

Estimation of Realistic Radiation Losses/Emissions in Combustion Systems

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INDIAN INSTITUTE OF TECHNOLOGY MANDI**

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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.



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Place: IIT Mandi

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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 NO_x 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, NO_x, 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

ACKNOWLEDGEMENTS	i
ABSTRACT	iii
LIST OF TABLES	xi
LIST OF FIGURES	xvi
NOTATION	xvii
List of Abbreviations	xx
1 INTRODUCTION	1
1.1 Non-Gray Radiative Heat Transfer	3
1.1.1 Spectral broadening mechanism	5
1.1.1.1 Natural Broadening	5
1.1.1.2 Collisional broadening	5
1.1.1.3 Doppler Broadening	6
1.2 Radiative Heat Transfer Analysis	6
1.2.1 Line-by-line Model	7
1.2.2 Narrow-Band Model	7
1.2.3 Wide-Band Model	7
1.2.4 Global Model	8
1.3 Radiation in Combustion	8
1.4 Implementation in OpenFOAM	10
1.5 Thesis Organisation	11
2 Literature Survey	13
2.1 Radiation heat transfer	13
2.2 Hydrogen Combustion	19
2.3 Methane Combustion	21

2.4	Objective of thesis	24
2.5	Epilogue	24
3	Problem formulation and numerical procedure	25
3.1	Introduction	25
3.2	Problem definition	25
3.2.1	Laminar hydrogen combustion	25
3.2.2	Turbulent methane combustion	26
3.3	Governing equations for laminar combustion	27
3.3.1	Total mass conservation	27
3.3.2	Species mass conservation	27
3.3.3	Multi-component diffusion	28
3.3.4	Unit Schmidt number diffusion model	29
3.3.5	Momentum conservation for laminar combustion	30
3.3.6	Energy conservation for diffusion flame	30
3.3.7	Adiabatic flame temperature calculation for hydrogen combustion	31
3.3.8	Chemical mechanism in H ₂ -air combustion	31
3.3.8.1	Chemical reaction	31
3.4	Governing equations for turbulent combustion	33
3.4.1	Continuity equation	33
3.4.2	Momentum equation	33
3.4.3	Energy conservation for turbulent Combustion	34
3.4.4	Adiabatic flame temperature calculation for methane combustion	34
3.4.5	Chemical mechanism for CH ₄ -air combustion	35
3.4.6	Turbulence chemical interactions modelling	35
3.4.7	Mechanism of NO _x formation	36
3.4.7.1	Factors for NO formations	36
3.4.7.2	Thermal NO	37
3.4.7.3	Calculating NO mass fraction	38
3.5	Radiative Transfer Equation	39
3.5.1	Attenuation by absorption and scattering	39

3.5.2	Augmentation by emission and in-scattering	40
3.5.3	The radiative transfer equation	41
3.5.4	Radiative heat flux	41
3.5.5	Divergence of radiative heat flux	41
3.5.6	Boundary condition for radiative transfer equation	41
3.6	Radiation modelling	42
3.6.1	Calculations of radiation properties	42
3.6.1.1	HITEMP database	42
3.6.1.2	Line-by-line model	45
3.6.1.3	Narrow band model	45
3.6.1.4	Wide band model	46
3.6.2	Full spectrum k - distribution formulation	46
3.6.2.1	Full spectrum method for homogeneous method	47
3.6.3	Full spectrum k -distribution method for mixture of gases	49
3.6.3.1	Superposition mixing model (SMM):	49
3.6.3.2	Multiplication mixing model (MMM):	49
3.6.3.3	Hybrid mixing model (HMM):	50
3.6.3.4	Modest-Riazzi mixing model (MRMM):	50
3.6.4	Planck-mean absorption coefficient	51
3.7	Numerical method- Finite Volume Method (FVM)	52
3.7.1	Finite Volume Schemes	52
3.7.1.1	Time derivative schemes	53
3.7.1.2	Euler	55
3.7.1.3	Convective schemes	55
3.7.1.4	Upwind and linear upwind	56
3.7.1.5	QUICK	57
3.7.1.6	Laplacian schemes	57
3.7.1.7	Gradient schemes	58
3.7.2	Finite volume method RTE	59
3.8	Closure	60
4	OpenFOAM directory/file structure and implementation of non-gray radiation models	61

