady state its velocity was found to oscillate around a certain positive mean value. However, values of the evaporation Damkohler number examined in were restricted to the range 2-50 for which there is little direct interaction between the evaporation and the reaction front. In contrast, in the present research we focus on spray premixtures with Da significantly smaller than 2 for which droplets are traversed by the reaction zone and continue to evaporate in the oxygen-free region behind it.

Numerical Investigation of Continuous Detonation Engine

Yetao SHAO, Meng LIU, Jianping WANG, Toshitaka FUJIWARA

Three dimensional numerical simulation of a rotating detonation engine (RDE) is carried out in coaxial tube chamber to reveal its physical characteristics. Multi-cycle process of RDE is numerically obtained qualitatively agree with the former experiment results. Some key problems about RDE achieving such as fuel injection, pre-combustion, detonation structure are discussed. At last, we made a propulsion performance analysis about RDE by several different numerical cases.

Flame Propagation in a Channel with Obstacles

Zhihua CHEN, Zhangfeng YING, Baochun FAN, Jingfang YE, Yingxia SHENG Both the experiments and numerical simulations have been performed to investigate the premixed flame behavior during its propagating in a rectangle chamber with various obstacles mounted on the bottom wall. A high speed shadowgraph system was used to visualize the flame front development. Two different obstructions have been studied, their corresponding sequential images and numerical results are presented and used to quantify the flame speed and shape. Our results show that the flame accelerates as it passes over the obstacle and then decelerates due to the existence of recirculation zone behind the obstacle. Significant changes in flame structures and transitions found from laminar to turbulent combustion induced by the interactions between the flame and obstacle have been discussed.

Blast Wave Mitigation by Particulate Foams

Michael LIVERTS, Alexander BRITAN, Gabi BEN-DOR, Helen SHAPIRO The present study examines the (i) reflection of a shock wave and a blast wave pressure, from the foam face; (ii) transmission through the foam face; and (iii) mitigation inside the particulate foam. Since wet aqueous foams of desired specification are difficult to reproduce, handle, and quantitatively characterize the fact that experiments were conducted in a single facility is a potentially important consideration. A vertical position of the shock tube simplified the issues since the gradient of the liquid fraction in the draining foam coincides with the direction of the shock wave propagation. Under these, much simplified test conditions, the resulted flows could be treated as one-dimensional and the shock wave mitigation depends on the intensity and profile of the incident shock wave, the duration of the foam decay, and on the particle concentration, n.

LES of a Large-Scale Detonation Experiment in the RUT Facility

Mateusz ZBIKOWSKI, Dmitriy MAKAROV, Vladimir MOLKOV

The Large Eddy Simulation model of planar detonation, previously verified against the ZND theory, is applied to reproduce experimental pressure dynamics in the complex geometry of the RUT facility of 192 m^3 volume. The model is developed for large scale applications of hydrogen safety engineering and quite insensitive to grid size (0.1 m) due to avoiding of Arrhenius chemistry substituted by pre-calculated by CANTERA software detonation velocity. In spite of planar initiation of detonation instead of "point" initiation simulation results are in a reasonable agreement with the experiment.

Complex Study of Nonequilibrium Phenomena in Shock Wave Front in the Various Noble Gases Containing Small Admixture of $Fe(CO)_5$

Alexander DRAKON, Sergey KULIKOV. Alexander EREMIN

The purpose of the study is a linking analysis of nonequilibrium radiation picks observed in shock-heated mixtures of noble gases with a small admixture of $Fe(CO)_5$. Two different mechanisms for this phenomenon are discussed - high energy collisions in the zone of translation relaxation and recombinative overexcitation of iron clusters formed as a result of the fast dissociation of Fe(CO)s behind the shock wave. Analysis of experimental data based on the results of the Monte Carlo non-stationary method of statistical simulation (another name DSMC) and kinetic calculations could bring the bright insight in these complex phenomena. Results of simulation for the shock wave Max number (M) equal to 3.5 and of mixture containing 0.01% of $Fe(CO)_5$ show that distributions GH of relative velocities g for pairs containing molecules of $Fe(CO)_5$. GH exceeds substantially its equilibrium values behind the wave. The observed maximal overshoot (MO) is about 1015. Obtained distributions GL of g for pairs containing one molecule of He and one molecule of $Fe(CO)_5$ didn't show noticeable deviation from corresponding equilibrium values. Simulation for the case 1% of $Fe(CO)_5$ and M=3.5 had shown that MO is about 107 for GH. The performed estimations have shown that experimentally observed intensive non-equilibrium effects in mixtures containing about 1%$Fe(CO)_5$ in an inert gas could not be explained in high-energy collisions approach convincingly and predominantly originated by the rapid exothermic processes of iron clusters growth. For further investigation of possible effects, caused by high-energy collisions in a shock wave front, the additional high-sensitive measurements in the mixtures containing less than 0.1% $Fe(CO)_5$, where the processes of cluster growth could be neglected, are required.

Propagation of the Reaction Front of Dry Biomass Particles In a Fixed Bed

Mehdi BIDABADI. Jalil FEREYDOONI. Milad SHOKOUHMAND, Alireza RAHBARI In this paper, a theoretical analysis of the speed of the propagation of the reaction front downwards against the air flow in a fixed bed of burning biomass particles has been studied. The analysis concentrates on a situation in which the reaction front moves in opposite direction with respect to the gas flow through the fixed bed For this purpose we solve energy equations for both oxidizing gas flowing against the moving reaction wave and solid fuel in the bed. The reaction speed reaches a steady state soon after reaction at the surface, if the inlet air temperature is the same as the initial temperature of the fixed bed. Modeling of the quasi-steady-state speed of propagation of the reaction front is considered and theoretical temperature of gas and fuel and velocity of the reaction front are derived The model can be used as a tool to study the influence of available parameters of process, such as biomass species, particle density, and air flow velocity to the fuel bed on the flame front velocity and gas and particle temperature. These parameters studied theoretically and an agreement between experimental and estimated results was achieved.

The Chemical Structures of Laminar Opposed-Jet Diffusion flames of $CH_„$/CO Versus Air

Chih-Yung WU, Y.-Y. CHENG, T.-W. CHANG, Yueh-Heng LI, Y.-C. CHAO, Tsarng-Sheng CHENG

In the present study, the flame characteristics of laminar diffusion opposed-jet flames of CHд/CO versus air were studied. The combustion characteristics of carbon monoxide, which is a major intermediate product in hydrocarbon flames, are different from those of most alkanes. Its oxidation can be characterized by dry oxidation, i.e. CO + 0_2->$C0_2$ + O. However, it is very difficult to ignite and sustain the dry oxidation process in practical combustion. Generally, the oxidation of CO can be significantly accelerated by the reaction

CO + OH *-> $C0_2$ + H when there is a small amount of hydrogen-containing species in the fuel or oxidizer stream [1]. The burning velocity of CO with hydrogen containing species liberated from hydrogen, alkanes, or even water vapor is several orders higher than that of dry oxidation [2], Moreover, the effect of hydrogen and hydrocarbon addition on the CO flames has been further experimentally and numerically studied [2-7] In our previous study [6-7], the effect of CO addition on the characteristics of methane/air premixed flames was examined systematically. It has been concluded that the effect of CO addition on the laminar burning velocity of the stoichiometric CH_4/CO/air flames is due mostly to the transition of the dominant chemical kinetic steps. It has been well know that a diffustion flame consists of fuel-rich zone, fule-lean zone and reaction zone. The radicl pool in reaction zone provide enough H, O and OH atom by diffusion to ignite fuel and to decompose oxygen. Moreover, since carbon monoxide is a major intermediate of hydrocarbon flames, the intrinsic interaction between the original CO in the blended fuel and that produced from oxidization of hydrocarbons is worthy to be deeply investigated. Based on the similar methodologies of the previous study, a laminar diffusion opposed-jet flame of CH_4/CO versus air was numerically studied. Calculated chemical kinetic structures for selected flames are compared and the key reactions that affect the flame structure and are also discussed.

