Course Number: 70140103	**Course Title: Advanced combustion theory**
Lecture hours（授课学时）:48	**Credits:3**
Term Offered: Spring	**Instructor(s): Yao Qiang, Li Shuiqing**
Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering	

Course Description:

The course is designed to teach in English and Chinese. Half of the class will be with lectures and half of the class will be in the form of seminar. The main contents are turbulent combustion which includes an introduction to turbulence, turbulent premixed combustion, turbulent non-premixed combustion and turbulent partial premixed combustion. Turbulent combustion theory is still under development. The lectures will focus on the basic concepts in the turbulent combustion and the basic principle to solve a problem in turbulent combustion. Modelling is the major methods based on different combustion phenomenon and several models to deal with these turbulent combustion processes will be introduced in the lectures. In the part of seminar, the students will be divided into different groups. The students will study the new development, new problems or new problems related to combustion. They will read the references, find the issues and define the problems. The students are encouraged to ask questions, to criticize the existing research results. The class will be an environment not only for learning but also for study.

Week		lecture	seminar
1.		An introduction of the class(2 hour)	Groups formed and topics to be selected(1 hours)
2.		An introduction to turbulence(2 hours)	Groups to report their last week's work First Extension reading materials
3.		An introduction to Premixed turbulent Flame(2 hours)	First Extension reading materials-reports: group
4.		An introduction to Non-premixed flame(2 hours)	Groups to report their last week's work
5.		×	Groups to report their first stage work
6.		Premixed turbulent combustion(2 hours)	Groups to report their last week's work
7.		×	Groups to report their last week's work

			2nd Extension reading materials
8.		Premixed turbulent combustion(2 hours)	2nd Extension reading materials-reports: group
9.			Groups to report their last week's work 2nd Extension reading materials
10.		×	Second stage report of the group work
11.		Non premixed turbulent combustion(2 hours)	Groups to report their last week's work
12.		×	Non premixed turbulent combustion: extension reading materials-reports
13.		Non premixed turbulent combustion(2 hours)	Groups to report their last week's work
14.		×7:20-9；45PM	Non premixed turbulent combustion: extension reading materials-reports
15.		Partial premixed combustion	Groups to report their last week's work
16.		×	Final presentation(30 minutes presentation+ 15 minutes discussion/group)
17.		Oral examination June 25th Thursday.	

Course Number: 80140032	Course Title: Numerical Methods in Heat Transfer
Program:	**Term Offered: Fall**

Instructor(s): Prof. David M. Christopher

Course Description:

Course Objectives:

* To study numerical methods used for solving the Navier-Stokes equations and the energy equation for laminar and turbulent flow in various geometries.
* To introduce widely-used commercial software used to solve the Navier-Stokes and energy equations (Fluent)

Course syllabus:

I. Types of Governing Equations and Boundary Conditions

II. Conduction Heat Transfer

A. Steady State One-Dimensional Conduction Finite Difference Concepts
B. Two-Dimensional Conduction Finite Difference Concepts
C. Boundary Fitted Coordinates
D. Transient Conduction
E. Commercial Heat Transfer Software, Fluent
F. Grid generation with Gambit

III. Convection Heat Transfer

A. Governing Equations
B. Turbulence
C. Natural Convection Heat Transfer
D. Convective Heat Transfer Analyses using Fluent
E. Convergence considerations

IV. Advanced Topics

A. Radiation
B. Two-Phase Flow (VOF method)
C. Porous Media
D. Periodic Flows (turbomachinery)

Grading:

30% Homework
30% Research project
40% Final exam

Course Number: 80140072	**Course Title:** Principles of Coal Combustion Pollutant Formation and Control
Lecture hours（授课学时）: 32	**Credits:** 2
Term Offered: Autumn	**Instructor(s):** Prof. ZHUO Yuqun

Program: Tsinghua-RWTH Aachen Double Master’s Degrees Program on Thermal Engineering

Course Description:

Coal is the most important primary energy source in China. Its related pollution is also one of the biggest challenges in environment protection in China and even the world. This course covers all the major pollutants formed during coal combustion, including SO_2, NOx, particulate matters, trace elements, and CO_2, and focuses on:

- the environmental impacts of each pollutant;
- the fundamentals of pollutant formation in and after coal combustion;
- the mechanisms of pollutant removal and corresponding emission control technologies;
- the pros and cons of each technology in application;
- and, the future trends of emission control;

The aim of the course is to give students a comprehensive yet in-depth view on the environment protection efforts made by Chinese power industry.

