BACKGROUND

- Stringent regulations on aircraft emissions
- A requirement of accurate and reliable soot models to accelerate combustor design process
- Gaps in understanding of the physicochemical pathways of soot formation

OBJECTIVE

- To develop an advanced sectional method-based soot model for the prediction of soot in terms of chemical evolution and particle formation in conditions relevant to the aero-engines
- To develop a soot modeling approach coupled with the Flamelet Generated Manifolds (FGM) chemistry for the Large Eddy Simulation (LES) applications
- To assess and investigate the impact of various turbulence/chemistry interaction models on predictive capabilities of the developed soot models in various TRL test rigs and combustor configurations

APPROACH

- Numerical simulations using the in-house developed solver, CHEM1D and Flamelet Generated Manifolds (FGM) chemistry
- Turbulent flame simulations with LES approach using a massively scalable ALYA solver

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REDUCING BUBBLE INDUCED LOSSES IN ALKALINE WATER ELECTROLYSIS

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BACKGROUND

- Excess energy from fluctuating renewable energy resources can be stored in Hydrogen gas.
- Alkaline water electrolysis is not efficient enough and therefore not profitable.

OBJECTIVE

- Increase the effective surface area of the electrode i.e. reduce coverage of bubbles on the electrode surface.
- Reduce ohmic losses in the electrolyte due to the presence of bubbles.
- Increase cell efficiency by operating the electrolysis cell at high pressure and current density.

APPROACH

- Fully resolved simulations of bubble growth, bubble coalescence in the electrolyte and at the electrode surface.
- Experimental measurements of bubble size, current density, potential, bubble rise, bubble detachment and bubble coalescence.
- An Euler-Euler or Euler-Lagrange model to simulate an entire electrolysis cell that is optimized with closure relations obtained from fully resolved simulations and experiments.

*Fig 1: Gas bubble production at an electrode surface*
BACKGROUND

• In steel production, controlled quenching is crucial to reach the desired steel properties.
• Generally, steel quenching occurs by impingement of multiple water jets.
• The physics of this process are not yet understood.

OBJECTIVE

• Gain physical understanding on the boiling heat transfer regimes.
• Provide accurate heat transfer estimations to improve process control.

APPROACH

• Upgrade lab setup to allow quenching of moving surfaces at speeds up to 9 m/s.
• Experimentally study quenching of moving hot steel plates by water jet impingement.
• Obtain heat flux estimations through temperature measurements at various locations.
• Improve physical understanding through high speed recordings.
BACKGROUND

- In the modern ironmaking process, hot air is blown into blast furnaces.
- There is a coke packed-bed around the hot air injection zone.
- Hot air creates a void space, commonly known as “raceway”, in the coke packed-bed.

OBJECTIVE

- Find the optimal operating conditions for minimal CO₂ emission.
- Improve the coal combustion efficiency.

APPROACH

- Computational Fluid Dynamics (CFD) + Discrete Element Method (DEM) simulations.
- Implement heat and mass transfer, and combustion into the model.
- Validate the model with experiment data.
BACKGROUND
• Fluctuating renewable energy production demands dense energy storage
• Metals powder pose a safe, clean and CO₂-free solution

OBJECTIVE
• The metal fuel cycle requires efficient metal-oxide to metal conversion (reduction)
• Hydrogen can be a green reducing agent, if produced from renewable energy

APPROACH
• Determining kinetics by thermogravimetric analysis and drop tube experiments
• Development of a single particle model
• Coupling the reaction with particle motion and fluid flow using CFD-DEM simulation
• Performing lab-scale fluidized bed measurements

SEM images of combusted/reduced iron particles (at 3 temperatures)
BACKGROUND

- Our society is running out fossil fuels and warming up our planet by huge amount of CO₂ emission
- Metal powders have high energy density and are CO₂-free energy carriers, which could be alternative fuels

OBJECTIVE

- Conducting measurements on fundamental combustion properties, such as burn time and burning particle temperature
- Validating numerical model developed for iron combustion
- Investigating characteristics of flame propagation by lifted micro-flames

APPROACH

- Constructing experimental setup for reliable measurements
- Developing optical diagnostic methods for determining burn time and temperature

Fig. 1 Schematic diagram of the particle generator.