Development of Richtmayer-Meshkov Instability at Interaction of Diffusion Mixing Layer of Two Gases with Passing and Reflected Shock Waves

Alexander FEDOROV, Gennadii RUEV, Vasilii FOMIN

The problem of mixing of gases with strongly differing molecular weights is an urgent topic for simulation of explosion phenomena in layer systems. Indeed with an action of shock waves on a contact surface between hydrocarbons and air conditions can be realized which are favorable for the explosive hazard mixture formation. It makes the investigation of the mixing of light and heavy gases under the shock wave influence to be important. Instability development in an area of the gas mixing with accelerated movements of the gases is an urgent task for energy commulation facilities and devices as well. Traditionally a mixing layer is considered to be a density discontinuity surface, i.e. a contact discontinuity. Shock wave interaction with a disturbed contact discontinuity leads to the Richtmayer-Meshkov instability. Finally in vicinity of the initial contact discontinuity a region of turbulent mixing is formed which separate the compressed gas flows Numerous papers devoted to the numerical simulation of the Richtmayer-Meshkov instability based on the Euler equations did not take into account an influence of mutual penetration of the gases. Therefore it is believed to be interesting to investigate the problem on a base of two-velocity two-temperature approach for the gas mixture where the each mixture component has its own velocity and temperature. This approach allows to describe different stages of the instability development process taking into account the gas interpenetration Previously a shock and compression wave interaction with a mixing layer has been studied.

Combustion Synthesis of Nanocomposite Powders Using Mechanocomposite-Precursors

Tatiana TALAKO, Andrei LETSKO, Piotr VITIAZ, Tatiana GRIGORYEVA, Nikolai LYAKHOV Results of investigation of combustion processes in metal-oxide powder mixtures with aluminothermal reactions when using nanocomposite-precursors formed as a result of mechanochemical interaction of the mixture components at the stage of mechanical activation (MA) are presented. Usage of mechanocomposites as the SHS precursors allows formation of nanocomposite synthesis product inheriting the precursor's structural morphology. Complete reduction of metal oxides with aluminum at the stage of mechanical

activation is not a necessary condition to preserve nanocomposite structure in the SHS powders.

Detonation Initiation Assisted with Pre-excitation of the Reactive Medium by Non-Equilibrium Plasma

Ivan ZAEV, Igor KIRILLOV. Boris POTAPKIN

Recently the several approaches were proposed to use the non-equilibrium plasma to initiate detonation in pulsed detonation engines, operating on conventional but the weakly sensitive to detonation hydrocarbon fuels. In several papers by A. Starikovskiy et al. the nanosecond discharge in the form of fast ionization wave was used to initiate detonation in the stoichiometric propane-oxygen mixture at pressures below atmospheric (0.2 - 0.6 atm) and energy depositions of the order of 0.1 - 10 J depending on the fraction of the nitrogen in the mixture (from 12% to 60%). Dr. Gundersen et al. used pulsed corona discharge to ignite the ethylene- and propane-air mixtures (atmospheric pressure) at several points inside the shock tube and thus accelerate the deflagration-to-detonation transition due to more rapid pressure increase inside the ignition section The energy deposition by plasma was about 0.6 J and only deflagration-to-detonation with the run-up distance about 1 m was observed. Both techniques used the plasma to directly ignite the reactive mixture, which required extremely high over-voltages and relatively high energy input. The required parameters of the electrical discharges could be achieved only with the specially designed complex techniques and infrastructure The compromise between the energy cost of the detonation initiation and complexity of the installation could be achieved by combining the classical method of detonation initiation, e.g. shock wave from the spark, and increase of the chemical activity of the reactive medium in local inhomogeneities. Such local pre-excitation of the medium can be intentionally achieved with the non-equilibrium plasma. The usefulness of this approach was demonstrated experimentally, conducted in RRC Kurchatov institute, where the pulsed corona chemically excited the propane-oxygen-nitrogen mixture at atmospheric pressure, while the conventional spark was used for ignition/detonation initiation. This technique allowed to initiate detonation in stoichiometric propane/butane-oxygen mixture diluted with up to 50% of nitrogen with overall energy deposition (pulsed corona and spark) 0.5 J and at short distance (less than 0.2 m). The main argument for application of the non-equilibrium plasma in detonation initiation is related with the observation, that such plasma can produce chemically active species which broaden the ignition limits and reduce the ignition delays [1] thus stimulating the detonation initiation. But the detonation formation is a non-stationary process of coupling between the leading shock wave and ignition front. Therefore even for the qualitative judgement about the result of the coupling not only the chemical but gas dynamical processes and their mutual influence should be taken into account. In the present work the theoretical investigation of the detonation initiation process by a shock wave, propagating in reactive gas. preliminary excited by the non-equilibrium plasma is carried out. It is based on computational fluid dynamics simulations of the detonation initiation with detailed account for the increased chemical activity of the reactive gas by localized (in space) plasma preexcitation.

PrIMe: System Approach to Predictive Modeling of Combustion

Michael FRENKLACH, Zoran DJURISIC, Michael GUTKIN, Devin YEATES, Xiaoqing YOU

Optimizing combustion efficiency and understanding the mechanisms that prevent full energy utilization of fuels relies on detailed knowledge of the underlying physics and chemistry. These systems are generally complex enough that models have been used to explore the effect of different feed and reactor conditions and have been successful in optimizing fuel mixtures and combustor performance. However, the models are extremely

complex and often controversial The data, which parameterize the models and are compared to model predictions, are themselves complex and often open to interpretation. Further, they are developed by multiple labs using different technologies To keep track of models, parameters, and data in an integrated framework has proven a necessity in the field of Combustion. The initiative we call PrIMe is designed to fill this need. In its scientific content, PrIMe is a system approach aimed at establishing the infrastructure, both scientific and cyberinfrastructure (CI), in support of developing predictive models of combustion. The present article provides a brief description of the current infrastructure, focusing on new additions, primarily those to the PrIMe Data Model and PrIMe Workflow Application

Slow Propagation Dynamics of Detonation in a Non-uniform Gas: a Large Activation-Energy Analysis

Pierre VIDAL

We study the dynamical conditions of propagation of the self-sustaining detonation regime in gases whose initial temperature and dilution are variable in the case where the gradients of initial state are parallel to the propagation direction We analyse the slow dynamics of the detonation supposing that the initial variations have the same order of smallness as the unsteadiness and curvature of the detonation front. We obtain an hyperbolic evolution law for the detonation front as the solution to an eigenvalue problem based on the asymptotic limit of the high activation energies for which the induction time of the chemical decomposition process is considered much larger than the heat-release time We study the effect of the shock dynamics of this self-sustained detonation front on the induction time and we integrate the evolution law in some examples of distinct or combined, dispersive or localized variations in the initial temperature and of the mass fraction of a dilutant. We show the existence of a bifurcation set of initial conditions that separates the self-sustained detonations that will continuously achieve the CJ regime from those whose dynamics eventually fail to initiate the chemical decomposition because the dynamical induction length becomes too long. We find that the characteristic critical lengths associated with the initial or boundary conditions are larger than the CJ characteristic chemical length of reference by several orders of magnitude, a well-established experimental feature of gaseous detonations. We identify a subcritical limit and a supercritical limit which, respectively, give necessary and sufficient conditions for detonation. Below the subcritical limit, the combustion front cannot be coupled to the shock front because the volumetric expansion rate behind the shock is too large. Above the supercritical limit, the relaxation from an overdriven detonation regime to the self-sustaining regime or from one self-sustaining regime to another self-sustaining regime is a continuous process, without decoupling and recoupling of the combustion and shock fronts. We interpret the domain between these limits as the parametric zone in which experiments show successive decouplings and transverse recouplings of the combustion and shock fronts before the final self-sustained CJ regime.

Investigation of Heat Transfer and Heterogeneous Reactions during the Slow Cook Off of a composite Propellant

Philippe GILLARD, Baptiste LONGUET

The use of aluminum/ammonium perchlorate/HTPB propellant is common and is normally well known. However some accidents occur when such substances are slowly heated below the ignition temperature. Although most of these propellents are heterogeneous, numerous models of self ignition published in literature are based upon two homogeneous phases (gas and solid). Interfaces between different solid phases are not considered. More over the interactions of products of decomposition of ammonium perchlorate and HTPB are not elucidated. The influence of pressure, during self heating, is not clearly described. The aim

of this work is to build a new modeling of the above interactions during slow heating of such propellents. The phenomenon was previously described by experimental approaches performed in the laboratory. Heat and mass balance will be considered both in solids and gas phase. The interaction of products of decomposition of both ammonium perchlorate and HTPB binder is shown thank to previous experiments and a specific numerical model allows reproducing this trend Mass and heat transfers are taken into account in each particle of ammonium perchlorate and inside the matrix of HTPB binder The chemical reaction in the gas phase is in interaction with adsorption desorption of several species at surface grains The whole set of equations is solved thank to Comsol multiphysic solver and the numerical results are compared with mass loss measure by means of thermogravimetric device.