Course Number:	**Course Title:** Data Processing in Thermal Engineering
Lecture hours（授课学时）:32	**Credits: 2**
Term Offered: Spring	**Instructor(s): Dr. Zhe Wang**
Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering	

Course Description:

The course will provide an introduction for the data processing methods used in thermal engineering measurement. The general outline of the course is as following:

1. Introduction
2. Z Transform
3. Fourier Transform
   3.1 Continuum Fourier Transform
   3.2 Discrete Fourier Transform
   3.3 Fast Fourier Transform
4. Radom Signal Processing
5. Analysis of Variance
6. Multi-variate linear regression
7. Artificial neural network
8. Wavelet Transform
9. Orthogonal Design
10. Partial Least Square

Course Number: 80140172	**Course Title:** **Flame and Gas Combustion**
Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering	**Term Offered:** Fall
Instructor(s): Prof. Hai ZHANG	
Lecture hours（授课学时）: 32	**Credits: 2**

Course Description:

This course is on combustion science and technology, focusing on the flame and gas combustion. It covers and mathematically describes in detail various fundamental flame phenomena. It also emphasizes on chemical kinetics, which is essential to understand the non-equilibrium combustion processes and control mechanisms. The course not only covers the basic laws and phenomena related to chemical reaction, reaction rate and path，but also illustrates the importance and complexity of the role of chemical kinetics in combustion examples. The roles of chemical kinetics, together with molecular transport, aerodynamics, heat and mass transfer are discussed for the flame structure and dynamics of the laminar, turbulent, premixed and non-premixed flames. Through the course study, students are expected to more deeply understand the fundamentals of flames and gas combustion, including the reaction mechanisms and physical insights in the processes of flame propagation, ignition, stabilization and extinction, and pollutant formation. The course is divided into 11 chapters.

The first chapter is a general introduction of the course. Chapter 2 reviews equilibrium thermodynamics which relates the initial and final states of a chemical–reacting thermodynamic system; Chapter 3 examines the mechanisms and rates of these reactions, and illustrates the importance of the role of chemical kinetics in combustion with the examples of oxidation processes of some conventional fuels; and Chapter 4 discusses the non-equilibrium processes of heat, mass and momentum transport which non-uniformities in temperature, concentration and velocity exist in the flow, Chapter 5 presents the general governing equations for chemical-reacting flows and their application in some special cases.

Chapter 6 starts our study of combustion system by examining the structure of diffusion flames. In Chapter 7, we study the physical and mathematical description of the flame structure, laminar flame speed and its measurements of premixed flames, and discuss the principles of flame stabilization. In Chapter 8 the critical phenomena of ignition and extinction are analyzed, with physical and mathematical description. The aerodynamic response of convective and diffusive non-uniformities is studied in Chapter 9. Chapter 10 studies the flames in the turbulent flow. It discusses the turbulent effect on the flame structure, propagation and stabilization of premixed and non-premixed flames.

The course ends with Chapter 11 of the NOx Formation and Control, an application example of chemical kinetics and gas combustion.

