Estimation of Realistic Radiation Losses/Emissions in Combustion Systems

A THESIS

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SHREESH S PARVATIKAR

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DECLARATION

This is to certify that the Thesis entitled **"Estimation of Realistic Radiation Losses/Emissions in Combustion Systems"** submitted by me to the Indian Institute of Technology Mandi for the award of the Degree of Master of Science (by research) is a bonafide record of research work carried out by me under the supervision of Dr. Pradeep Kumar. The content of this Thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any Degree or Diploma.

Shreesh S Parvatikar

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Place: IIT Mandi

Date: 1^{st} November 2021

THESIS CERTIFICATE

This is to certify that the thesis titled **Estimation of Realistic Radiation Losses/Emissions in the Combustion Systems**, submitted by **Shreesh S Parvatikar**, to the Indian Institute of Technology, Mandi, for the award of the degree of **Masters of Science (by Research)**, is a bonafide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

Even today, 80% of the world's energy needs are dependent on fossil fuel which invariably has an impact on the environment. Hydrogen in the hydrocarbon combustion increases NOx and soot formation Pashchenko [2017], nevertheless, it also provides higher temperature in the combustion phenomenon. Furthermore, hydrogen combustion can mitigate some of the environmental problems and also have the potential to fulfill major energy needs. The radiative heat transfer contributes as losses in combustion phenomenon, thus, important for accurately determining the temperature, NOx, soot, other species and efficiency of the system. The primitive approach for radiation modeling is the assumption of a gray participating medium that considers the radiation parameters independent of the spectrum, which is a highly unrealistic approach. The high fidelity hydrogen combustion model requires accurate modeling of radiation. A novel non-gray radiation model which is based on the Full Spectrum $k-$ distribution (FSK) method, named the nonGrayAbsorptionEmission model has been developed in the OpenFOAM framework - an open-source software. The new nonGrayAbsorptionEmission model assigns a set of absorption coefficients depending on the thermodynamic state of gases in the combustion system from the in-house database. This model further avails the flexibility of choosing different sets of absorption coefficients for a given thermodynamic state to trade-off between the accuracy and computational resource requirements.

Various test cases are developed to validate the different stages of development. The Planck mean model is a very simplistic approach towards modeling spectrally varying absorption coefficients. Therefore it is widely used in the combustion community. But this model is only valid for optically thin mediums. Therefore it is imperative to find the global radiation model that is a non-gray radiation model. Hence in this study, the Planck mean model is compared with the full spectrum $k-$ distribution method (FSK). The non-gray radiation models are highly computationally expensive and hence an independent study is performed to find optimum FSK points required for the study.

The numerical results of the laminar diffusion hydrogen flame suggest that the FSK model is more realistic and accurate than the Planck mean model. The non-gray FSK model reduces the peak temperature considerably and matches very well with the experimental results. Further, it estimates the radiative heat flux on the boundaries of the computational domain. In these simulations, molecular diffusivity of the mixture is obtained from Sutherland law assuming unit Schmidt number. There is little deviation in the temperature profiles due to the fact that Hydrogen being the lightest molecule, special attention is needed for the estimation of its diffusivity, and therefore, there is a need for the implementation of a multicomponent diffusion model. The study is further extended to non-premixed turbulent co-piloted methane combustion to estimate the radiation losses/emissions. The standard SANDIA D flame configuration is considered for the investigation. For these simulations, the Planck mean model is employed and is compared with the experimental results. The results reveal satisfactory agreement with experiments, however, the high fidelity radiation model, which involves the mixing model for the mixture of gases for the FSK method, is required to implement for the hydrocarbon combustion phenomenon. Nevertheless, the mixing models for the FSK method are developed and tested for the canonical cases for the purpose of proof of the concept.

From the study, results reveal that the Planck mean model reduces the peak temperature by around 180-190 K, whereas the non-gray FSK model shows the huge reduction of 270-280 K compared to the no radiation making FSK method a realistic radiation model. The study also concluded with the important results that the maximum radiative heat flux incident on the air inlet for hydrogen and methane combustion systems are 900 and 236 (W/m^2). NO_x emission is also evaluated especially for the CH_4 combustion case as 145 ppm.

TABLE OF CONTENTS