Calculation of Special Modes of Detonation Propagation in Tubes

Lioudmila GVOZDEVA, Dmitriy BAKLANOV, Irina RYZHKINA

Different cases of sudden appearance of regions with extremely high pressures have been analyzed during detonation propagation in tubes. The explanation of the phenomena has been found in the formation and propagation of unsteady system: shock wave - combustion zone. Thus the detonation occurs in a previously compressed gas. In this work analytical method of calculation of multstep detonation is suggested. The calculation made for the detonation in a combustion chamber with variable cross section, give results sufficiently well agree with experimental data.

Investigation of the Onset Condition of Oblique Detonation Wave Cell Structures

Jeong-Yeol CHOI

A comprehensive numerical study was carried out to identify the on-set condition of the cell structures of oblique detonation waves (ODWs). Mach **7** incoming flow was considered with all other flow variables were fixed except the

flow turning angles varying from **35°** to **38°** For a given flow conditions theoretical maximum turning angle is **38.2°** where the oblique detonation wave may be stabilized The effects of grid resolution were tested using grids from **255x100** to **4,005x1,600** The numerical smoked foil records exhibits the detonation cell structures with dual triple points running opposite directions for the **36°** to **38°** turning angles. As the turning angle get closer to the maximum angle the cell structures gets finer and the oscillatory behavior of the primary triple point was observed. The thermal occlusion behind the oblique detonation wave was observed for the **38°** turning angle.

Computer Simulation of Dynamics of Reactive Systems

Vladimir LEITSIN, Maria DMITRIEVA, Tatiana KOLMAKOVA

The powder mediums able to gasless exothermal chemical conversions are considered. Conditions of mechanochemical synthesis at dynamic (shock) loading of green compacts of reactive components mixture and inert filling agent are studied. The dynamic loading impulse can be generated at detonation of condensed explosive being in contact with initial compact or at collision of high-speed plunger with it. The matter compression is accompanied by collapse of pores and intensive mixing of the components, friction on the surface of particles and their deformation. In aggregate, these processes determine mechanical modification of powder materials. Heterogeneous powder material, generated from the mixture of reactive components and inert filling agent, has a macroscopic structure of concentration inhomogeneity of components and porosity. Mechanical activation is bound up with plastic deformation and destruction of surface layers of powder components particles. Local heating due to exothermicity of mecanochemical conversions can determine phase transfers and aggregative state change, including melting of low-melting component. An evaporation of a component is possible. The porous mediums mechanics approach is applicable to simulation of mechanical behavior of powder body. Shock compression is

characterized by inhomogeneity of plastic deformation, so by inhomogeneity of mechanical activation by particles volume The law of conservation of energy of reacting powder layer is represented by a boundary problem with heat sources and sinks. Filtration of melt of the low-melting component under porous pressure gradient provides convective heat and mass transfer. Macrokinetics of chemical conversions is represented by multilevel model of reactive cell wherein the parameters depend on the structure scale, phase concentration, phase state, and on the degree of mechanical activation of reactive mixture. As a criterion of nanostructure of shock synthesis product formation is considered a fulfillment of conditions of non-equilibrium synthesis processes initiation at the initial stage of chemical conversions: achievement of necessary level of the mixture mechanical activation, change of reactive mixture aggregative state, fulfillment of statistical criterion of "turbulent" conditions of compression. An "initial" and a current level of reactive powders shock activation are considered. Impulse (on intensity) processes of particles burning of a powder mixture cause chemiluminescent flashes. The mechanoluminescence of the sample back surface can be caused by microspall fracture effects during the moments of a shock wave fronts exit and in the burning wave. For ultradispersed powder reactive materials zones of nonstationary condition of dynamic compression are most probable regions of nanostructure formation. Considering the incubating times of powder components modification allows to apply the model for shock synthesis of nanocomposites. The characteristics of thermal and luminescent emission from the surface of reactive powder compacts account for the parameters of state of the reactive medium, attainable pressure levels, and kinetics of the relevant chemical reactions. That means that the obtained results can serve as a basis for development of contactless methods for monitoring the physicochemical processes in reactive powder materials.

Formation of Mechanical Sparks in Sliding Metal Contacts

Felix WELZEL, Toni OTT, Michael BEYER, Claus-Peter KLAGES, Stefan BITTERLICH, Wolfgang GERLINGER

For the use of mechanical equipment in explosive atmospheres, their ignition sources must be considered. Frictional processes caused by malfunctions can lead to hot surfaces and mechanical sparks. Sparks are defined as particles whose surface temperatures significantly exceed that of the wear contact. Responsible for that is the exothermic combustion of the particle. If both ignition sources, sparks and hot surfaces, appear in a wear contact, the predominant ignition source is unknown. Therefore, tests regarding spark formation were performed in a friction test bench using mild steel and stainless steel.

High-voltage Pulsed Driving Arc Applied to Ignition and Detonation

Kostyantyn KORYTCHENKO

The new ignition system producing of driving pulsed arc is offered in this work. High efficiency of the designed system is achieved due to the change of voltage applied to the discharge gap during the pulsed arc development.

The system allows effectively creating the thermal source, the volume of which is more than 5 mm^J by energy deposition about 1 J. It was experimentally confirmed the volume of the thermal ignition source is substantially multiplied at a motor-car spark-plug. The working frequency of the system can be more than 200 Hz.

CARS Application to the Vibrational/Rotational Temperature Measurement of Nitrogen behind Shock Waves over Mach Number 13

Takeshi OSADA, Youichi ENDO, Chikara KANAZAWA, Masanori OTA, Kazuo MAENO For the development of aerospace science and technology in Japan, it is necessary to develop the new and original space vehicles. Especially in returning phase of the space

vehicle from Japanese section of international space station, there are the produced strong shock waves and non-equilibrium heat problems in front of the leading surface of the reentering space vehicles. To deal with these problems, the reasonable design of heat shield materials and structures are required Today, however, the data of these problems for the design are not in satisfactory conditions. So it is of great importance to decide the high-enthalpy parameters for heat shield investigation. In this background we have been investigating the hypersonic measurement techniques for these phenomena and gathering the gas-dynamics and radiating data near the front surface of reentering space vehicles. The main purpose of this study is to measure the vibrational/rotational temperatures behind the hypervelocity strong shock wave by spectroscopic method with high power laser system and high-performance photo-electronics. The hypervelocity strong and radiating shock waves in front of the reentering space vehicles are simulated in our laboratory with a free-piston double-diaphragm shock tube. The vibrational/rotational temperatures are measured and estimated from the CARS (Coherent Anti-stokes Raman Spectroscopy) signal spectral data of nitrogen molecule behind the hypervelocity shock waves

Nonequilibrium Processes in Nitrogen Plasma Behind Strong Shock Waves

Ilya ARSENT'EV. Staly LOSEV. Alexander STARIK, Nataliya TITOVA The work is focused on the modeling studies of processes leading to formation of electronically excited atoms and molecules in the high temperature gas behind the shock wave and on the influence of these processes on plasma composition. The analysis was undertaken for nitrogen and nitrogen-argon plasmas. A kinetic model of nonequilibrium nitrogen-argon plasma was developed and verified using experimental data on $N_2(1+)$ and $N_2^*(1-)$ band radiation. Typical spatial profiles of species concentrations, vibrational, translational and electron temperatures are presented. It is shown, that the neglect of electronically excited atoms and molecules in the model can change the predicted values of electron and ion concentrations.

