Aero-thermochemical Systems

Academic Year: (2019 / 2020) **Review date: 06-05-2020**

Department assigned to the subject: Thermal and Fluids Engineering Department

Coordinating teacher: VERA COELLO, MARCOS

Type: Compulsory ECTS Credits : 6.0

Year : 3 Semester : 2

REQUIREMENTS (SUBJECTS THAT ARE ASSUMED TO BE KNOWN)

Calculus I, II
Physics I, II
Chemical Fundaments of Engineering
Writing and Communication Skills
Programming
Thermal Engineering
Engineering Fluid Mechanics

OBJECTIVES

The objective of this course is to provide the student a basic understanding of the science and technology of aerothermochemical systems.

Knowledge mastered in this course:
- Conservation equations for chemically reactive systems.
- Thermochemistry.
- Combustion kinetics.
- Knowledge of the main features of homogeneous reactive systems (critical extinction/ignition conditions, thermal and chain branching explosions, etc.).
- Fenomenologycal knowledge of flames.
- Mass energy balance on boilers and HRSG and performance analysis.
- Fossil Fuel-Fired Power Generation.
- Operational consideration on boilers and HRSG design, effects of Boilers and HRSG on plant efficiency.
- Determine the adequate methodology to obtain the required variables in an engineering problem (calculus, experiments, etc.).
- Present results in a rational manner, in terms of the relevant parameters.
- Comprehension of basic terminology to understand technical documentation and specific literature.

Specific capacities:
- Characterization of the composition of a mixture of ideal gases in terms of i) species mass fractions, ii) mole fractions and iii) molar concentrations.
- Determination of the composition of a chemically reacting ideal gas mixture in terms of the equivalence ratio.
- Determination of the adiabatic flame temperature of a chemically reactive mixture using atom-conservation equations and chemical equilibrium conditions for the product gases.
- Determination of reduced reaction mechanisms by sistematic application of the steady state approximation to full detailed mechanism.
- Determination of the critical ignition and extinction conditions for steady combustion in a well-stirred adiabatic reactor.
- Solution of convection problems involving solid-liquid and solid-vapor systems where takes place a change in phase of a fluid.
- Solution of radiation heat transfer problems in the presence of participating media.
- Thermal design of Coal Fired boilers.
- Thermal design of HRSG.

General capabilities:
- Analysis based on scientific principles.
- Multidisciplinar approach (use knowledge from several disciplines: Thermodynamics,

Engineering Fluid Mechanics, Thermal Engineering, etc.)
- Capacity to locate and understand basic literature on the subject.

Attitudes:
- Analytical attitude.
- Critical attitude.
- Cooperative attitude.

DESCRIPTION OF CONTENTS: PROGRAMME

1. The science of aerothermochemistry.

- Historical perspective.
- Combustion as a science.
- Current developments.

2. Multicomponent mixtures.

- Composition.
  * Mass fractions.
  * Molar fractions.
  * Concentrations.
- Equations of state for ideal gas mixtures.
  * The thermal equation of state.
  * The caloric equation of state.

3. Thermochemistry.

- Stoichiometric mixture.
- The equivalence ratio.
  * Product composition for complete combustion.
    + Lean combustion.
    + Rich combustion.
- Adiabatic flame temperature.
  * Definition.
  * Heat of combustion.
- Sample calculations.
  * Lean hydrogen-air combustion.
  * Lean methane-air combustion.
- Complete vs. incomplete combustion.
  * Major vs. minor species.
- Chemical equilibrium in reactive systems.
  * The equilibrium constant.
  * Dissociation of major species.
  * Effect of temperature and pressure.
- Sample calculations.
  * Dissociation of air.
  * Adiabatic flame temperature and product composition of stoichiometric/rich H_2 and HC-air mixtures.

4. Combustion kinetics.

- Chemical kinetics.
  * Types of elementary reactions.
  * Detailed and short mechanisms.
  * One-step irreversible models.
  * The limit of large activation energy.
- The steady-state approximation.
- Examples:
  * Hydrogen combustion.
  * Hydrocarbon combustion.
  * Zel'dovich analysis of NO production.

5. Combustion in homogeneous systems

- Conservation equations for chemically reacting systems

* Mass.
  * Momentum.
  * Species.
  * Energy
  * The heat release rate.
- Steady combustion in a well-stirred adiabatic reactor.
  * The Damköhler number.
  * Ignition and extinction: The S-shaped curve.
- Reactor design.

6. Flames.

- Premixed vs. Non-premixed flames.
- Examples:
  * Jet diffusion flames.
  * Flame/vortex interactions.

7. Power systems and steam generators.

- Transition from science to combustion technology.
- Fossil Fuel-Fired Power Generation (hereogeneous combustion of coal).
- Traditional and advanced burning technologies (IGCC, Chemical looping, Fuel cells, energy penalties of CO_2 capture).
- Fundamentals on new process for power production.
- Environmental aspects.
  * CO_2 capture.
- Steam Generator as a way to reduce CO_2 emissions.

