



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكرو فيلم

بسم الله الرحمن الرحيم



MONA MAGHRABY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم



شبكة المعلومات الجامعية التوثيق الإلكتروني والميكروفيلم



MONA MAGHRABY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم

جامعة عين شمس

التوثيق الإلكتروني والميكروفيلم

قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها
علي هذه الأقراص المدمجة قد أعدت دون أية تغيرات



يجب أن

تحفظ هذه الأقراص المدمجة بعيدا عن الغبار



MONA MAGHRABY



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING

**NUMERICAL INVESTIGATIONS ON A SMOKE MANAGMENT
SYSTEM IN AN ADMINSTRATION BUILDING'S ATRUIM**

A Thesis Submitted in Partial Fulfillment of the Requirements of the Degree of Master of
Science in Mechanical Engineering

Submitted by

Mohamed Hussein Ahmed Abdelaal

B. SC Mechanical Engineering, Power dept., 2006

Supervised by

Prof. Dr. Mahmoud Mohamed Kamal
Mechanical Power Engineering Department
Faculty of Engineering, Ain Shams
University

Dr. Hamdy Ahmed Hussein Abotaleb
Mechanical Power Engineering Department
Faculty of Engineering, Ain Shams
University

2021



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
NUMERICAL INVESTIGATIONS ON A SMOKE MANAGMENT
SYSTEM IN AN ADMINSTRATION BUILDING'S ATRUIM

Submitted by

Mohamed Hussein Ahmed Abdelaal

Master of Science in Mechanical Engineering

Examiners' Committee

| Name | Signature |
|--|-----------|
| Prof. Dr. Ramadan abd elaziz Amer | |
| Prof. Dr. Adel abd elmalek elahwany | |
| Prof. Dr. Mahmoud Mohamed Kamal | |
| Dr. Hamdy ahmed abotaleb | |

DEDICATION

To the soul of dear Hussein Ahmed Abdelaal

ACKNOWLEDGMENT

The author gratefully acknowledges Prof. Dr. Mahmoud Kamal and Dr. Hamdy ahmed abotaleb for their sincere and thoughtful guidance and assistance throughout the research undertaken. For their valuable comments added to this research, many thanks are due to Prof. Dr. Ramadan Amer and Prof. Dr. Adel Alahwany as members of the examining committee. Also, thanks are due to mother, elder brother and my wife “Namaa, Hosam and Sarah” for their support, understanding and encouragement as faithful companions.

Many thanks to Dr. Mahmoud bassiouny, Eng. Amin Hegazy, Eng. Mansour Abd elgwad Eng. Sayed Hussein, Eng. Ahmed Shawky, Eng. Ahmed Mostafa Anis and Mr. Khaled khalaf from MEDC, ECG, Dar where I passed the last fifteen years of my engineering career.

I would like to thank Eng. Mohannd yahia who gave me the wonderful support by his updated computer facilities which helped in studies undertaken in this research. Thanks to all who have brought great joy to my life and have managed to live though the demands of my career, it wouldn't have been without you, thank you so much,

Researcher Data

| | |
|-------------------------------|--|
| Name: | Mohamed Hussein Ahmed |
| Date of birth: | 14/12/1983 |
| Place of birth: | Alexandria, Egypt |
| Last academic degree: | Bachelor of Engineering |
| Field of specialization: | Mechanical Engineering |
| University issued the degree: | Faculty of Engineering (Alexandria University) |
| Date of issued degree: | 2006 |
| Current job: | Founder of CSC- Consultant |

Abstract

Smoke is considered the major reason of killing a lot of people in case of the building fire because of the reduction of visibility and asphyxiation fatalities occurred in the smoke event. The present research illustrates a numerical simulation on smoke propagation and smoke control for atrium in an administration building and investigates the effect of exhausting smoke by multi point extraction through rooftop exhaust fans on smoke layer height inside the atrium. ANSYS-FLUENT solver is used to solve two-dimensional Reynolds-averaged Navier-Stokes equations (RANS) combined with K- ϵ Realizable turbulence model for different study cases in an atrium. Two dimensional rectangular plan that is located at the center of atrium is simulated with the dimensions of 25m width and 20m height using T-squared fire with maximum heat release rate of 5 MW for 180 seconds. All parameters are predicted at vertical levels of 2, 13 and 17 m height from the ground floor. Results show that exhausting the smoke through rooftop exhaust fans maintain the smoke layer at higher level from the ground and has better effect on tenability conditions at human level, increasing make up air inlets levels adversely affect smoke layer height which reduce visibility at human level. Finally, the spacing between extract fans outlet is considered a major factor that should be optimized in order to avoid the plug-holing phenomena.