4.1	Introduction to OpenFOAM	61
4.1.1	OpenFOAM structure	62
4.2	FSK look-up table in OpenFOAM	63
4.2.1	non gray absorptionEmission model in OpenFOAM	63
4.3	Planck-mean absorption coefficient database in OpenFOAM	65
4.4	The radiative transfer equation in OpenFOAM	68
4.5	Implementation of nonGrayDiffusiveBoundaryCondition	69
4.6	Implementation of non-gray source term in OpenFOAM	72
4.7	Solver for turbulent compressible reacting flows	75
4.7.1	reactingFoam	76
4.8	Chemical properties	77
4.9	Closure	78
5	Verification and Validation Test Cases	79
5.1	Pure radiation	79
5.1.1	Square enclosure test case	79
5.1.2	Quadrilateral enclosure test case	80
5.1.3	2-D annulus test case	80
5.1.4	Cylindrical axisymmetric test case	81
5.1.5	Truncated cone axisymmetric test case	82
5.1.6	Rocket base plate heating	83
5.2	Non-gray implementation in OpenFOAM	83
5.2.1	Simple square cavity test case	84
5.2.2	Square cavity with wall temperature	85
5.2.3	Trifurcated cavity	85
5.3	Full spectrum k - distribution in OpenFOAM	86
5.4	Validation of reactive flow solver reactingFoam	88
5.4.1	Temperature profile	89
5.4.2	H ₂ O profile	90
5.5	Closure	91
6	Results and Discussions	93
6.1	Calculation of spectral absorption coefficient using HITEMP database	93

6.1.1	Carbon-dioxide	94
6.1.2	Water-vapour	94
6.1.3	Nitrous-oxide	96
6.1.4	Nitrogen-dioxide	96
6.2	Full spectrum k -distribution method	98
6.2.1	Solution of RTE for homogeneous and isothermal medium	98
6.2.1.1	Homogeneous isothermal medium with cold wall	100
6.2.1.2	Homogeneous isothermal medium with hot wall	101
6.2.1.3	Homogeneous isothermal medium with wall temperatures	102
6.2.2	Solution of RTE for non-homogeneous and non-isothermal medium	103
6.2.2.1	Non-homogeneous and isothermal medium	103
6.2.2.2	Homogeneous and non-isothermal medium	104
6.2.2.3	Non-homogeneous and non-isothermal medium	106
6.2.3	Solution of RTE for mixture of gases	106
6.2.3.1	Homogeneous and isothermal medium	108
6.2.3.2	Non-homogeneous and non-isothermal medium	109
6.3	Hydrogen combustion	110
6.3.1	Experimental setup	110
6.3.2	Simulation setup	110
6.3.3	Estimation of radiation loss in the hydrogen combustion using FSK look-up table	111
6.3.3.1	FSK-point sensitivity test	112
6.3.3.2	Angular discretisation independence	113
6.3.4	Species field	114
6.3.5	Temperature field	116
6.3.6	Absorption coefficient field	118
6.3.7	Radiative source/sink field	119
6.3.8	Chemical heat release rate	120
6.3.9	Radiative heat flux on the surfaces	120
6.4	Estimation of radiation loss in methane combustion system	123
6.4.1	Experimental Setup	124
6.4.2	Numerical Setup	124

6.4.3	Species profile	125
6.4.4	Temperature field	125
6.4.5	Absorption coefficient field	126
6.4.6	Radiative source/sink field	127
6.4.7	Chemical heat release rate	128
6.4.8	Distribution of radiative heat flux on surfaces	129
6.4.9	Distribution of NO _x	131
6.5	Closure	132
7	Conclusions and future scope of work	133
7.1	Full spectrum <i>k</i> – distribution method	133
7.2	Estimation of radiative losses in combustion systems	134
7.3	Scope for future work	135
A	<i>H</i>₂ reaction mechanism	136
B	<i>CH</i>₄ reaction mechanism	138