CANDIDATE'S DECLARATION

I hereby declare that the work present in this dissertation entitled "**Train Cabin Fire Simulation and Passenger Evacuation on FDS**" is being submitted in partial fulfillment of the requirement for award of degree of **Master of Technology** in Chemical Engineering with specialization in Industrial Safety & Hazard Management (ISHM), is an authentic record of my own work carried out under the supervision of **Dr.V.K.Agarwal**, **Professor and Head**, Department of Chemical Engineering, Indian institute of Technology Roorkee.

Date: 15th June, 2014 Piyush Kumar

Roorkee Enroll. No.- 12516007

CERTIFICATE

This is certifying that the above statement made by the candidate is correct to the best of my knowledge.

Dr. V.K. Agarwal

Professor and Head

Department of Chemical Engineering

Indian Institute of Technology Roorkee.

Roorkee, Uttarakhand-247667, India

ACKNOWLEDGEMENT

First I would like to thank God for giving me the health, the patience and the blessing that I have received from the beginning to the end of the Master's study. Next, I would like to express my deepest gratitude to my supervisor **Dr. V.K Agarwal**, Head of Chemical Engineering Department at IIT Roorkee. It would not have been possible to accomplish this thesis work without his sincere help, guidance, and support.

I am also heartily thankful to **Umesh Kumar** (PhD Scholar) for his valuable suggestion and support in last one year.

I would like to thank the entire faculty of Chemical Engineering Department for their constant support throughout my course work.

I want to acknowledge my lab-mates **Bhaskar Mehto, Baljinder Kaur and Veronica** for their valuable contributions and support towards the success of this work.

I would like also to take this opportunity to thank all my friends for their valuable ideas. Last but not least, I would like to thank my father Shri **Mithlesh Kumar** for his endless support and blessings.

Date: 15th June, 2014
Roorkee

Piyush Kumar
Enroll. No.- 12516007

ABSTRACT

Train cabins are closed enough that if accidently fire takes place inside it, it brings great hazards and consequently leads to traveling passenger to get hurt or die. To prevent it, the prominent objective should be to develop a fire safety design which can make sure that passengers can safely escape from it in the case of accidental fire in it. Such model can be developed by numerical simulation of fire and evacuation processes of those conditions. This is done by utilizing Fire Dynamics Simulator (FDS), provided by the National Institute of Standards and Technology (NIST), is basically Computational Fluid Dynamics (CFD) software mainly for the fluid movement in the fire. In this present work, we have carried out simulation by FDS for the interior fire smoke spreading process, temperature distribution, visibility, effect of doors and windows open/close conditions, effects of air-condition running and evacuation plans when an accidental fire take place at the center and the door respectively inside a train compartment including effect of passenger load and heat release rate factors. As automobile seats are made of polyurethane, so a portion (0.5m $\times$ 0.5m) of seat has been used as fuel for combustion and evacuation time results have been reported for the above stated different fire conditions.

CONTENTS

CANDIDATE'S DECLARATION **[i]**

ACKNOWLEDGEMENT **[ii]**

ABSTRACT **[iii]**

CONTENTS **[iv]**

LIST OF TABLES **[vii]**

LISTOF FIGURES **[viii]**

NOMENCLATURE **[x]**

CHAPTER 1 **INTRODUCTION** **1-2**

CHAPTER 2 **LITERATURE REVIEW** **3-6**

CHAPTER 3 **MOTIVATION** **7**

CHAPTER 4 **OBJECTIVES** **8**

CHAPTER 5 **MODELING APPROACH** **9-13**

5.1 Introduction..9

5.2 Mathematical Model..9

5.2.1 Continuity equation..9

5.2.2 Momentum conservation equation..9

5.2.3 Species conservation equation..9

5.2.4 Energy conservation equation..10

5.2.5 Gas state equation..10

5.3 Flashover prediction model for critical heat release rate..10

5.4 Gas flow rate..10

5.5 Combustion Model..11

5.6 CFL condition for time step and stability..11

5.7 Equation for evacuation..11

5.8 Waiting time equation..12

CHAPTER 6 **NUMERICAL METHODOLOGY** **14-27**

6.1 Geometry and mesh....14

6.1.1 Mesh information....14

6.1.2 Train cabin information....14

6.2 Simulated condition....17

CHAPTER 7 **RESULTS AND DISCUSSION** **18-41**

7.1 Simulation results at different fire location....24-29

7.1.1 Temperature profile....18-19

7.1.2 Smoke spread....20

7.1.3 CO concentration at left and right doors....21

7.1.4 Visibility....22-23

7.2 Simulation result of doors and windows open or not....24-25

CASE I: Fire at the center and doors and windows closed/open....24

CASE II: Fire at the right end and doors and windows closed/open....25

7.3 Simulation result about ACs ON/OFF conditions....26-27

CASE III: Middle seat fire and ACs are ON/OFF....26

CASE IV: End seat fire and ACs are ON/OFF....27

7.4 Simulation result of evacuation....28-36

7.4.1 Effects of Fire Location....28

7.4.2 Effects of HRR....37

7.4.3 Effects of Occupant loading....39

CHAPTER 8 CONCLUSION AND RECOOMENDATIONS 42

8.1Conclusion...42

8.2 Recommendations..42

CHAPTER 9 REFFRENCES 43-45

LIST OF TABLE

Table No.	Title	Page No.
Table 1	Mesh configuration	14
Table 2	Train Cabin information	14-15
Table 3	Fire condition to simulate	17
Table 4	Simulation results for scenarios S1, S2, S3, S4 and S5	28
Table 5	Evacuation results for scenarios S1, S2, S3 and S4 for HRR 0.3, 0.6 and 1.2 MW	37
Table 6	Evacuation results for scenarios S1, S2, S3 and S4 against passenger loading 0.5 and1.0 person/m^2	39