Keywords: CFD, Atrium, Smoke propagation, Visibility, Heat release.

NOMENCLATURE

| Symbol | Quantity |
|------------|--|
| C_p | Constant pressure specific heat , KJ/kg.k |
| C_g | Solid material specific heat, KJ/kg.k |
| V | Critical Critical velocity, m/s |
| Q | Heat Release Rate, Kw |
| T_0 | Ambient temperature, oC |
| D | Diffusion coefficient, Dilution parameter |
| g | Acceleration of gravity, m/s ² |
| h | Enthalpy; heat transfer coefficient , KJ/kg |
| h_α | Enthalpy of species α , KJ/kg |
| ΔH | Heat of combustion, KJ/kg |
| I | Radiation intensity |
| I_b | Radiation blackbody intensity |
| I_n | Radiation intensity integrated over the band n |
| $I_{b,n}$ | Radiation intensity of black body integrated over the band n |
| k | Thermal conductivity; suppression decay factor |
| K | Light extinction coefficient |
| K_m | Mass extinction coefficient |
| L | Length scale,m |
| Q | Total heat release rate, Kw |
| Q^* | Characteristic fire size, Kw |
| q | Heat flux vector , Kw/m ² |
| q | Convective flux to a solid surface, Kw/m ³ |
| q_r | Radiative flux to a solid surface, Kw/m ³ |
| R | Universal gas constant, J K ⁻¹ mol ⁻¹ |
| Re | Reynolds number |
| S | Unit vector in direction of radiation intensity |
| S | Visibility , m |
| Sc | Schmidt number |
| S_{ij} | Symmetric rate of strain tensor |
| T | Temperature |
| t | Time |
| W | Molecular weight of the gas mixture, Kg/mol |
| W_α | Molecular weight of gas species α , Kg/mol |
| X | (x, y, z) Position vector |
| X_α | Volume fraction of species α |
| Y_α | Mass fraction of species α |
| y_s | Soot yield |
| Z | Mixture fraction |
| Z_f | Stoichiometric value of the mixture fraction |

Table of Contents

| | |
|---|-----------|
| DEDICATION | 3 |
| ACKNOWLEDGMENT | 4 |
| Researcher Data | 5 |
| Abstract | 6 |
| NOMENCLATURE | 7 |
| List of Figures | 10 |
| List of Tables | 13 |
| Chapter 1 | 15 |
| 1.1 General | 15 |
| 1.2 Cause of fires in different buildings | 17 |
| 1.3 Hazard of Fires in Atria | 18 |
| 1.3.1 Temperature | 19 |
| 1.3.2 Visibility | 20 |
| 1.3.3 Toxic gases | 21 |
| 1.4. Tenability criteria..... | 22 |
| 1.4.1 Design Approach..... | 22 |
| 1.4.2 Tenability criteria for occupants | 24 |
| 1.5 Smoke Management | 24 |
| 1.6 Fire Design (Size, Location) | 25 |
| 1.7 Plug-holing phenomena | 27 |
| 1.8 The scope of this work..... | 28 |
| CHAPTER 2 | 30 |
| 2.1 Introduction | 30 |
| 2.2 Examples of previous researches..... | 30 |
| 2.2.1 Mechanical Smoke Exhaust System in an Atrium | 30 |
| 2.2.2 The effect of human movements on smoke propagation in building fire using numerical simulation | 35 |
| 2.2.3 Numerical simulation of smoke spread in an atrium in exist of fire scenario . | 39 |
| 2.2.5 Utilization of rooftop exhaust fans and sidewall fans for smoke extraction. | 47 |
| 2.2.6 Effect of leakage area from doors on stairwell pressurization..... | 53 |
| 2.3 History of smoke modeling and control strategy | 57 |
| 2.3.1 Modeling types of fire..... | 57 |
| 2.3.2 Overview on Zone Models | 61 |