Fig. 2 High-speed and long exposure images of burning particles.

Fig. 3 Burn time of 36-38μm iron particle.

Fig. 4 Peak temperature of 36-38μm iron particle.
BACKGROUND

- Droplet collisions are complicated phenomena yet occur in many industrial and geophysical processes. Understanding the underlying mechanisms is of great importance for accurate modeling of these processes.

- Sharp interface methods have no natural way of modeling topological changes of the liquid-vapor interface.

- A Diffuse Interface Model is better suited to handle topological changes of the liquid-vapor interface, such as breakup or coalescence of droplets.

OBJECTIVE

- Accurate simulations of droplet collisions in order to gain detailed insight into the underlying mechanisms of the collision process.

- Validate or improve coalescence models employed in sharp interface methods.

APPROACH

- Diffuse Interface Model based on the Navier-Stokes-Korteweg equations and the Van der Waals equation of state.

- Large-scale numerical simulations using the Finite Volume Method.

Figure 1: Initial configuration of the mass density and velocity field.

Figure 2: Example of a head-on droplet collision resulting in a reflexive separation.
BACKGROUND

- Flame speed data is vital for:
  - creating stable flames
  - preventing flashback in burners and engines
  - developing reaction mechanisms
- The Heat Flux method gives highly accurate results by creating a flat, nearly 1D flame

OBJECTIVE

- Extend the Heat Flux method to high pressures
- Evaluate flame speeds for fuel mixtures
- Include new fuels produced from sustainable sources, such as biomass and solar energy

APPROACH

- Design of a new setup for measuring liquid fuels under pressure
- Improvement of the Heat Flux burner
- Numerical simulations to closer investigate the quality of the created flames

Numerical simulation of flame stabilization on a single hole of the burner plate
BACKGROUND

- Occurrence of thermo-acoustic instability is a serious impediment to design combustion chambers.
- In domestic boilers, thermo-acoustic instabilities generate a high level of noise.
- Acoustic network models are powerful tools to analyse conditions of (in)stability appearance (see Fig. 1 and Fig. 2).

OBJECTIVE

- Study of thermo-acoustic systems
  - Two-port Network modeling.
  - Stability criteria.
- Prepare lab-scaled acoustic models of the system (see Fig. 3 and Fig. 4)
- Evaluate the acoustic performance of the flame and up/downstream sides of the burner.

APPROACH

- Evaluation of thermo-acoustic instabilities of a system based on reflection coefficients at the cold side.
- Study effects of reflection coefficients shown in Fig. 1 (i.e. $R_{up}$, $R_{in}$, $R_{dn}$) on the stability of the system.
- Derive the intrinsic thermo-acoustic instability criteria in frequency domain.
- Design acoustic devices at upstream and downstream sides of the burner with variable reflection coefficient.

Figure 1: Thermo-acoustic model of a combustion system

Figure 2: Sample of domestic boilers and its parts.

Figure 3: A test setup for measuring a reflection coefficient ($R_{in}$) of a burner with a flame.

Figure 4: Explanation of the above test setup.
BACKGROUND

- Seen the current state of the climate? Because of the CO₂?
- A solution: Capture CO₂ and convert it to other chemicals. But how easy is it?
- Use reactors specifically bubble columns.
- Bubble columns are often limited by larger bubble sizes.
- Cutting could increase the mass transfer.

OBJECTIVE

- Maximize the conversion of CO₂ using bubble column reactors.
- Studying the effect of bubble cutting on the improvement of reactions.

APPROACH

- Using Computational Fluid Dynamics (CFD) for predicting the flow in the column.
- By treating bubbles as particles.
- Modeling the bubble cutting process.
- Providing direction for the reactor design.
BACKGROUND

- Flame stabilization and ignition control in lean conditions are still major challenges in combustion science.
- Non-equilibrium plasma can be used to enhance lean flammability limit.
- Non-equilibrium plasma induced chemistry and its interaction with combustion are not well understood yet.