Course Number: 80140232	**Course Title:** **Gas Turbine: Key Technologies and Application**
Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering	**Term Offered:** Fall
Instructor(s): Prof. Ren, Jing	
Lecture hours（授课学时）: 32	**Credits: 2**

Course Description:

The course is aimed to provide the information of the key technologies regarding the stationary power generation gas turbine, and other turbine based systems aimed at zero-emission. The course will start with a short introduction to the history of the gas turbine and the clean energy system. The main part of the course includes the key technologies of turbine cooling, combustor and high temperature materials. The turbine system economics and operation is provided as the end part of the course to build up an overview concept of the gas turbine for the students. During the course， the students is asked to develop their own ideas on the key technologies of the gas turbine based on the innovation methodologies (Reverse engineering/SCAMPER/Six Hats and so on). As a main part of the course, the selected idea will be manufactured and tested on the test rig by the students in group. The general outline of the course is as following:

1. Introduction (history and features of the gas turbine)
2. Clean Energy System
   - 2.1 Simple and Combined Cycle
   - 2.2 Integrated Coal Gasification Combined Cycle (IGCC)
   - 2.3 Zero-emission Power (Oxyfuel, Hydrogen)
3. Key Technology of Turbine Cooling
   - 3.1 Basic Concept of Turbine Cooling
   - 3.2 Enhanced Internal Cooling
   - 3.3 Enhanced External Cooling
   - 3.4 Coupled Aero thermal Optimization
   - 3.5 Cooling idea: generation, evaluation and realization
4. Key Technology of Combustor
   - 4.1 Type and Feature of the Conventional Combustor
   - 4.2 Pre-mixed Combustion
   - 4.3 Multi-swirl Combustion
5. High Temperature Materials
   - 5.1 Super Alloy Development and Performance
   - 5.2 Protective Coating-Bond Coat and Top Coat
   - 5.3 Failure Mechanisms of Coating
6. Turbine System Economics and Operation (RAM)
   - 6.1 The Power Market Drivers
   - 6.2 Operating Strategies and Options

Course Number: 80140242	**Course Title: Radiative Heat Transfer in Participating Media**
Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering	**Term Offered:** Autumn **(as of 2018)**
Instructor(s): Prof. Huaichun Zhou	

Course Description:

Radiative heat transfer is the main heat transfer mode in high temperature circumstances, especially in traditional energy utilization and power generation industry, as well as in modern technology fields such as utilization of solar energy as renewable energy resources, biomedical diagnostics via optoelectronic technologies, and is related to the key issue of global warming where the radiative heat from the sun transfers through the atmospheric space of the earth. In this course, the basic concepts and laws on radiation are briefly introduced, and then four major parts are organized to cover the main aspects of the topics of the course.

The first part deals with the concepts, theory, and simplifications related to traditional radiative heat transfer issues, such as the Radiative Transfer Equation (RTE) and the simplifications at some extreme cases, and optically-thin and –thick media.

The second part focuses on the solution of RTE numerically. This part is very useful for students to analyze qualitatively and quantitatively the radiative heat transfer problems in practice. Main methods, such as Discrete Ordinate method (DOM), Monte Carlo method (MCM), and DRESOR method, will be described fundamentally with computation codes for simple cases.

The third part is radiative properties of gases, particles and particle cloud suspended in the space, and solid surfaces. For the gas radiative properties, the development of high-resolution spectral databases, the main spectral models such as Narrow-Band model, Wide-Band model and Global-Band model are introduced, focusing on the Statistical Narrow-Band (SNB) model. For the radiative property of particles, the Rayleigh scattering theory, the Mie theory, and the property of particle cloud, are briefly outlined. For the surface property, the influence of roughness is emphasized.

The fourth part is given for the application of radiative heat transfer in traditional energy and power industry, and some new technology fields. The first area is the radiative transfer in gradient refractive index media where the change of transferring direction of radiation plays a key role and shouls be taken account for. The second area is the radaitive transfer in combustion processes, which is the main power source in thermal engineering, such as boilers, furnaces, inner combustion engines, and gas turbines. As an inverse radiative transfer problem, radiative images are used to reconstruct the two- or three-dimensional temperature distributions inside boilers and furnaces.

Course Number: 80140262	Course Title: Optimization of Energy Systems
Lecture hours（授课学时）: 32	**Credits: 2**
Term Offered: Autumn	**Instructor(s): Dr. Liu Pei**

Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering

Course Description:

This course covers state-of-the-art optimization based techniques for energy process synthesis, process design and process operability. Emphasis is placed on mathematical modelling via mixed integer and continuous optimization formulations.