| | |
|---|-----|
| CHAPTER 3 | 66 |
| 3- CFD and Governing Equations | 66 |
| 3.1 Introduction..... | 66 |
| 3.2 CFD Models | 66 |
| 3.3. Governing Equations | 69 |
| 3.3.1 Species and Mass Transport | 70 |
| 3.3.2 Momentum Transport..... | 70 |
| 3.3.3 Transportation of Energy..... | 71 |
| CHAPTER 4 | 73 |
| 4- VALIDATION | 73 |
| 4.1. Introduction | 73 |
| 4.2 Validation of Experimental model | 73 |
| 4.3 Fire heat release rate | 74 |
| 4.4 Validation Procedures..... | 75 |
| 4.4.1 Domain: | 75 |
| 4.4.2 Mesh generation: | 75 |
| 4.4.3 Boundary Conditions | 77 |
| 4.4.4 Numerical Procedures | 77 |
| 4.4.6 Validation Results | 77 |
| CHAPTER 5 | 81 |
| 5- Results and discussion | 81 |
| 5.1 Introduction..... | 81 |
| 5.2 2D Case study | 81 |
| 5.3 2D cases results | 83 |
| 5.4. 3D Case | 93 |
| CHAPTER 6 | 100 |
| 6- Conclusions and Future Work | 100 |
| 6.1. Conclusions | 100 |
| 6.2. Future work Suggestions..... | 101 |
| REFERENCES..... | 102 |
| APPENDICES..... | 106 |

List of Figures

| | |
|--|----|
| Figure 1. 1 Atrium Examples. | 16 |
| Figure 1. 2 partially opened atrium. | 16 |
| Figure 1. 3 fully opened atrium. | 16 |
| Figure 1. 4 Leading sources of ignition [3]. | 18 |
| Figure 1. 5 Tolerance time for exposure to convected heat [4]. | 20 |
| Figure 1. 6 Walking speed versus smoke density [4]. | 21 |
| Figure 1. 7 Tolerance to CO and HCN [4]. | 21 |
| Figure 1. 8 Occupants not exposed to smoke [6]. | 22 |
| Figure 1. 9 Tenability Criteria-Short Exposure. | 23 |
| Figure 1. 10 Tenability Criteria to be sampled at 2.5m from finish floor level. | 23 |
| Figure 1. 11 The smoke management system [2]. | 25 |
| Figure 1. 12 Fire design curve [8]. | 26 |
| Figure 1. 13 Plug-holing effect on the smoke layer [9]. | 27 |
| | |
| Figure 2. 1 Hot smoke test in the atrium [10]. | 31 |
| Figure 2. 2 Heat release rate and mass loss rate measured by oxygen consumption method [10]. | 33 |
| Figure 2. 3 Estimation of the smoke layer interface [10]. | 34 |
| Figure 2. 4 Schematic diagram of the two-layer zone model. | 34 |
| Figure 2. 5 The structure of the room, (a) Three- dimensional view of the room,(b) top view of the room, (c) side view of the room (XZ plane), (d) side view of the room (YZ plane) [11]. | 36 |
| Figure 2. 6 Temperature and velocity field distribution [11]. | 37 |
| Figure 2. 7 Velocity field distributions in XY plan [11]. | 37 |
| Figure 2. 8 Temperature distributions in XY plan [11]. | 38 |
| Figure 2. 9 Temperature distributions in YZ plan [11]. | 38 |
| Figure 2. 10 Schematic diagram of the PolyU/USTC atrium [12]. | 39 |
| Figure 2. 11 Schematic diagram for different locations of fire sources. | 40 |
| Figure 2. 12 Heat release rates distribution [12]. | 41 |
| Figure 2. 13 Descent of smoke layer at different fire locations [12]. | 42 |
| Figure 2. 14 Distribution of mean soot density at different fire locations [12]. | 42 |