The Mathematical Model for Predicting the Pyrolysis of Wood Particles

Mehdi BIDABADI, Milad AZIMI, Sara MONTAZERINEJAD, Alireza RAHBARI In this research, the structure of laminar, one-dimensional and steady flame propagation in uniformly premixed particle-wood is analyzed. The structure of the flame is composed of three zones: a preheat zone, a narrow reaction zone and a post flame zone. In the preheat zone, the rate of reaction between fuel and oxidizer is assumed to be small and also it is presumed that the fuel particles vaporize to yield a gaseous fuel of known chemical structure when enter the reaction zone. Then in the reaction zone, composed of gas, tar and char combustion, the convective terms and vaporization terms in the conservation equations are presumed to be small and in the post flame zone, the diffusive terms in the conservation equations are assumed to be small in comparison with other parameters. The governing equations in each zone, considering these assumptions, are solved using the required boundary and matching conditions. Consequently, the variation of burning velocity and flame temperature as a function of equivalence ratio are presented as the outcome of this study.

Decomposition of Azomethane in Shock Tube as the Example of "Concerted" Decomposition Mechanism

YuriPETROV, Yuri KARASEVICH, Stanislav TURETSKII

Our own measurements and published experimental data on azomethane decomposition at 850–1430 K, in conjunction with a theoretical analysis of this reaction, provide convincing evidence for its occurrence via the "concerted" mechanism in this temperature range Most of the available experimental data cannot be described within the framework of the

"classical" theory of unimolecular reactions. The comprehensive analysis of all low- and high-temperature data on decomposition of azomethane has been lead. The need for direct time-resolved low-temperature data on AM decomposition is emphasized. The assumption of "concerted" decomposition of azomethane allows to interpret values of $k,^{obs}$ measured at high temperatures in the newest direct experiments, as the valid rate constants of

decomposition of azomethane. Hence, these kinetic data quite reasonably can be used to describe the decomposition of azomethane as "calibrated" source of CH_3-radicals in a wide range of temperatures and pressures.

Operator Splitting in Simulation of Detonation Structure

Yaser MAHMOUDI, Kiumars MAZAHERI

The effect of four splitting procedures; two first order splitting named (i) hydrodynamic-kinetic; H-K splitting, (ii) kinetic-hydrodynamic; K-H splitting and two second order Strang type splitting, (Hi) (H/2)(K)(H/2) and (iiii) (K/2)(H)(K/2) on the cellular structure of detonations are compared. It is found that a minimum grid size of 25 cells per half reaction length (hrl) is required to capture a convergent cell structure in all methods. Results indicate that the number of cells that should be refined behind the shock front (NLB), differs in various splitting procedure. 30 cells are required for both first order splitting methods, 10 cells for (H/2)(K)(H/2), and 30 cells for (K/2)(H)(K/2) method. The CPU time required for K-H is significantly lower than that of other methods. The Strang splitting (H/2)(K)(H/2) leads to the most CPU time.

Reduced Chemical Reaction Model of Methane/Oxygen Mixture

Youhi MORII, Nobuyuki TSUBOI, Mitsuo KOSHI, Hiroyuki OGAWA, A. Koichi HAYASHI, Taro SHIMIZU

Methane fuel has many advantages; such as good availability, low cost, and clean burning for gas turbine or rocket engines. Therefore, there are many experimental or numerical researches to use methane fuel commercially. However, the stagnation pressure in the chamber is much higher than the atmospheric pressure. So that, it is difficult to do experiments in order to understand the combustion process in detail. On the other hand, when the methane combustion is numerically simulated, it is important to select the reliable chemical reaction model in order to obtain the good results. The GRI-Mech, which is wdely used for the numerical simulations for the methane combustion, is reported that the results such as ignition delay time agree well with the experimental data under atmospheric pressure state, however, it cannot predict them under high pressure state. Recent computers are improving rapidly. To understand methane combustion in detail, the combustion process can be calculated not only by ignition delay times and 1D laminar flame velocity but also by CFD simulations to be understood in detail. However, the detailed chemical reaction models are not available for CFD simulations because computational cost is high. So reduced chemical reaction models are required for CFD simulations. But even some detailed chemical reaction models have problems for high pressure states so it is necessary to estimate the reliability of existing detail and reduced chemical reaction models or to construct a new model. The present paper shows the comparison between the numerical results and the experimental data. Then, new reduced reaction models are constructed by using the reliable detailed chemical reaction model.

Numerical Simulation on Propagating Process of $H_2/0_2$ Cylindrical Detonation with Detailed Reaction Model

Makoto ASAHARA, Nobuyuki TSUBOI, A. Koichi HAYASHI, Eisuke YAMADA Cylindrical detonation has been investigated numerically with a one-step reaction model to understand its propagation mechanism and the critical energy. This reaction model describes a change in physical values on reaction process to be simple. On the other hand,

a detailed chemical reaction model consists of a lot of elementary reactions to deal with the detailed dynamics of heat release. In this paper, the propagating process of the cylindrical detonation with the detailed chemical reaction model is discussed. According to the grid resolution study in two-dimensional simulation, the required grid size to resolve of the cellular structure in a stoichiometric $H_2/0_2$ gas mixture is finer than 5.0 цт when the pressure and temperature of ambient region are 1atm and 300K. Furthermore, as for the relation between their cell sizes and the initiation energies, the cell size becomes smaller as the initiation energy increases However, the cells propagating along the diagonal direction are affected by the numerical dissipation on the orthogonal grid system

Modeling of Lifted Jet Flames Using a New Flame Extinction Model

Saurabh GOEL, Sudarshan KUMAR

Lifted flames are observed when the velocity of a jet of fuel discharging into the surrounding air is increased beyond a certain critical value. Several models have been proposed to explain and predict the flame stabilization of lifted flames but none of these models have been completely validated. In the present work, eddy dissipation model has been used for modeling combustion reaction and three different turbulence models are used to predict the averaged flow properties in the turbulent jet flow Comparisons have been performed for variation of various properties such as center line temperature and mass fractions of various species along the axial and radial directions. The dependence

of combustion process on the choice of domain size and on co-flow velocity has also been studied to ensure that the present studies are independent from the effects of such boundary conditions

Auto-ignition of Diesel Fuel at High Temperatures and Pressures

Kirill SEVROUK, Mohamad ASSAD. Vladimir LESCHEVICH. Oleg PENYAZKOV. Venkat TANGIRALA, Narendra JOSHI

Most aviation fuels are mixtures of a large number of hydrocarbons and the chemical kinetic processes occurring in combustion of such fuels at high temperatures have not been sufficiently validated. There is scarcity of data on auto-ignition of heavy fuels at high temperatures and pressure. Only limited data have been reported for ignition of Diesel fuels in jet-stirred reactors and in shock tubes Thus, there is an obvious lack of experimental data for high-temperature combustion and auto-ignition of Diesel fuel and its surrogates in air. The objectives of this study are as follows:

• to investigate systematically combustion and ignition properties of Diesel No.2 at 4.7-10.4 atm, temperatures 1065 - 1838 K, and stoichiometries ϕ = 0.5 - 2;

• to compare auto-ignition of premixed Diesel fuel/Air mixtures with a Jet-A/air mixture at equivalent post-shock conditions;

• to obtain reference data on ignition of Diesel fuel/Air mixtures at high temperatures itself.