This course will focus on:

- Principles of continuous optimization
- Principles of modelling with integer variables
- Principles of mixed-integer linear and nonlinear optimization
- Applications to:
  - Energy Systems
  - Cost-Environmental-Energy Trade-Off Analysis

1. **Project**

- Weight: **25%** of final mark
- The project should not take more than 8 hours to complete

2. **Syllabus**

- Introduction to Process Synthesis - Decision making in process synthesis: issues and criteria, systematic approaches to process synthesis
- Nonlinear Optimization
  Basic concepts in optimization: optimal points, feasible region, convexity
  Unconstrained optimization: optimality conditions, active set strategies, SQP, reduced gradient methods.
  Application to flow-sheet optimization
- Modelling discrete alternatives
  Modelling of superstructures: binary variables, prepositional logic
  Heat exchanger network synthesis
- Mixed-integer programming
  Mixed-integer linear programming: overview of methods available, branch-and-bound
  Mixed-integer nonlinear programming: branch-and-bound, Generalized Benders decomposition, Outer-approximation

Course Number: 80140272	**Course Title: Utilization Technology of Renewable Energy**
Lecture hours（授课学时）:32	**Credits:2**
Term Offered: Spring	**Instructor(s): Dr. Wang Shujuan**
Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering	
Course Description: **As we know, the utilization of renewable energy resources play very important role in reducing CO2 emissions. The course will give some fundamental knowledge on renewable energy resources, mainly focuses on solar energy, including:** **1. Introduction of renewable energy resources** **2. Basic knowledge on solar energy** **3. Solar collector** **4. Solar thermal utilization** **5. Concentrating solar power** **6. Solar PV** **7. Solar PV/T** **Also, some energy resources originated from solar energy, as wind and biomass, will be introduced in the course.**	

Course Number: 80140292	**Course Title: Energy strategy for sustainable development**
Lecture hours（授课学时）:32	**Credits:2**
Term Offered: Spring	**Instructor(s): Dr. Ma Linwei**

Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering

Course Description:

This course aims to teach basic knowledge on regional energy system (from primary energy to demand driver), various energy production and utilization technologies, and method of energy strategic planning and management. The contents mainly include:

1) Basic concepts: what is energy? what is energy system? what are the components of energy system and how do they interact with each other? what is sustainable development? what is energy strategy for sustainable development?
2) Status quo of global and Chinese energy system: total production and consumption, primary energy mix, energy efficiency, GHG emissions, regional patterns, challenges for sustainable development etc.
3) The main components of regional energy system, including:
    a) Primary energy production and conversion: fossil fuels (oil, gas, coal), nuclear, and renewable energy
    b) Energy end-use: transportation, buildings and industries
4) Methods of energy strategic planning and management, and national energy strategy for sustainable development, including energy strategies and energy policies of China and other main countries
5) Methods of energy system analysis: system engineering, energy balance and Sankey diagram, energy-economic analysis, LCA analysis, stakeholder analysis, energy system models etc.
6) On-course practices of making energy strategy for sustainable development of China

Course Number: 80140313	**Course Title: Electrochemical Energy Conversation and Storage**
Lecture hours（授课学时）:48	**Credits: 3**
Term Offered: Spring	**Instructor(s): Dr. SHI Yixiang**

Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering

Course Description:

This course covers a variety of topics concerning the fundamental principles and technologies in the field of electrochemical energy conversion and storage. The course focuses on basic principles, thermodynamics; reaction kinetics; transport phenomenon and the electrochemical characterization with regards to DC techniques (controlled potential, controlled current) and AC techniques (voltammetry and impedance spectroscopy). Also the course introduce the applications of theory and experimental methods in the aspects of typical electrochemical energy conversion and storage technologies, such as fuel cells, electrolysis, batteries, super capacitors. In addition, the application of the energy conversion and storage unit in a system, especially considering the distributed power generation systems by merging the renewable energy and fossil energy.