8. Boilers and heat recovery steam generators (HRSG).

- Principles of boiler operation.
- Classification of boilers.
  * Water tube-boilers.
  * Fire/smoke tube boilers.
- Boiler Specifications.
- Fundamentals of boiler heat transfer design.
- Fuel type.
- Boiler slagging and fouling.
- Fuel ash corrosion.
- Definitions used in boiler efficiency calculations.
- Heat absorption and efficiency calculations (Heat fired, steam generator efficiency direct and indirect method) (off-design example)
- Pseudoadiabatic flame temperature.
- Combine cycle and cogeneration application of HRSG and waste heat boilers.
- Gas turbine HRSGs.
- Flue gas composition, gas pressure, fired and unfired modes.
- Design temperature profile calculations.
- Emission Control in HRSGs.
- Improving the HRSG efficiency.

9. Heat transfer in boilers and HRSGs

- Liquid side:
  * Phase equilibrium and dimensional parameters in boiling and condensation.
  * Boiling heat transfer.
  * Boiling modes (The boiling curve).
  * Pool boiling.
  * Forced convection boiling (external, internal).
  * Special topic on Heat transfer in Fossil Fuel-Fired Power Generation: HEAT TRANSFER IN CONDENSERS: CLOSED FEEDWATER HEATERS, cFWH¿s.
- Gas side:
  * Fundamentals.
    + Gas side heat transfer in boilers and HRSGs.
    + Gas radiation (nonluminous).
    + Absorption coefficient and optical thickness.
    + Absorptivity and emissivity.
    + Radiative exchange in a gas filled enclosure.

+ Particle matter radiation (luminous).
* Heat radiation in furnaces, boilers and HRSGs.
  + Heat Radiation models in Furnaces.
    The speckled enclosure.
  + Convective heating surfaces in boilers and HRSGs.
    Finned and bare tubes.
    Convection radiation problems in convective surfaces.

10. Thermal design of boilers and HRSG.

- Coal-fired boilers design.
  * Principles of Boiler Operation.
  * Major steam-water boiler components.
  * Steam Drum and steam water system.
  * Furnace thermal design.
  * The well-stirred combustion chamber model.
- HRSG boilers design.
  * Water tube HRSG boiler design consideration.
  * HRSG design issues.
  * Thermal design aspects of unfired HRSG.
  * Sizing of HRSG¿s.
  * Case study.

LEARNING ACTIVITIES AND METHODOLOGY

Teaching methodology will incluye:

1. Lectures: The students will be provided with lecture notes and recommended bibliography.
2. Problem solving sessions related with the course topics.
3. Homework problems aiming at student self-evaluation.
4. Development and interactive presentation of guided works, including three lab sessions as direct application of theory.

Additionally, collective tutorship could be included in the programme.

ASSESSMENT SYSTEM

ORDINARY CALL:

- Continuous evaluation (60% of the total grade)

Contents:
  - Practical problems covering the topics of the program
  - Short theoretical questions
  - Test quizzes
  - Laboratory reports (attendance to laboratory sessions is compulsory)

- Final exam (40% of the total grade)

Contents:
  - Practical problems covering the topics of the program
  - Short theoretical questions
  - Test quizzes

A minimum mark of 4 in the final exam will be required to pass the subject

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EXTRAORDINARY CALL: 2 options

- Final exam (100 % of the total grade)

or (similar to the ordinary call)

- Continuous evaluation (60% of the total grade) + Final exam (40% of the total grade)

% end-of-term-examination:	60
% of continuous assessment (assigments, laboratory, practicals…):	40

BASIC BIBLIOGRAPHY

- C. K. Law Combustion Physics, Cambridge Univ. Press, 2006
- F. P. Incropera Introduction to heat transfer, John Wiley & Sons, 2006
- G. F. Hewitt Process heat transfer, CRC Press, 1994
- I. Glassman Combustion, Academic Press, 1985
- K. K. Kuo Principles of Combustion, John Wiley & Sons, 1986
- K. Rayaprolu Boilers for power and process, CRC, 2009
- R. A. Strehlow Combustion Fundamentals, McGraw-Hill, 1985
- S. R. Turns An Introduction to Combustion, Mc. Graw Hill, 1996
- V. Ganapathy Industrial boilers and heat recovery steam generators: design, applications, and calculations, CRC Press, 2002

ADDITIONAL BIBLIOGRAPHY

- F. A. Williams Combustion Theory (2nd ed), Benjamin/Cummings, 1985
- J. D. Buckmaster & G. S. S. Ludford Theory of Laminar Flames, Cambridge Univ. Press, 1982
- R. C. Flagan & J. H. Seinfeld Fundamentals of Air Pollution Engineering, Prentice-Hall, 1988
- Y.B. Zeldovich, G.I. Barenblatt, V.B. Librovich & G.M. Makhviladze The Mathematical Theory of Combustion and Explosions, Consultants Bureau, 1985

BASIC ELECTRONIC RESOURCES

- Biblioteca E.T.S.I.Aeronáuticos (UPM) . Aerothermochemistry, 50 años de su publicación, Gregoria Millán y el grupo de combustión: http://aerobib.aero.upm.es/millan/Index.htm
- Chris Morley . GasEq: http://www.gaseq.co.uk/
- N. Peters . Fifteen Lectures on Laminar and Turbulent Combustion: http://decane.itv.rwth-aachen.de/fileadmin/LehreSeminar/Combustion/SummerSchool.pdf
- NASA . ThermoBuild: http://www.grc.nasa.gov/WWW/CEAWeb/ceaThermoBuild.htm