Initiation of Hydrogen-Air Detonations at Nonuniform Conditions

Kirill SEVROUK. Oleg PENYAZKOV. Khaled ALHUSSAN

The development of three-dimensional approaches for description of flow structure and energy release associated with a gaseous detonation are actual from theoretical point of view and practical applications, which have began to develop recently The taking into account of three-dimensional phenomena and interactions is also extremely important under considerations of reacting flows accompanied with shock waves. In this work we have attempted to study initiation mechanisms of combustion and detonation at nonuniform flow and boundary conditions modeling the reaction behavior within the structure of hydrogen/air detonations for pressures 2-25 atm, temperatures of 850-1850 Ë The flow inhomogeneities were produced by changing the geometry of reflecting wall at interactions with an incident shock wave of different intensities. The measurements were compared with

a reference data obtained behind normally reflected shock waves. Induction times and auto-ignition modes of the mixtures (strong, transient and weak) were determined for wedge and conical walls of similar geometry. Particular attention has been paid in experiments to determining the critical ISW intensity required for initiation of different auto-ignition regimes

Direct Initiation of Detonation in Small Initiation Reaction Rate

Seyed *Abdolmehdi HASHEMI, Abolfazl FATTAHI*

Depending on initiation energy, three regimes of initiation could be observed; subcritical, critical and supercritical. These three regimes is compared here for high and low the chain initiation reaction rate. For a relatively high initiation reaction rate, In the subcritical regime , the shock pressure decreases rapidly as for a strong non-reactive blast wave. As the blast decays to larger distances, the chemical heat release starts to influence the blast wave propagation. But the chemical reaction zone fails to couple to the shock front and the blast continues to decay. If the initiation energy increases, the critical regime is observed. In this case, the shock front and the reaction front first decouple as the blast expands. However, unlike the subcritical case, the decoupling in the critical case stops after the blast wave has decayed to a certain shock pressure. During decaying period an explosion occurred in the unreacted mixture which preheated by the shock front. This explosion reaches the shock front and amplifies it to the pressure about P_{sh}=15 to form an overdriven detonation wave. The overdriven wave eventually decays to a self-sustained detonation wave. The regimes of direct initiation is also obtained for a relatively small reaction rate of the chain initiation. By comparing with the previous case, some differences are observed in the critical initiation. When initiation reaction rate is large, the shock pressure in critical initiation has decayed to P_{s_n}=4, while by small initiation reaction rate, the shock pressure has decayed only to P_{sn}=8. This shows that for a successful initiation, the shock pressure during initiation is not allowed to decrease below a critical value. This critical value increases when initiation reaction rate decreases. So when ti (characteristic time of initiation step) increases enough, critical initiation takes place without decreasing the shock pressure below the corresponding CJ detonation shock pressure. In such cases, critical initiation becomes similar to the supercritical initiation. Another difference between these two cases, is that decaying period of the initial blast, is shorter for the larger ti. This results from the first difference, which the shock front could not decrease below a certain value and therefore the decaying period becomes short. In the

decaying period the reaction zone decouples from the shock front. The longer decaying period yields more distance between the shock front and the reaction zone. So a large portion of combustible mixture which preheated by the decaying shock, is between the shock front and the reaction zone. When ti is small, the reaction could initiate and propagate through this medium and form a strong pressure pulse or a new detonation wave (this case) behind the leading shock front.

Model of Explosive Crystallization in Thin Films Based on the Nucleation and Growth Approach

Oscar RABINOVICH, Boris KHINA, Pavel GRINCHUK

At present, the phenomenon of explosive crystallization (EC) of thin amorphous films is an experimentally well-studied process that presents a separate class of fast-reaction autowaves driven by the enthalpy difference between the glass (amorphous) and crystalline state of various mono and binary systems. As a rule, EC is observed in thin films (~ 1 urn) within a rather narrow range of film thicknesses and substrate temperatures. For a low (subcritical) temperature and film thickness, propagation of the EC wave is suppressed by high heat losses; for a too high temperature and film thickness, the stable glass becomes unstable, and spontaneous multi-zone self-ignition and crystallization occurs. In most cases, the EC wave has two phase transition zones connected in the thermal sense, viz. a leading

endothermal zone of glass melting, whose existence is supported by heat-releasing zone of melt crystallization. The conditions for stable EC-wave propagation are determined by complex interaction between thermodynamic, thermophysical and kinetic characteristics of both zones. Prediction of these conditions is of great importance for a variety of technological applications related to semiconductor electronics, solar cell industry, etc. Nevertheless, modern theoretical models of EC should be considered as approximate and not reflecting certain important details of the phenomenon, in particular, the fast crystallization process. For example, the classical Wilson-Frenkel model for the phase boundary velocity often are applying to both melting and crystallization zones. However, it is known that this model overestimates the velocity of the crystallization front. It is evident that a more adequate model should be based on a more detailed description of the nucleation kinetics and crystal growth in the crystallization zone. In the present work, an attempt is made to use the Kolmogorov-Avrami-Mehl-Johnson (KAMJ) formalism for the nucleation and growth of product grains in the transient liquid phase which is formed in the EC wave.

Micro Engine Combustion Numerical Fluid Dynamics Analysis

Janusz PIECHNA, Andrzej TEODORCZYK

This paper presents an idea and results of 2D and 3D numerical CFD simulations of the combustion process inside micro-engine construction dedicated for air propulsion. The engine is designed as the simplest construction realizing the idea of a constant volume combustion principle An atypical fuels, hydrogen peroxide and hydrogen, are used. The H202 is decomposed in exothermic reaction increasing pressure inside the chamber of constant volume. The free oxygen being the result of decomposition process is then used to afterburn injected hydrogen. The high pressure water steam content of the reaction chambers is periodically decompressed by the jet nozzles, generating torque. The paper describes the micro-engine idea, and discusses results of numerical simulations of combustion and flows that visualize pressure, velocity, temperature, and species distributions inside the engine components

Kinetics of Plasma Assisted Combustion At Low Reduced Electric Fields

Liang WU. Alexander FRIDMAN, Andrey STARIKOVSKIY

A numerical study of the ignition of hydrogen-oxygen mixtures with the participation of singlet oxygen molecules has been performed It was showed that it agrees well with the measurements from experiment. It follows from the analysis of the calculated results that, with single delta oxygen molecules, the great amount of active species with fast reactions lead to the decrease of ignition delay time Besides, in order to obtain best results at various conditions, relatively low E/n (-10 Td) is required in pure oxygen electric discharge, while larger value of E/n (-300 Td) is recommended for high efficiency in air plasma.

Development of Pulsed Surface Dielectric Barrier Discharge and Its Application for Ignition Initiation

Maryia NUDNOVA, Andrey STARIKOVSKIY

The measurements performed have shown overheating of the discharge region under fast (τ < 1us) thermalization of the plasma inputed energy. Independent measurements of the gas translational temperature in the plasma layer by emission diagnostics, measurements of the pressure dynamics near the surface, structure of the flow field demonstrate self-consistent picture of the process development. The measurements have shown that the mean values of such heating for the plasma layer can reach 70, 200, and even 400 K for 7-, 12- and 50-ns pulse durations,

respectively. Thus SDBD can be used for effective combustion initiation and stabilization under high-pressure gas conditions.

Hydrodynamics of Explosion: Models and Software for Modeling Explosions and Estimation of Their Consequences
Konstantin STEPANOV, Yuri STANKEVICH, Andrei SMETANNIKOV Physical and hydrodynamic processes accompanying explosions of condensed explosives and fuel-air mixtures have been considered. Wide-range equations of the state of explosion products and air have been derived. A physical model and a program code have been developed for modeling one-dimensional hydrodynamics of explosion This firmware forms the basis for estimation of explosion consequences.

Numerical Modeling the Dynamics of Flow at Explosion above a Surface
Andrei SMETANNIKOV, Yuri STANKEVICH, Konstantin STEPANOV The hydrodynamics of the processes occurring at explosion of condensed high explosives (HE) in air is considered. Are discussed physical model and technique of calculation for modeling two-dimensional hydrodynamic flow arising at explosion of spherical and cylindrical charges at some height above a surface of a ground. For closing the gas dynamic equations the Jones-Wilkins-Lee equation of state is used The results of calculations have allowed to receive detailed spatial - temporary picture of arising flow, to study creation, propagation and subsequent attenuation of shock waves. The initial form of a charge forms essential influence on dynamics of flow and form of area engaged by products of explosion.

Detonations in Densely Obstructed Channels

Takanobu OGAWA. Vadim GAMEZO, Elaine ORAN

Channels with obstacles provide a convenient environment where we can control the flow inside the channel by changing the obstacle configuration and thus have been extensively used for the studies of flame acceleration and detonation propagation In this study, we simulate detonation in densely obstructed channels to study the effect of obstacle spacing on detonation. The result of numerical simulations shows that the obstacle spacing as well as the channel height affects the propagation regime of detonation For the channel height we used in this study, the quasi-detonation regime was observed for wider obstacle spacing. For shorter obstacle spacing, however, detonation propagates at CJ velocity virtually without being affected by obstacles, since it reaches the next obstacle before being extinguished by diffraction. It is also found that the detonation is followed by a secondary shock, which is composed of transverse shocks generated by local explosion in unburned gas between the obstacles left behind the detonation. The position and the structure of the secondary shock are also discussed.