Course No.	Contents
1	**Overview & Introduction** Basic physics of electrochemical cells, Faraday's law, principles of electrochemical energy conversion and storage
2	**Electrochemical Thermodynamics (I)** a. Interface and phase potential b. Gibbs free energy c. Nernst equation and open circuit voltage
3	**Electrochemical Thermodynamics (II)** a. Concentration cells b. Introduction to statistical electrochemical thermodynamics
4	**Electrochemical Thermodynamics (III)** **Group Discussions** **Topics:** Thermodynamics in fuel cells, electrolysis cell, batteries and capacitors
5	**Electrochemical Reaction Kinetics(I)** a. Mass action kinetics b. Elementary reaction c. Homogenous reaction kinetics d. Collision theory e. Reaction kinetics formulation based on collision theory
6	**Electrochemical Reaction Kinetics(II)** a. Heterogeneous reaction kinetics b. Elementary species thermodynamic characteristics c. Sticking coefficient d. Activation energy and reaction rate
7	**Electrochemical Reaction Kinetics(III)** a. Electrode potential b. Butler-volmer equation, Tafel equation

		c. Interface electrochemical reaction kinetics d. Quantum basis of electrode reactions	
	8	**Electrochemical Reaction Kinetics(IV)** **Group Discussions** **Topics:** Electrochemical reaction kinetics in fuel cells, electrolysis cell, batteries and capacitors. Especially considering hydrocarbon fuel electro oxidation reaction mechanisms	
	9	**Transport phenomenon(I): Charge Transfer** a. Homogenous charge transfer b. Heterogeneous charge transfer c. Electronic and ionic conductors d. Solid electrolyte e. Mathematical formulation	
	10	**Transport phenomenon(II): Momentum and Mass Transport** a. Effects of momentum transport b. Convection: forced and natural c. Diffusion within electrode d. Homogenous reaction-diffusion coupling e. Mathematical formulation, optimization strategy	
	11	**Transport phenomenon(III): Heat Transfer** a. Thermal sink and source in electrochemical system b. Thermal management in fuel cells c. Thermal management in batteries	
	12	**Transport phenomenon (IV)** **Group Discussions** **Topics:** Design and optimization strategies of transport processes	
	13	**Electrochemical measurement** a. Steady state measurement: DC polarization curve b. Cyclic voltammetry c. Electrochemical impedance d. In-situ measurement: Raman, FTIR spectra	
	14	**Electrochemical energy conversion and storage system** a. Fuel cell system b. Battery and supercapcitor system for energy storage c. Power to gas or liquid d. Power electronics e. System analysis and design	
	15-16	**Project presentations** Proposed topic: novel electrochemical conversion and storage technologies Report contents: Background, literature review, principles, process scheme description, evaluations and comments on proposed technology routes (encourage personal views) Assessment indicator：innovativeness, practicability and understanding of the fundamentals in electrochemical conversion and storage processes	

Course Number: 80140333	**Course Title:** **Combustion Chemistry**
Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering	**Term Offered:** Fall
Instructor(s): Prof. You, Xiaoqing	
Lecture hours（授课学时）: 48	**Credits: 3**

Course Description:

This course is to provide students with the understanding of the fundamental and application of combustion chemistry with topics ranging from a review of thermodynamics, thermochemical properties, basic quantum and statistical mechanics, reaction mechanisms and modeling, transition state theory, combustion kinetic model development and validation, fundamental combustion experiments, to surrogate fuels and kinetic mechanism for practical fuels. The Course focuses on the development, validation and analysis of the combustion kinetic models, which will help students advance the understanding of combustion at molecular level and learn the frontier of the combustion kinetic research.