LIST OF FIGURES

Figure No.	Title	Page No.
Figure 1	Driving force of the buoyant flow across the vent of the compartment fire	10
Figure 2	The physical characteristics model of evacuation person	12
Figure 3	Model of the train cabin (a) Lateral View (b) Top View	16
Figure 4	Temperature rise when fire source is at (a) middle seat (b) right end seat	18
Figure 5	Temperature profile at right end seat at t= 250s at (a) middle seat (b) right end seat	19
Figure 6	Smoke profile at t= 120s at (a) middle seat (b) right end seat	20
Figure 7	CO concentration plot at left door for different locations of fire at t=250s	21
Figure 8	Visibility profile at the middle seat at (a) t= 100s and (b) t=260s	22
Figure 9	Visibility profile at the right end seat at (a) t= 100s and (b)t= 260s	23
Figure 10	Smoke profile from the middle seat at t= 200s when (a) all doors and windows are close (b) all doors and windows are opened	24
Figure 11	Smoke profile at the right end seat at t= 200s when (a) all doors and windows are close (b) all doors and windows are opened	25
Figure 12	Temperature profile at the middle seat at t= 200s when (a) ACs are ON (b) ACs are OFF	26
Figure 13	Temperature profile at the right end seat at t= 200s when (a) ACs are ON (b) ACs are OFF	27
Figure 14	Evacuation profile at (a) t=10s, (b)t=30s, (c) t= 50s,(d) t=70s and (e) t=90s under S1	29
Figure 15	Evacuation No. in safe time of t = 90s under S1	30
Figure 16	Evacuation No. in safe time of t = 90s from different exit under S1	30

Figure 17	Evacuation profile at (a) t=10s, (b)t=30s, (c) t= 50s,(d) t=70s and (e) t=90s under S2	31
Figure 18	Evacuation No. in safe time of t = 90s under S2	32
Figure 19	Evacuation No. in safe time of t = 90s from different exit under S2	32
Figure 20	Evacuation profile at (a) t=10s, (b)t=30s, (c) t= 50s,(d) t=70s and (e) t=90s under S3	33
Figure 21	Evacuation No. in safe time of t = 90s under S3	34
Figure 22	Evacuation No. in safe time of t = 90s from different exit under S3	34
Figure 23	Evacuation profile at (a) t=10s, (b)t=30s, (c) t= 50s,(d) t=70s and (e) t=90s under S4	35
Figure 24	Evacuation No. in safe time of t = 90s under S4	36
Figure 25	Evacuation No. in safe time of t = 90s from different exit under S4	36
Figure 26	Relationship between heat release rate (HRR) and TET, WT, WT/TET. (a) HRR and TET & WT (b) HRR and WT/TET for S1	38
Figure 27	Relationship between passenger loading and TET, WT, WT/TET. (a) Passenger loading and TET & WT for S1 (b) Passenger loading and WT/TET for S1 c) Passenger loading and WT/TET for S1	40-41

NOMENCLATURE

$\tilde{\rho}$ = filtered density, kg/m^3

k = thermal conductivity, W/m K

D_l= material diffusivity, m^2/s

$\tilde{u}_i$ = Favre-filtered velocity m/s

Y_l= Single mass concentration for component l

$\tilde{h}$ = enthalpy J/kg

q^r= radiative heat flux

$\frac{D\bar{p}}{Dt}$ = material derivative

$\widetilde{w}$= Favre-filtered species source term

$p_{0=}$ Pressure, Pa

T= Temperature, K

R= Gas constant

M_l= Molecular weight of component l, kg/ mol

v_{O_2}= stoichiometric coefficient of O_2 in the combustion reaction

W_{O_2}= weight of O_2 used in combustion

v_F= stoichiometric coefficient of fuel in the combustion reaction

W_F= weight of fuel burned

Y_F= mass fraction of fuel burned

Y_{O_2}= mass fraction of oxygen used in combustion

$Y_{O_2}^{\infty}$= ambient mass fraction of oxygen

Y_F^I= fuel mass fraction in fuel stream

A = duct area

h = enthalpy of the fluid in the duct.

ΔP = fixed source of momentum (a fan or blower)

L = length of the duct segment

K = friction loss of the duct segment

R_t = radius of the circle of the human body

R_d = size from the center of the body to the outermost end of shoulders

R_s = radius of the shoulder circle.

$x_i(t)$ = position of the agent i at time t

f_i(t) = force exerted on the agent by the surroundings

m_i= mass

ξ_i(t) = small random fluctuation force.

v_t = travel speed, m/s

D= population density,(in number of persons/m2 of floor area)

t_{trav}= the travel time,s

t_{wait} = Waiting time.s