Kinetic Modeling of Hydrogen-Light Hydrocarbon-Air Mixtures Combustion

Remy MEVEL, Kodjo COUDORO. Gabrielle DUPRE, Claude-Etienne PAILLARD In order to face the problems arising from fossil fuel consumption, pollution and limited stock, the use of clean hydrogen as an energy vector represents a good alternative However, the shift from a fossil energy to a hydrogen based economy faces several major issues, including cost efficiency of hydrogen production and safety. In order to reduce the safety issues of H? use, the addition of few tens of percent of natural gas can represents a good solution. In this frame, the potential hazards of such mixtures have to be characterised. For hazard evaluation, the first element is a reliable detailed kinetic scheme. In the present study, three modern kinetic models, the Konnov's model, the Dagaut's model and the GRI-mech 03, have been evaluated with respect to a large set of experimental data, including shock-tube, flame speed, jet-stirred reactor and detonation cell size, of hydrogen-methane-air and hydrogen-natural gas-air mixtures. For flame speed data modeling, the three models are as reliable. For detonation cell size predictions, the model of Konnov is the best. For jet-stirred reactor data, the model of Dagaut furnish significantly better results. For shock-tube data, each model present some advantages according to the composition and the temperature ranges considered. Important chemical reactions are underlined through sensitivity and reaction pathway analysis.

Explosion of Free Hydrogen Jet Release

Andrey GAVRIKOV, Anton ALEKSANDROV, Viktor ALEKSEEV, Eugeniy CHERNENKO, Aleksander EFIMENKO, Alexei MAYOROV. Ivan MATSUKOV, Nikolay SCHEPETOV, Sergey VELMAKIN, Nikolay ZARETSKIY

The objectives of the presented experimental work is investigation of hydrogen release distribution and combustion, modeling possible emergency situation at industry scale. Results of large scale experiments on distribution and combustion in an open and congested area are presented The mass of hydrogen in experiments varied from 50g to 1000g with ejection rate from 180 to 220 g/s. Qualitative characteristics of high momentum hydrogen jet releases distribution and subsequent combustion were obtained. The maximum overpressure in experiments with additional congested area reached dP = 0.4 atm. Using partial confinement of congested area turbulent combustion regime with the maximum overpressure more than 10 atm was obtained. This scenario is definitely dangerous and should be taken into account in development of hydrogen safety prevention and mitigation measures.

Propagation of the Reaction Front of Dry Biomass **Particles in a Fixed Bed**

Mehdi BIDABADI, Jalil FEREYDOONI, Alireza RAHBARI, Milad SHOKOUHMAND In this paper, a theoretical analysis of the speed of the propagation of the reaction front downwards against the air flow in a fixed bed of burning biomass particles has been studied. The analysis concentrates on a situation in which the reaction front moves in opposite direction with respect to the gas flow through the fixed bed. For this purpose we solve energy equations for both oxidizing gas flowing against the moving reaction wave and solid fuel in the bed. The reaction speed reaches a steady state soon after reaction at the surface, if the inlet air temperature is the same as the initial temperature of the fixed bed. Modeling of the quasi-steady-state speed of propagation of the reaction front is considered and theoretical temperature of gas and fuel and velocity of the reaction front are derived. The model can be used as a tool to study the influence of parameters, such as biomass species, particle density, and airflow velocity to the fuel bed on the flame front velocity. These parameters studied theoretically and an agreement between experimental and estimated results was achieved.

Numerical Simulations of Self-Ignition of Hydrogen in a Pipe by Rupture of Pressure Boundaries

Bok Jik LEE, Hyoung Jin LEE, In-Seuck JEUNG

Recent experimental observations showed that pressurized hydrogen might be ignited spontaneously when it is released into air by the failure of pressure boundaries, through downstream pipes of sufficient length. In this case, the mixing between hydrogen and air within the downstream tube is speculated to be a key process for the self-ignition of hydrogen to take place. Direct numerical simulations have been conducted to visualize the process of mixing and self-ignition of hydrogen within a pipe after the rupture of disk at bursting pressure of 86.1 atm. Several assumptions on the geometry of pressure boundary at the moment of rupture are chosen to see their effects. Numerical simulations show that the shock interaction downstream of the pipe caused by the initial failure geometry enhances the mixing process, hence causes the self-ignition within the pipe

A Study of Combustion Mode Transition using a New Supersonic Mixer in Dual-Mode Scramjet Engine

Chae-Hyoung KIM, In-Seuck JEUNG, Byungil CHOI, Yoshinori MATSUBARA, Toshinori KOUCHI, Goro MASUYA

A Mach 2 hydrogen-air supersonic combustor model with no diffuser was designed and operated in atmospheric inflow condition. A new supersonic mixer, which is named as vent slot mixer (VSM), is developed and fabricated to use as the device of the fuel-air mixing. Compared with the step mixer, the VSM has an effect to increase the mixing efficiency and the combustion efficiency. At low enthalpy condition, plasma jet torch was used as the igniter and the flame-holder Isolator was designed with using the pressure ratio 2.05, the combustion mode transition from supersonic combustion to subsonic combustion could be seen with successive equivalence ratio range. The mode of supersonic combustion and subsonic combustion is frequently changed during the dual-mode transition.

Diagnostics of Instantaneous Flow Structure in Swirling Premixed Flames by Optical Techniques

Sergey ALEKSEENKO, Vladimir DULIN, Yuriy KOZOREZOV, Dmitriy MARKOVICH, Sergey SHTORK

The present work is devoted to experimental study of flow/flame structure of premixed swirling jet flames at various combustion regimes. The swirl rate based on geometry of the swirlers was varied from 0 to 1.0. Stereo PIV technique combined with pressure probe was

used for the measurements to investigate role of large-scale vortices in turbulent structure of the flames. Besides, chemiluminescence images were used to determine an average position of the flame front.

Visualization of Discharged Shock Waves and Vortex Rings Using the Background Oriented Schlieren

Toshiharu MIZUKAKI

Results of shock-related-flow visualization using background-oriented schlieren method (BOS), which employees more simple optical system than ordinary schlieren method dose, are shown Without well collimated light, shock-related phenomena emerging from a shock tube are clearly visualized by BOS. This result suggests that flow visualization of large scale explosions and real-gun firing would be carried out without fragile optics at test field.

Behaviour of Rods during Striking Interaction with the Screen Protection of an Explosive Substance

Svetlana AFANASYEVA. Nicolay BELOV, Nicolay YUGOV

The given work is aimed at the numerical study of particularities of the striking interaction of cylindrical rods made of metalloceramics TiB2+Fe in comparison with rods made of steel and tungsten-nickel-iron (TNI) at the interaction with space-separated multilayer plates, shielding an explosive substance. The solution of the problem is done in full three-dimensional production within the framework of mathematical model [1].

Experimental Investigation of the Influence of Obstacles on Flame Propagation in Propane-Air Mixtures and Dust-Air Suspensions in a 3.6 m Flame Acceleration Tube

Trygve SKJOLD, Ivar B. KALVATN, G/ste *A. ENSTAD, Rolf K. ECKHOFF* Dust explosions pose a hazard whenever a sufficient amount of combustible material is present as fine powder, there is a possibility of dispersing the material forming an explosive dust cloud within a relatively confined volume of air, and there is an ignition source present Detailed modelling of industrial dust explosions from first principles is a formidable task, and current methods for mitigating the effects of industrial dust explosions therefore rely on empirical correlations obtained from a limited number of experiments. Recent efforts at simulating the course of dust explosions by combining computational fluid dynamics (CFD) and correlations for turbulent flame propagation with combustion parameters derived from standardized experimental tests have produced promising results. However, the results indicate that the correlations for turbulent burning velocity used in various CFD codes for gaseous fuel-air mixtures are less successful in reproducing the experimental trends observed for dust explosions. The aim of the present work is to investigate these discrepancies further, and to develop improved models that can benefit future use of CFD-codes in consequence assessments for industrial plants. This paper describes an experimental study performed in a 3.6 metres flame

acceleration tube on the influence of obstacles on flame propagation in two types of combustible mixtures: propane-air mixtures, and mechanical suspensions of maize starch in air. The experimental approach is similar to that of Pu et al., but with a somewhat larger apparatus, and with an up-to-date data acquisition system. The flame acceleration tube consists of three equal sections of length 1.2 metres, and internal cross-section 0.27 m * 0.27 m. The tests described here are limited to constant volume explosions, but the tube also allows for vented explosions. For gaseous fuels, the explosive mixture is prepared by evacuating the tube and controlling the addition of gas by monitoring the pressure. Tests are typically performed with initial turbulence generated by injecting air from a high pressure reservoir, and this secures thorough mixing prior to ignition. For solid fuels, air from the high pressure reservoir disperses the dust in a pre-dispersion chamber, before the dust is injected into the vessel through nozzles. An

ignition source, either a spark or a chemical igniter, initiates the combustion process in one end of the tube. Different types of sensors (thermocouples, capacitive sensors, optical sensors, and high-speed video) measure flame arrival along the length of the tube, and piezoelectric pressure transducers measure pressure development inside the tube