| | |
|---|----|
| Figure 2. 15 Distribution of mean temperature at different fire locations [12]. | 43 |
| Figure 2. 16 Schematic diagrams for the atrium configurations . | 44 |
| Figure 2. 17 Shots of Smoke layer at ceiling level for the three shapes. | 44 |
| Figure 2. 18 The descent of the smoke layer on a side wall after the ceiling is covered in the three atrium configurations . | 45 |
| Figure 2. 19 Temperature as a function of height at 60s. | 46 |
| Figure 2. 20 Atrium geometry . | 47 |
| Figure 2. 21 Case 1 results . | 49 |
| Figure 2. 22 Case 2 results . | 51 |
| Figure 2. 23 Case 3 results . | 53 |
| Figure 2. 24 Description of model geometry. | 54 |
| Figure 2. 25 Pressure Difference Contours for Cases A,B,C,D at $v=2.52$ m/s. | 55 |
| Figure 2. 26 Pressure difference Contours for cases A, B, C, D at $v=2.73$ m/s. | 56 |
| | |
| Figure 3. 1 Performance-based Fire Safety Diagram. | 68 |
| | |
| Figure 4. 1 Schematic diagram of PolyU /USTC atrium [10]. | 74 |
| Figure 4. 2 Final Atrium Mesh. | 76 |
| Figure 4. 3 Temperature distribution along the atrium height (Case V 1). | 78 |
| Figure 4. 4 Temperature distribution along the atrium height (Case V 2). | 79 |
| | |
| Figure 5. 1 Schematic diagram of the 2D test section | 81 |
| Figure 5. 2 Temperature Contours after 60s | 84 |
| Figure 5. 3 Temperature Contours after 120s | 84 |
| Figure 5. 4 Temperature Contours after 180s | 85 |
| Figure 5. 5 Mass fraction of Co_2 Contours after 60s | 85 |
| Figure 5. 6 Mass fraction of Co_2 Contours after 120s | 85 |
| Figure 5. 7 Mass fraction of Co_2 Contours after 180s | 86 |
| Figure 5. 8 Mass fraction of Co Contours after 60s | 86 |
| Figure 5. 9 Mass fraction of Co Contours after 120s | 86 |
| Figure 5. 10 Mass fraction of Co Contours after 180s | 87 |

| | |
|---|----|
| Figure 5. 11 Pressure Contours after 60s | 87 |
| Figure 5. 12 Pressure Contours after 120s | 87 |
| Figure 5. 13 Pressure Contours after 180s | 88 |
| Figure 5. 14 Velocity Contours after 60s | 88 |
| Figure 5. 15 Velocity Contours after 120s | 88 |
| Figure 5. 16 Velocity Contours after 180s | 88 |
| Figure 5. 17 Schematic diagram indicating the three measuring point's locations (dimensions In Meter). | 89 |
| Figure 5. 18 Predicated temperature distributions at point A with different cases | 90 |
| Figure 5. 19 Predicated temperature distributions at Point B | 90 |
| Figure 5. 20 Predicated temperature distributions at Point C | 91 |
| Figure 5. 21 Predicated mass fraction of Co distributions at point B | 91 |
| Figure 5. 22 Predicated mass fraction of Co ₂ distributions at Point B | 92 |
| Figure 5. 23 Predicated mass fraction of Co ₂ distributions at point C | 92 |
| Figure 5. 24 Predicated mass fraction of Co distributions at point C | 93 |
| Figure 5. 25 3D Model | 94 |
| Figure 5. 26 clear height variation with time | 95 |
| Figure 5. 27 Temperature distribution after 5 minutes | 96 |
| Figure 5. 28 Distribution of Co ₂ after 5 minutes | 96 |
| Figure 5. 29 Distribution of Co after 5 minutes | 97 |
| Figure 5. 30 Temperature distribution after 10 minutes | 97 |
| Figure 5. 31 Distribution of Co ₂ after 10 minutes | 98 |
| Figure 5. 32 Distribution of Co after 10 minutes | 98 |