1. Introduction (2)
2. Basic concepts in quantum chemistry and statistical mechanics (6)
   2.1 Valence bond theory and molecular orbital theory
   2.2 Chemical bonds in organic molecules
   2.3 Group additivity and bond energy
   2.4 Statistical mechanics description of thermochemical properties
3. Chemical kinetics and reaction rate rules (8)
   3.1 Chemical reaction rate (reaction type, the law of mass action, chain reaction, the Arrhenius law)
   3.2 Chemical reaction mechanism (explosion limit of hydrogen, NTC behavior)
   3.3 Collision theory
   3.4 Transition state theory
   3.5 Unimolecular reaction and RRKM theory
4. Combustion kinetic model development (8)
   4.1 Reaction network (low temperature, high temperature)
   4.2 Reaction rate determination
   4.3 Thermal database and transport database
   Mid-term exam
5. Combustion kinetic model validation – homogeneous systems (6)
   5.1 Jet-stirred reactor
   5.2 Flow reactor
   5.3 Shock tube/ Rapid compression machine
6. Combustion kinetic model validation – non-homogeneous systems (8)
   5.4 Premixed flame
   5.5 Coflow / counterflow nonpremixed flame
   5.6 Combustion bomb
   5.7 Experiments for elementary chemical steps
7. Combustion kinetic mechanisms for practical fuels (10)
   7.1 Surrogate fuels
   7.2 C0-C4 core mechanism
   7.3 Kinetic mechanism for surrogate fuels
   7.4 Kinetic mechanism for biofuels
   7.5 Kinetic model for pollutant formation

Course Number: 80140342	**Course Title:** Combustion Physics I
Program:	**Term Offered:** Spring
Instructor(s): Prof. Chung K. Law	
Lecture hours（授课学时）: 32	**Credits:** 2

Course Description:

Combustion Physics I is about the fundamentals of combustion science, including the introduction/review of chemical thermodynamics, kinetics and transport phenomena; derivations of conservation equations of combustion system, theory of non-premixed and premixed flames, as well as the flame structure analysis.

1. Introduction
    1.1 Combustion phenomena and fundamentals
    1.2 Scientific disciplines comprising combustion
    1.3 Course schedule
2. Review of chemical thermodynamics and kinetics
    2.1 Thermodynamics: chemical equilibrium, thermodynamics laws, adiabatic flame temperature
    2.2 Kinetics: Arrhenius law, reaction rate theory, chain reaction
3. Transport phenomena
    3.1 Diffusion coefficient: from phenomenology to kinetics
    3.2 Schmidt / Prandtl / Lewis numbers
4. Conservation equations
    4.1 Derivation of conservation equations
    4.2 Coupling function
    4.3 Reaction sheet assumption
    4.4 Revisit adiabatic flame temperature
5. Nonpremixed flames
    5.1 Chambered flame
    5.2 Burke-Schumann flame
    5.3 Vaporization
    5.4 Droplet burning
6. Premixed flames
    6.1 Rankine-Hugoniot relation, deflagration and detonation
    6.2 Flame structure
    6.3 Asymptotic analysis and flame speed
7. Asymptotic structure of flames
    7.1 Structure of premixed flames
    7.2 Structure of nonpremixed flames
    7.3 A unified structure of flames

Course Number: 80140352	**Course Title:** Combustion Physics II
Program:	**Term Offered:** Fall
Instructor(s): Prof. Chung K. Law	
Lecture hours（授课学时）: 32	**Credits:** 2

Course Description:

Combustion Physics II is concentrated in the theoretical modeling and analysis of different combustion phenomena: i.e., the flammability, extinction and stabilization of flames; aerodynamics of flames involving stretch and stabilities; and flames in different fluid environments including turbulent flows, boundary layer flows, two-phase flows and supersonic flows.

1. Introduction
    - 1.1 Introduction of different combustion phenomena
    - 2.2 Review of Combustion Physics I
    - 2.3 Course schedule
2. Limit phenomena
    - 2.1 Flammability and explosion limit
    - 2.2 Extinction
    - 2.3 Flame stabilization
3. Aerodynamics of laminar flames
    - 3.1 Flame stretch: stretch rate, phenomenology and analyses
    - 3.2 Flame instability: cellular instability and pulsating instability
4. Combustion in turbulent flows
    - 4.1 Introduction of turbulence
    - 4.2 Diagram of turbulent flame
    - 4.3 Turbulent flame speed
    - 4.4 Simulation of turbulent flame
5. Combustion in boundary layer flows
    - 5.1 Assumptions and governing equations
    - 5.2 Blasius flow
    - 5.3 Ignition and stabilization
    - 5.4 Jet flow: height, stabilization and blow off
6. Combustion in two-phase flows
    - 6.1 Droplet combustion
    - 6.2 Fuel vapor accumulation
    - 6.3 Droplet collision
    - 6.4 Spray combustion
    - 6.5 Solid particle combustion and material synthesis
7. Combustion in supersonic flows
    - 7.1 Supersonic flows and sound wave
    - 7.2 Rankine-Hugoniot relation and Chapman Jouguet detonation
    - 7.3 ZND structure of detonation waves
    - 7.4 Detonation instability and initiation

