ME 606| Combustion

Course Plan

Instructor: Dr. Dilip Srinivas Sundaram

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Instructor's office: 6/356

Lecture room: 7/105

Lecture hours: F slot (Monday and Thursday, 11:30-12:50)

Teaching assistant: Prasanna Kulkarni

General description

This is a foundational course on combustion, which is an important process that finds applications in numerous propulsion and energy-conversion devices such as rockets, gas turbine engines, automobile engines, power plants, missiles, explosives, and industrial processing. The course is open to undergraduate and postgraduate students of all disciplines and it caters to the minor in automobile engineering. The focus will be on fundamental concepts related to combustion, including thermodynamics of chemically reacting systems, chemical kinetics and oxidation mechanisms of common fuels and propellants, governing equations for chemically reacting systems, simplified reactor/combustion models, combustion in premixed and non-premixed systems, liquid droplet and solid particle combustion. Combustion involves an array of physicochemical processes and the course will therefore integrate concepts of heat transfer, fluid mechanics, thermodynamics, and chemistry for engineering applications.

Course contents

I. Introduction

Definition, history, and applications of combustion

II. Chemical thermodynamics

Property relations, ideal gas, conservation of mass, first law of thermodynamics, stoichiometry, standard enthalpy of formation, absolute enthalpy, enthalpy of combustion, adiabatic flame temperatures, second law of thermodynamics, Gibbs free energies, equilibrium constant, chemical equilibrium analysis.

III. Chemical kinetics

Elementary and global reactions, order and molecularity, elementary reaction rate, collision theory and bimolecular collision rates, equation of Arrhenius, rates of reaction and their measurements, transition state and recombination rate theories, chain reactions, Lindemann's theory for first order reaction, Chain branching explosions, surface reactions, steady state approximation, partial equilibrium approximation, sensitivity analysis.

IV. Oxidation mechanisms of fuels

Hydrogen-oxygen system, carbon monoxide oxidation, oxidation of aliphatic hydrocarbons, methane combustion, mechanism reduction, mechanisms of NO formation, formation and control of CO, soot, and particulates

V. Conservation equations for multicomponent reacting systems

Fick's law of diffusion, continuity equation, species mass conservation equation, Navier-Stokes equations, energy equation, multicomponent diffusion, Shvab-Zeldovich formulation, concept of a conserved scalar

VI. Reactor models

Basic chemical reactors, constant pressure and constant volume reactors, well-stirred reactor, plug-flow reactor

VII. Detonation and deflagration waves of premixed gases

Detonation vs deflagration, Hugoniot curve, Chapman-Jouguet detonation wave velocity, Detonation wave structure, Deflagration-to-Detonation Transition (DDT), Detonation limits

VIII. Premixed laminar flames

Flame speed, flame speed measurement methods, Classical flame theories: Mallard and LeChatelier's theory and Theory of Zeldovich, Frank-Kamenetsky and Semenov, Contemporary solution methods, flame quenching, flame stabilization, flammability limits, and ignition.

IX. Non-premixed flames

Non reacting laminar jet, Jet flames, Burke and Schumann's theory, phenomenological analysis, laminar diffusion flame jets, flame lengths, Counterflow flames, evaporation and burning of single fuel droplet, combustion of solids.

Learning objectives

Upon completion of this course, students should be able to:

1. demonstrate a strong understanding of all fundamental concepts related to combustion
2. demonstrate familiarity and good understanding of oxidation mechanisms of common fuels
3. conduct chemical equilibrium analysis for a variety of reacting systems
4. use basic reactor models to investigate ignition and combustion characteristics of fuels and propellants
5. demonstrate a strong understanding of concepts related to ignition and combustion behaviors of solid, liquid, and gaseous combustion systems
6. apply governing equations of chemically reacting flows to conduct a computational study on the ignition and combustion behaviors of fuels and propellants.
7. use well known computer programs to solve chemical equilibrium, chemical kinetics, and combustion problems

Texts and references

Text

Kenneth K. Kuo, *Principles of Combustion*, Second Edition, Wiley, 2005.
Stephen R. Turns, *An Introduction to Combustion: Concepts and Applications*, Third edition, McGraw-Hill (Indian Edition), 2012

References

Irvin Glassman, Richard A. Yetter, and Nick Glumac, *Combustion*, Fifth edition, Academic Press, 2014.
Chung K. Law, *Combustion Physics*, First edition, Cambridge University Press, 2010.

Grading

Assignments - 30 %
Projects - 30 %
Assessment I – 20 %
Assessment II – 20 %

Assignment policy

Students can work together to solve assignment problems. However, each student must submit own independent write up. Assignments have to be submitted by the due date and time to avoid any late submission penalty. The late submission penalty is as follows:
a. For submissions past the due time on the due date, a penalty of 10 % will be applied.
b. For submission after midnight of the due date, a penalty of 25 % will be applied.
c. For submissions past 24 hours after the midnight of the due date, a penalty of 50 % will be applied and so forth.

Assignment format

Assignments are important means of learning during coursework. A clear organized solution of a problem is more important than the final numerical answer.
1. Begin each problem on a new page.
2. Clearly state the problem, listing the knowns and unknowns.
3. Use schematics and drawings wherever necessary.
4. List all assumptions and approximations.
5. Approach the problem from fundamentals and solve it in a systematic manner.
5. Pay more attention to the procedure than the final answer.
6. Write what you learnt from the problem.

Honor code

Students are expected to adhere to the IIT Gandhinagar honor code.