A Simplified Model for Pollutant Emission Prediction from a Gas Turbine Combustor

Mohamed Sassi, Yasser El-Wahdi, and Abdullah Ramsey

The Petroleum Institute, PO Box 2533, AbuDhabi, UAE

msassi@pi.ac.ae

1. Introduction

Combustion is a very complex phenomenon that includes the interactions between fluid mechanics, heat transfer, mass transfer, and chemical kinetics. In turbulent combustion, the turbulence-chemistry interactions make things even more complicated in terms of turbulence and combustion closure models. One is then forced to simplify the chemical kinetics model to be able to account for better turbulent flow transport [1], or to simplify the fluid mechanics by using ideal flow chemical reactors that account for detailed chemical kinetics [2]. Both of these last two approaches rely on complicated computational models that require high cpu times. This inhibits their use in process simulator software for quick chemical process case studies.

The objective of this work is thus to develop a quick design tool for gas-turbine combustors that accounts for the effects of reactant stream splitting, recirculation ratio, and combustion staging, among other operating conditions on the turbine efficiency and pollutant emissions. We have therefore used the process simulator HYSYS [Version 3.2] to generate a simplified process flow sheet model for the gas-turbine. A network of ideal flow chemical reactors in series and/or in parallel is used to simulate the combustor. This model is often complemented by CFD modeling to determine the stream flow rates into the different reactors of the network. The developed design tool is very efficient and features results that are in relatively good agreement with much more sophisticated models.

2. Key Features

The conceptual model for the gas-turbine combustor has to account for the primary combustion zone, the secondary zone, and the air dilution region, see Fig. 1. These are modeled by two well-stirred reactors in series, followed by a plug flow reactor; respectively. A schematic of the used model is shown in Fig. 2. Provision is made for variable recirculation ratios of combustion products in the first reactor to account for the high swirl recirculation zone characteristic of gas-turbine combustion. In addition staged combustion is modeled by splitting the air and/or the fuel streams between the primary and the secondary combustion zones, with judicious selection of the proportioning of the various flow rates into each reactor. These last are generally obtained from non-reacting flow simulations on CFD codes, which are much simpler to run that reacting flow models.

Detailed chemical kinetics for hydrocarbon-air combustion include hundreds of reactions between over fifty different specie. However, quasi-global mechanisms based on few multi-step reactions have proven to be sufficient for most of engineering problem approximations. In this work, a four-step chemical reaction scheme for propane oxidation is used, along with the extended Zeldovich mechanism for the nitric oxide NO-formation. The N2, O2, O, and OH are assumed at their equilibrium values, while the N atoms

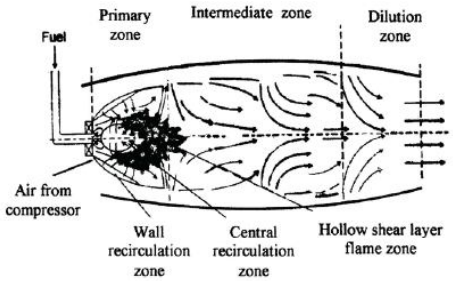


Fig. 1. Typical design of a conventional gas-turbine combustor.

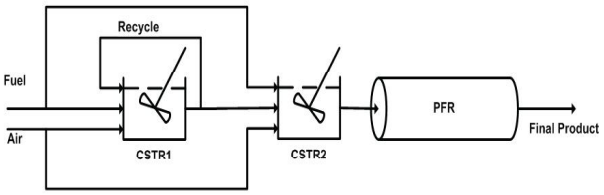
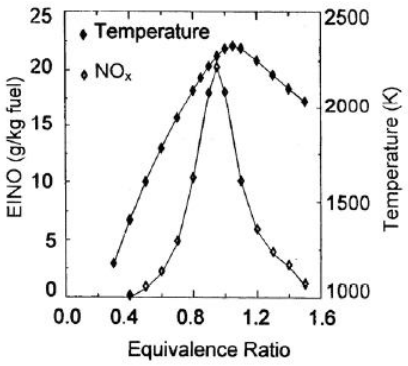
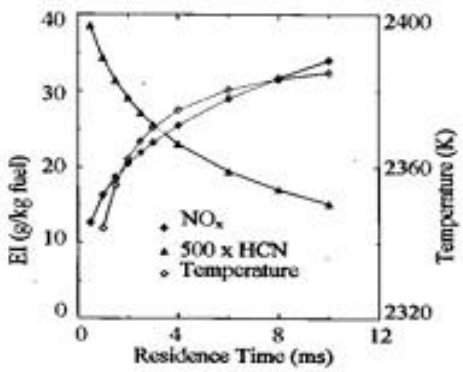