Course Number: 80140363	**Course Title:** **Physics of Gases and Non-equilibrium Phenonena**
Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering	**Term Offered:** Fall
Instructor(s): Prof. Xu, Haitao	
Lecture hours（授课学时）: 48	**Credits: 3**

Course Description:

This course covers the physical foundation and mathematical treatment that lead to continuum descriptions of flows of microscopically discrete particles, including both molecules and inelastic hard spheres. Materials taught include introductory kinetic theory, molecular velocity distribution at equilibrium (Maxwellian distribution), molecular collisions and the mean free path, molecular transport, non-equilibrium kinetic theory, the Boltzmann equation, binary collisions and collision integrals, the Chapman-Enskog solution of the Boltzmann equation, successive approximations, Euler Equation, Navier-Stokes equation, transport coefficients.

Chapter 1: Introduction of the course
- 1.1 Objectives, contents, evaluation, etc.
- 1.2 Review of mathematical tools

Chapter 2: Introductory kinetic theory
- 2.1 Distribution of molecular velocity function
  molecular model, velocities, the distribution of molecular velocities, mean values
- 2.2 Flow of molecular properties
- 2.3 Pressure, temperature and internal energy

Chapter 3: Boltzmann equation
- 3.1 Derivation of Boltzmann equation
- 3.2 Molecular encounters and dynamics of binary collision
- 3.3 Equilibrium solution of Boltzmann equation and Maxwellian velocity distribution

Chapter 4: Introduction of molecular transport
- 4.1 Mean free path, collision frequency and persistence of velocity
- 4.3 Elementary theories of the transport phenomena

Chapter 5: The non-uniform state of a simple gas
- 5.1 General method of solution of Boltzmann equation
- 5.2 The first approximation, Euler equation
- 5.3 The second approximation, Navier-Stokes equation

Chapter 6: Transport phenomena
- 6.1 Transport coefficients: shear and bulk viscosity
- 6.2 Transport coefficient: thermal conductivity
- 6.3 Transport coefficients: comparison of theory with experiment

Chapter 7: Gas mixture (6)
- 7.1 Gas mixture at equilibrium (1)
- 7.2 The non-uniform state of a gas mixture (2)
- 7.3 Transport coefficients of a gas mixture (3)

Course Number: 80140373	Course Title: Experimental Techniques for Physics of Fluids
Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering	**Term Offered:** Spring
Instructor(s): Prof. Sun, Chao, Prof. Xu, Haitao	
Lecture hours（授课学时）: 48	**Credits: 3**

Course Description:

Advanced experimental techniques for flow measurements are introduced based on the "measurement quantities and measurement processes" in physics of fluids. These techniques to be discussed in the course include digital image analysis, high-speed imaging, particle image velocimetry, Laser-Doppler anemometry, hot-wire anemometry, particle tracking and micro/nano-PIV. In the lectures, principles and specific advantages and limitations of the techniques will be discussed. This knowledge will be taught in lectures and deepened with research articles and homework questions. Following the lectures, hands-on experiments will be organized. In groups of two students, a specific measurement problem will be solved with one of the techniques presented in the course. The participants design the experiment, write a concise report and prepare a presentation on their work. Grades will be given on the written report (30%), the presentation (40%) and the handed in homework (30%).