OBJECTIVE

- Make plasma-assisted combustion efficient.

APPROACH

- Set up experimental facility to study plasma-assisted low-temperature combustion kinetics.
- Parametric study to find best plasma type and plasma parameters.
- Apply optical laser diagnostics to improve fundamental understanding.
DESIGNED EXPERIMENTS FOR EFFICIENT ENGINES
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BACKGROUND
- Paris Agreement restricts CO₂ emitted by heavy-duty vehicles
- Engine efficiency will play a key role in reaching mandated targets
- Fuel flexible engines are crucial for clean and sustainable transportation

OBJECTIVE
- Investigate the maximum efficiency potential of a dual-fuel combustion concept
- Compare dual-fuel performance with that of conventional diesel combustion

APPROACH
- Use Design-of-Experiments methodology for dedicated engine tests
- Analyze experimental data to pave the way for efficiency improvements

**Experimental results**
Efficiency and emissions can be optimized by tailoring fuel injection
Note how virtually zero NOₓ is emitted at peak efficiency

**Principle of Reactivity Controlled Compression Ignition (RCCI)**
A dual-fuel concept that works with any two fuels of different reactivities

/ POWER AND FLOW
BACKGROUND

- There is an increasing demand for cost-efficient and high-quality prints on broad range of materials
- Inkjet printing technology provides an optimal combination of scalability, customization and price

OBJECTIVE

- Surfactants, a key component in ink, improve the drying and wetting of inkjet droplets
- Exact mechanisms of surfactant-enhanced drying process are still unknown

APPROACH

- Develop a lubrication model of an evaporating water droplet with surfactants on a substrate
- Extend the model with additional factors, such as porous substrates, moving contact lines, salts and multi-layer droplets
- Perform an analysis on the effect of surfactant properties on the internal flow in a drop
BACKGROUND

- Efficient recycling of end-of-life plastic has become a major economic and environmental concern.
- Most of current recycling strategies lead to “downcycling” of plastic.
- Magnetic density separation (MDS) is a high-resolution technique which incorporates magnetic liquids and engineered magnetic fields to separate plastic particles based on their mass densities.

OBJECTIVE

- Gain a fundamental understanding of the particle-fluid-particle interactions in MDS.
- Investigate the temporal and spatial characteristics of turbulence in MDS.

APPROACH

A combined numerical and experimental approach:
- Direct numerical simulation of particle-laden channel flow of a magnetic fluid + Particle tracking velocimetry experiments
- Numerical simulation of flow instabilities behind a flow laminator + Laser Doppler anemometry and particle image velocimetry experiments

Magnetic density separation of 4-mm spherical particles in a paramagnetic liquid. Particles are colored based on their mass densities. The horizontal color bar corresponds to the vertical component of fluid velocity.

/ POWER AND FLOW
BACKGROUND
- Plasma can be used to improve flame stability
- Plasma can increase ignition kernel size and reduce ignition delay

OBJECTIVE
- Gain understanding on the interaction between plasma and combustion
- Develop an efficient, numerical model

APPROACH
- Detailed chemistry simulations of plasma and combustion processes
- Reduce chemistry of plasma-combustion interaction to do 3D simulations

Different mechanisms of combustion enhancement due to plasma discharge
BACKGROUND

- Partially premixed swirl flames are practical in gas turbine engine
- LES-FGM modeling is promising to obtain reliable combustion prediction while improve the computation efficiency

OBJECTIVE

- Combustion prediction with LES-FGM
- Results validation with experiment

APPROACH

- Mesh with 8,000,000 hexahedral cells
- Chemical reduction with multi-dimension FGM, including the mixture fraction, enthalpy and progress variable
- Implementation of the FGM and LES for combustion based on OpenFOAM
- Validation against the radical (OH) distribution (OH-PLIF) and flow field (PIV) from experiment

This is a one-year program and financially supported by the China Scholarship Council (CSC)

/ POWER AND FLOW
Background

- The clearance exists between the rotor and end wall, results in tip leakage vortex (TLV) and tip cavitation.
- Cavitation can threaten the stable operation of an axial flow pump due to its adverse impacts such as blockage in the passage, pressure pulsation, efficiency loss, noise and vibration.