Experimental study of DDT for hydrogen-methane-air mixtures in tube with obstacles

R. POROWSKI, A. TEODORCZYK

To investigate the deflagration-to-detonation transition for stoichiometric hydrogen-methane-air mixtures experimental studies were performed in 6m long circular cross section tube with inner diameter D=140mm (full diameter of 170mm). The initial conditions of stoichiometric hydrogen-methane-air mixtures were 1 atm and 293 K with different hydrogen content. The flame propagation and pressure wave were monitored by pressure transducers and ion probes. Pressure transducers were located at different positions along the channel to collect data concerning DDT and detonation development. Experimental channel is consisted of four sections (2x2 m and 2x1 m) jointed together and with different configurations of obstructions inside. Configurations of obstacles are used with BR from 0.3 to 0.7. An internal diameter (d) of particular circular obstacles is chosen between 77 mm up to 117 mm and number of obstacles varies from 12 to 35. Obstacles inside the tube are located at various distance which is equal to 1xD=140 mm, 2xD=280 mm and 3xD=420 mm

Reduced Chemical Kinetic Mechanism for Biodiesel Fuel

Hiroyuki YAMADA

The published detailed chemical kinetic mechanism for methyl decanoate proposed by Westbrook and co-authors consists of reactions over 7000. It takes too much time to simulate with this mechanism and it is difficult to apply the mechanism to CFD calculations. Thus, this study proposes reduced kinetic mechanism for methyl decanoate. The reactions in the mechanism are reduced to blow 4000 by ignoring minor reaction paths in compression ignition and flame propagation process. Comparisons between the full mechanism and the reduced mechanism were made, and the results are in good agreement with each other.

Numerical Simulation of Flame Instability Induced by an In-Line Pre-Heating Effect

Akter HOSSAIN, Nobuyuki OSHIMA, Yuji NAKAMURA, Marie OSHIMA In this study, the evolution of strong pair vortex in ahead of flame tip due to the pre-heating treatment and its influence are investigated by the flow simulation of time-dependent governing equations for two-dimensional reacting flows using low Mach number approximation under zero gravity environment. Combustion chemistry is modelled by the single-step irreversible exothermic chemical reaction between ethylene and oxygen. For simplicity, the bulk viscosity, Soret effect, Dufour effect and the pressure gradient diffusion and radiation process are neglected. The finite volume method (FVM) is adopted to discretize the system of governing equations for reacting flows on a hexahedral structured grid cells. The discretized system of equation is solved by using Front Flow Red, a multi-scale and -physics flow solver. The computed results show that the strong pair vortex in ahead of flame tip is generated through the extreme deformation in the flame front caused by the pre-heating treatment over narrow zone along the center line of the channel. This pair vortex interacts with the flame tip and slips down on the flame surface towards the upstream of the channel and shows flame oscillation during the propagation The computed results are also compared with the results of experiment, in terms of the level of deformation in the shape of flame front along the center line, conducted by Tsuchimoto et al. (2007) where $C0_2$ laser is applied along the center line of the gas chamber. This comparison reveals that the shapes of flame tip, in simulation as well as in experiment, are very similar

even though the overall shapes of flame front are different. Therefore, it is thought that the appearance of a strong vortex pair in ahead of flame tip due to pre-heating effect could be one of the possible trigger of flame oscillation observed in the aforementioned experiment.

Study of Dust Explosion Suppression by Means of Explosion Suppression Systems of Different Volumes

Marian Gieras, Michail Kaluzny. Rudolf Klemens

The presented research was aimed at developing and testing of a super fast explosion suppression systems of 2 dm^3 and 5 dm^3 volume, using smokeless powder or pyrotechnic material as an explosive charge and sodium bicarbonate or water as the suppressing materials. Final outcome of the work is a suppression system, characterized by high efficiency and reliability, independently from applied extinguishing substance. Research proved also that for dust explosion water is a very good suppressing medium

PIV Measurements of Centrally Ignited Outwardly Propagating Turbulent Premixed Flames at Reduced and Elevated Pressures

Chien Chia LIU, Steven SHY, Hsing Chung CHEN. Ming Wei PENG

This study aims to measure flow statistics of centrally ignited, outwardly propagating flames in a turbulent reactive environment of methane-air mixtures at reduced and elevated pressures using a newly-established high-pressure cruciform burner and PIV. The cruciform burner is composed of two perpendicular cylindrical vessels, equipped with a pair of counter-rotating fans and perforated plates at each end of the horizontal vessel, and placed in the interior of a large pressure-absorbing safety chamber. The burner is capable of generating intense isotropic turbulence, where the fan frequencies can be up to 180 Hz. The vertical vessel of the cruciform burner has four sensitive pressure-release valves installed symmetrically, so that the pressure increment inside the burner during explosion can be neglected due to the relative large volume of the safety chamber. Two sets of four quartz windows are installed on each of both inner and outer chambers allowing direct visualizations and optical measurements of flame-turbulence interactions in two perpendicular directions. Preliminary PIV results will be presented, in which variations of spatiotemporal scales due to flame-turbulence interactions will be discussed and area for further studies will be identified.

Modeling of SHS Systems under Impact and Electro Thermal Explosion

Vassili GORELSKI. Ivan KHOREV

Shock-wave treatment of powder mixture is very promising for producing modified materials. Particular interest attaches to chemical reactions (synthesis) accompanied by shock-wave processing The products may have improved properties as a result of high-pressure treatment. Chemical reactions in mixtures of elemental powders are often accompanied by rapid release of large amount of energy. The energy release, unlike that in detonation of explosives, is generally manifested by the generation of high temperature, often exceeding the melting temperature of reaction products. Computation results for the case of taking chemical reaction between nickel and aluminum into account allow to conclude that process of thermal explosion occurs only in the case of enough high heating rate. It was evident that depending on heating rate the processes may differ in principle. If in case of high heating rate the reaction takes place all over the sample then in case of lower heating one can see a combustion wave propagation from the center of the sample to its end and lateral surfaces.

Investigation of Hydrogen-Oxygen Mixture Combustion in the Flow of Steam

Sergey ALEKSEENKO, Nikolai PRIBATURIN, Vladimir FEDOROV, Maksim ALEKSEEV, Anatolii SOROKIN