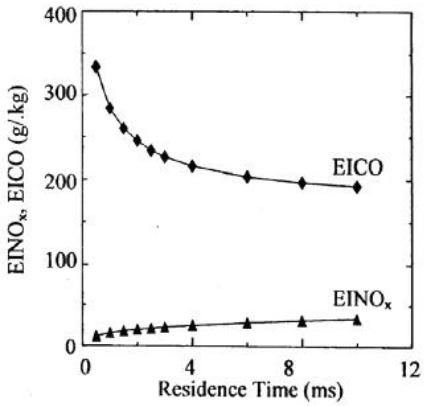
Fig. 2. The used reactor network with the different chemical stream distribution.



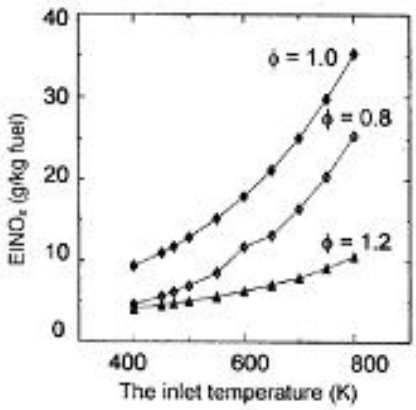
a) The total emission of NO_x in the combustor as a function of the equivalence ratio.



b) Profiles of NO_x, HCN, and temperature as a function of the residence time at an equivalence ratio of 1.



c) Opposite effects of the residence time on the NO_x and CO formation in the primary zone.



d) Variation of NO_x as a function of the inlet temperature in the primary zone for different equivalence ratios.

Fig. 3. Illustration of sample model results obtained.

are assumed in steady state [3]. These assumptions are justified by the long chemical kinetics times of the Zeldovich mechanism compared to the fast combustion chemistry characteristic times. The effects of the recycle ratio, air temperature, reactor residence time; among other operating conditions; on pollutant emissions from the gas-turbine combustor are studied and presented in the following. Model results are illustrated in Fig. 3.

3. Conclusions

A simplified model for gas-turbine pollutant emission predictions has been developed for use within chemical process simulator. The model is a quick design tool for case study generation. The model predictions are in relatively good agreement with more sophisticated combustion models.

4. References and Bibliography

1. Hidouri, A., Gazzah, M.H., Ben Ticha, H., and Sassi, M., 2003, "Interaction Entre Combustion et Turbulence dans un Jet Axisymétrique," les Annales Maghrébines de l' Ingénieur, vol. 16, no. 2.
2. Hamdi, M., Ben Ticha, H., and Sassi, M., 2004, "Simulation of Pollutants Emissions From a Gas Turbine Combustor," Combustion Science and Technology, vol. 176, pp. 1-16.
3. Turns, S. R., 2000, "An Introduction to Combustion, Concepts and Applications," McGraw Hill, 2nd Edition.

Author Biographies

Dr. Mohamed Sassi is a joint Faculty member between the Chemical and Mechanical Engineering Programs at the Petroleum Institute (PI), Abu Dhabi, UAE.

Dr. Sassi's co-authors are Graduating Senior Students in Chemical Engineering at the PI.