Objective

- The cavity patterns in the tip region.
- Unsteady perpendicular cavitating vortices (PCV).
- Transient pressure evolution associated with PCVs.

Approach

- Verifying the applicability of Large Eddy Simulation (LES) and cavitation model in an axial pump.
- Discussing the effects of TLV, lateral jet and pressure oscillation on the PCV, as well as the characteristics of the velocity field, pressure field, vorticity field and turbulent kinetic energy and its generation.
- Performing high-speed photography and pressure pulsation measurements to capture the evolution of TLV and induced-PCVs.
BACKGROUND

• The bubble motion in bubble columns is highly dynamic and complex. This can be understood and analyzed in a great detail based on the direct numerical simulation (DNS).

• The interfacial force models are demanded to close the E-E or E-L models. Reliable and generalized closures are expected to be extracted from the DNS data.

OBJECTIVE

• Establish a benchmark for bubble columns.

• Find generalized relations to describe the interfacial forces (e.g. drag, lift and wall forces) acting on the bubbles.

APPROACH

• A lab-scale bubble column will be fully modelled via DNS, coupled with Volume-of-Fluid method for interface tracking.

• The DNS database will be analyzed by using deep learning approach.

A preliminary DNS result of air bubble swarms rising in quiescent water.
BACKGROUND

- Iron powder as energy carriers: high energy density, zero CO₂ emissions.
- Reduction of combusted iron oxides is required using renewable energy.
- Methanol as an alternative reducing agent: reduction at relatively low temperature; avoid high-temperature sintering/sticking problem.

OBJECTIVE

- Explore the feasibility of methanol as a reducing agent.
- Model the reduction process of iron oxide particles.

APPROACH

- Experimental methods (TGA, HDT) to determine the reduction kinetics.
- CFD-DEM simulations for reactor modelling.

Envisioned metal fuel cycle

Power-to-Metal

Metal-to-Power

Renewable energy

Reduction

Combustion

Industrial heat

Mobility

Electricity

Envisioned metal fuel cycle

/ POWER AND FLOW
Introduction

Inkjet printing is the most widely spread technique for printing. Ranging from small consumer models to large professional machines this technology can be used to recreate digital images fast and with high resolution. The printing can be done on paper, but also on other materials, such as metals, plastics, textiles and more. Besides that, a large spectrum of liquid materials can be used as "ink" ranging from molten metals to even biological tissue. All these applications, combined with its versatility, make inkjet printing a key technology in a growing market.

An important factor for successful inkjet printing is having a good control of the drying process. In order to do this, surfactants are often added to the mixture. These ‘surface-active agents’ reduce the local surface energy, thus modifying the interfacial shear stress. This can result in a so-called Marangoni flow, which causes the flow field to circulate rather than flow towards the contact line as it does under standard conditions (see Figure 1). However, still much remains unknown about the exact dynamics of droplets with surfactants.

Project description

Previously, a 2D lubrication model was created, which is able to simulate the drying process of a water droplet with soluble surfactants over time. However, this model is unable to take into account nonaxisymmetric effects, such as substrate topology, inclined substrates and convective evaporation. Thus, a 3D model is required to incorporate these factors. The creation of this 3D model is the main goal of this project.

The first step is to get familiar with the existing 2D model. You will analyze the code, perform some simulations and read background literature. As soon as you are comfortable with the material, you will start working on the second part of your project, which is the building of your own code. You will program a simple 3D numerical model that can predict the evaporative behavior of pure liquid droplets. When this works, you will add surfactants and maybe even more features such as nonflat substrates. Lastly, you will write a thesis in which you publish your results.

Contact

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References