Results of simulation and experimental studies on combustion of the hydrogen-oxygen mixture in the steam flow are presented here. The scheme of solution to this problem was as follows. Steam with temperature T1 and constant flow rate Q1 was fed to the inlet of a tube with diameter D and length L. The stoichiometric mixture of hydrogen and oxygen with flow rate Q2 was supplied along the tube axis through a nozzle with diameter d. Since steam is the product of this mixture combustion, at full mixture combustion only steam, whose temperature T2 is significantly higher than initial temperature TI, should exist at the tube outlet. The work deals both with possibility of production of pure high-temperature steam at the tube outlet and with the process of hydrogen-oxygen combustion in a co-current flow of low-temperature steam. To verify the simulation methods, the experiments with varying tube diameter (from 15 to 40 mm), tube length (from 100 to 250 mm), flow rates of steam of hydrogen-oxygen mixture were carried out at a laboratory setup. These experiments were carried out under the atmospheric pressure; steam was fed to the tube inlet at a temperature of 100°C. Mixture combustion in the tube was visualized; the temperature at the tube outlet was measured; and completeness of hydrogen-oxygen combustion was determined depending on the ratio between flow rates Q1 and Q2 To determine the completeness of mixture combustion, the known principle of steam condensation in a big volume of cold water was used. The amount of gases non-condensed in water determines the degree of combustion completeness in a flow of pure steam. It was found out that the main effect on completeness of hydrogen-oxygen combustion in the steam flow is made by a relative content of a combustible mixture in the initial steam flow. Such a flow was simulated on the basis of motion and energy equations, determination of the mass shares of H_2 and 0_2 and the standard $\kappa - в$ model of turbulence. Simulations were made by the finite-volume method at a uniform grid. The thermal-physical properties of components were calculated by the polynomial approximations;

the mixture properties were determined in approximation of the multicomponent ideal gas. Difference approximations of the second accuracy order were used for all equations. Calculations were resulted in the fields of flow velocities, temperatures, and concentrations of hydrogen, oxygen and steam. Comparison of calculation and experimental data indicates their satisfactory correspondence. It is shown that combustion of the hydrogen-oxygen mixture in the steam flow may provide high-temperature steam with a minimal amount of non-condensed gases. In experiments we have reached a stable long-period operation at 12000C. Dependence of the steam temperature at the tube outlet on the ratio of initial flow rates of steam and combustible mixture was determined.

Transition of Spontaneously Ignited Hydrogen Release into a Jet Fire

Maxim BRAGIN, Vladimir MOLKOV

The main objective of this study is an insight into physical phenomena underlying spontaneous ignition of hydrogen at sudden release from high pressure storage and its transition into the sustained jet fire This work describes modelling and large eddy simulation (LES) of spontaneous ignition dynamics in a tube with a rupture disk separating high pressure hydrogen storage and the atmosphere. It is demonstrated that a chemical reaction commences in a boundary layer within the tube, and propagates throughout the tube cross-section after that. Simulated by the LES model dynamics of flame formation outside the tube has reproduced experimental observation of combustion by high-speed photography, including vortex induced "flame separation". It is concluded that the model

developed can be applied for hydrogen safety engineering, in particular for development of innovative pressure relief devices.

Competition between Self-Ignition and Deflagrative Burnout in Hydrogen-Air Mixture Heated by Reflected Shock Wave

Sergey MEDVEDEV, Gennadii AGAFONOV, Sergey KHOMIK. Boris GELFAND The analysis of probable competition between the processes of self-ignition and deflagrative burnout in hydrogen-air mixtures heated by reflected shock wave demonstrates that early stage appearance of even thin near-wall burning zones at relatively low temperatures (T<1000 - 1100 K) inevitably disturbs overall volume of mixture under investigation The suggested estimations are conservative.

The Comparison between Measured and Calculated Temperature at Focusing of Shock Wave in Hydrogen-Air Mixture

Sergey MEDVEDEV. Vyacheslav ZHUKOV. Sergey KHOMIK. Boris GELFAND The investigations of shock focusing in lean (7-9%) hydrogen in air mixtures was performed by use of a shock tube with the endwall shaped in the form of concave symmetric wedge reflector. It was found that shock focusing serves as a powerful technique for initiation of detonation and deflagration regimes Along with pressure recording and optical visualization a specially designed double-wavelength photodiode detector was used for the emission/temperature measurements. It was found that maximum temperature levels are attained in the vicinity of the reflector apex The measured value of peak temperature TP grows up with the increase of the Mach number M of the incident shock wave. Typical values of peak temperature falls in the range of TP = 2000-4000 K at M = 2.5-3. The importance of evaluation of TP values is due to the fact that the process of detonation initiation is controlled by the high-temperature regions arising due to the shock focusing inside a reflector cavity.To get further insight into the problem of shock focusing in reactive gaseous media numerical simulations were performed by use of GasDynamicsTool (GDT Software Group) package The 2D calculations were executed at rectangular non-adaptive grid accepted in GDT. The dimension of the calculation cell was 0.1 mm. The physical length of the calculation domain was varied in the range of L= 100-200 mm and the height was specified as 27 mm (to reproduce half of rectangular shock tube of 54 x 54 mm^2). The typical calculation step was 100 ns. Numerical simulation demonstrates all basic features of detonation and deflagration initiation revealed in experiments by optical visualization. It was found that measured and calculated temperature - time histories in the vicinity of the apex of a reflector are in a satisfactorily agreement between each other. The advantage of the numerical simulation is the possibility to elucidate the peculiarities of transient regimes when detonation is initiated outside of the reflector cavity.

Numerical Investigations on the Three-dimensional Flow Patterns of the Continuous Rotation Detonation

X.H. *JIANG. B.C. FAN. X.D. ZHANG. MY. GUI. Z.H. CHEN*

Based on the three-dimensional Euler equations coupling with chemical reactions, the phenomena of the continuous spin detonation in an annular combustor were numerically studied by using high-resolution Roe scheme and MPICH2.0 parallel computing in the body-fitted coordinate system and wave structure in the flow field were discussed in detail according to the calculated results. Even the combustor are partly filled with the combustible gas. the spin

detonation wave can propagate steadily in the layer of premixed gas. And detonation products rapidly move towards the ambient air, which lead to the possibility of self-sustaining supply of fresh mixture into the combustor.

Observations of Wire Ignition Phenomena at Excess Electric Current Application in Reduced Gravity

Yasuhiro KIDO, Osamu FUJITA, Takeshi KYONO, Hiroyuki ITO, Yuji NAKAMURA A most likely cause of fires in space is the combustion of the electric wire harness of spacecraft, which generally start by a short circuit or overloading of an electric wire. Therefore it is important to know the ignition characteristics of overloaded wires in microgravity to improve fire safety in space, and in future space exploration missions, activities on the surface of the Moon and Mars must be considered. Therefore fire safety issues under reduced gravity conditions should also be investigated in research on fire safety in space. In previous research, the authors reported dramatic extensions of ignition limits with the supplied electric current in microgravity. A comparison of the ignition processes in microgravity and normal gravity were also reported. At present there is no published data the effect of gravity intensity changes, reduced gravity effects, on wire ignition. The present work performed ignition experiments of overloaded wire under reduced gravity conditions attained by aircraft parabolic flights. In this study, overloaded wires exposed to reduced gravity conditions were observed and a determination of the occurrence of ignition was made. An ignition map showing ignition conditions based on electric current and gravity conditions was developed. The behavior of pyrolyzed gas motion was also observed with a high speed camera and optical methods in reduced gravity to discuss the relationship between pyrolyzed gas motion and wire ignition.

Study on Propagation Characteristics of the Shock Waves Driven by Gaseous Detonation Wave

Shinpei KATO, Satoru HASHIMOTO, Akane UEMICHI, Jiro KASAHARA, Akiko MATSUO We experimentally investigated propagation characteristics of the shock wave driven by a gaseous detonation wave. In general, shock waves can be generated by solid explosives or shock tubes. Although solid explosives are possible to generate shock waves even in unconfined space, it can not generate repeatedly. On the other hand, although shock tubes are relatively easy-to-use, it is also not capable of generating shock waves repeatedly In the present research, we generate shock waves repeatedly in free space using the technology for gaseous detonation wave which is one of combustion waves and propagates at from 2 to 3 km/s. Generally, a gaseous detonation wave can be generated with a cylindrical tube filled with detonable gas, where one side is closed and the other side is open The detonation wave begins to propagate from the closed end to the open end right after high-energy ignition. The detonation wave diffracts at the open end, and burned-pressurized gas pushes atmospheric air as a piston and creates a shock wave. Moreover, it has become possible to operate this cycle periodically at higher frequency. These mean that we could easily create finite pressure waves repeatedly in arbitrary space and arbitrary intensity at high frequency using recent pulse detonation engine (PDE) technology. In order to utilize the shock wave, its characteristics of propagation should be investigated. As for previous studies, there has been a few investigations about propagation characteristics in far field from a source of the shock wave while there has been a lot of investigations about that especially in vicinity region of a source. In the present study, we carried out optical visualization in vicinity region of the end of the detonation tube. In far field (200 m far from the tube end), we conducted fixed-point observations using piezo pressure gauges in order to obtain overpressure time-histories of the shock and pressure waves in the axial direction of the detonation tubes.