The general outline of the course is as follows:

1. Introduction of the course
   - 1.1. Objectives
   - 1.2. Content
   - 1.3. Examples
   - 1.4. Grades
2. Digital imaging analysis and high-speed imaging
   - 2.1. Capillarity phenomena
   - 2.2. Digital imaging analysis
   - 2.3. High-speed imaging
3. Measurements of complex flows
   - 3.1. Thermal Anemometry
   - 3.2. Laser Doppler Velocimetry
   - 3.3. Particle Image Velocimetry
4. Journal club I
   - 4.1. Presentations from students on research articles
5. High-speed Particle Tracking Velocimetry
   - 5.1. Motion of particles, droplets and bubbles in complex flows
   - 5.2. Distribution of particles, droplets and bubbles in flows
   - 5.3. Velocity and acceleration measurements

6. Measurements of Microfluidics
    6.1. Special aspects of microfluidics
    6.2. Measurement techniques (microPIV and others)
7. Measurements of convective heat transfer
    7.1. Global heat transfer
    7.2. Local heat transfer
8. Journal club II and project design
    8.1. Project design
9. Project
    9.1. Experiment and data analysis: experiment 1, experiment 2
    9.2. Presentation
    9.3. Report

Course Number: 80140383	**Course Title:** **Combustion Diagnostics**
Program: Tsinghua-RWTH Aachen Double Master's Degrees Program on Thermal Engineering	**Term Offered:** Spring
Instructor(s): Prof. Chao, Xing	
Lecture hours（授课学时）: 48	**Credits: 3**

Course Description:

The main content of the course is based upon different types of interactions between radiation (light) with matter (gas molecules, atoms, or particles), which includes fundamental theories of molecular spectroscopy, theory and methods for laser-based combustion diagnostics, and molecular beam mass spectroscopy. Different light-matter interaction usually includes energy transfer and transitions between the quantum energy levels. Considering the knowledge background of the potential audience, who will mostly be graduate students from thermal engineering, the course with first establish concepts for quantized energy based on a brief review of quantum mechanics, and introduce the distribution and transition mechanisms between the different energy levels for different types of molecules. This will lead to the characteristics and main components of the molecular spectra, and furthermore the relationship between the gas condition and the resulted spectra, which will be used to interpret information in the data analysis of the measurement. Based on the need for experimental realization, the course will also introduce fundamentals of common opto-electrical devices, such as lasers and optical detector, and study the theory and application of combustion diagnostic methods through hands-on lab experiments. The general outline of the course is as following:

1. Introduction
    - 1.1 Overview for combustion diagnostics
    - 1.2 Different class of methods (optical and probing methods)
2. Molecular spectra and energy levels
    - 2.1 Rotational spectra
    - 2.2 Ro-vibrational spectra
    - 2.3 Electronic spectra
3. Absorption/Emission spectroscopy
    - 3.1 Quantitative absorption and emission
    - 3.2 Lineshapes
    - 3.3 Quantitative measurements of absorption spectra
4. Laser induced fluorescence
    - 4.1 Two-level model
    - 4.2 Modifications of the two-level model
    - 4.3 Extension to two dimensions (PLIF)
    - 4.4 LIF applications
5. Rayleigh and Raman spectroscopy
    - 5.1 Light scattering
    - 5.2 Rotational and vibrational Raman spectra
    - 5.3 Introduction to experimental systems and application examples
6. Spectroscopy equipment and other laser-based diagnostic methods

- 6.1 Optical sources and detectors
- 6.2 Cavity enhanced methods
- 6.3 Coherent anti-stokes Raman spectroscopy
- 6.4 Miscellaneous laser diagnostic techniques and development trends

7. Molecular beam mass spectrometry
- 7.1 Single photon ionization mass spectrometry
- 7.2 Resonance-enhanced multiphoton ionization
- 7.3 Photoelectron spectroscopy and Photoelectron / photoion coincidence spectroscopy
- 7.4 Aerosol mass spectrometry

8. Gas chromatography and gas chromatography / mass spectrometry
- 8.1 Gas chromatography / mass spectrometry
- 8.2 2-Dimentional-gas chromatography
- 8.3 Molecular beam combined with gas chromatography

Experiments:
1. Flame species measurement with MBMS
2. Species measurement during the pyrolysis process with GC/MS decomposition process
3. Absorption measurements for ambient O_2 and temperature