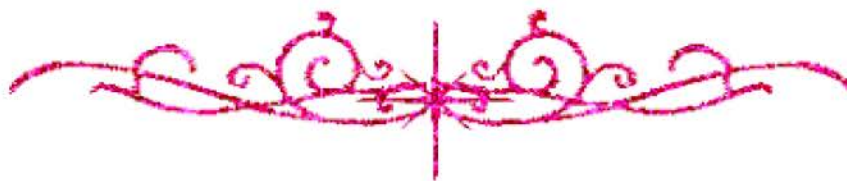


بسم الله الرحمن الرحيم





شبكة المعلومات الجامعية التوثيق الالكتروني والميكروفيلم



جامعة عين شمس

التوثيق الإلكتروني والميكروفيلم

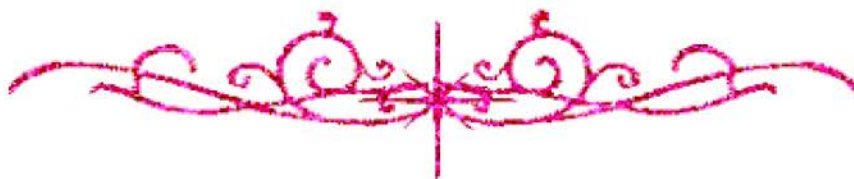
قسم

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





NUMERICAL INVESTIGATIONS OF SMOKE MANAGEMENT IN ROAD TUNNEL WITH AND WITHOUT CURTAINS

By

Eng. Hashim Ali Neama AL-Akam

A Thesis Submitted to the Faculty of
Engineering at Cairo University in Partial
Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE

In

MECHANICAL POWER ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2020

NUMERICAL INVESTIGATIONS OF SMOKE MANAGEMENT IN ROAD TUNNEL WITH AND WITHOUT CURTAINS

By

Eng. Hashim Ali Neama AL-Akam

A Thesis Submitted to the Faculty of Engineering
at Cairo University in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

In

MECHANICAL POWER ENGINEERING

Under Supervision of

Prof. Dr. Essam E. Khalil

Professor Mechanical Power
Department Faculty of
Engineering
Cairo University

Prof. Dr. Ahmed A. Medhat

A. Fahim
Professor of Power Mechanical
Engineering in the Electro-
Mechanical Research Institute
Housing & Building National
Research Center

Dr. Gamal El Hariry

Associate Professor Mechanical
Power
Department Faculty of
Engineering
Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2020

NUMERICAL INVESTIGATIONS OF SMOKE MANAGEMENT IN ROAD TUNNEL WITH AND WITHOUT CURTAINS

By

Eng. Hashim Ali Neama AL-Akam

A Thesis Submitted to the Faculty of Engineering
at Cairo University in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

MECHANICAL POWER ENGINEERING

Approved by the Examining Committee

Prof. Dr. Essam E. Khalil

Thesis Main Advisor

Prof. Dr. Mustafa Abdul-Hameed Rizq

Internal Examiner

Prof. Dr. Mohammed Fayek Abed Rabbo

External Examiner

Professor, Mechanical Power Engineering Department Faculty of Engineering, Benha University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

2020

Engineer: Hashim Ali Neama AL-Akam
Date of Birth: 29/04/1992
Nationality: Iraqi
E-mail: hashimalakam@yahoo.com
Phone: (+2) 01111799142
Address: 24 Kambeez St, mosadak st., Dokki ,Giza,Egypt
Registration Date: 01/03/2017
Awarding Date: / / 2020
Degree: Master of Science
Department: Mechanical Power Engineering
Supervisors: **Prof. Dr.** Essam E. Khalil



Prof. Dr. Ahmed A. Medhat A. Fahim

Dr. Gamal El Hariry

Examiners: **Prof. Dr.** Essam E. Khalil (Thesis main advisor)
Prof. Dr. Mustafa Abdul-Hameed Rizq (Internal examiner)
Prof. Dr. Mohammed Fayek Abed Rabbo (External examiner)
Professor, Mechanical Power Engineering Department, Benha University

Title of Thesis:
NUMERICAL INVESTIGATIONS OF SMOKE MANAGEMENT IN ROAD TUNNEL WITH AND WITHOUT CURTAINS

Key Words:
(Smoke Management; Vehicular Tunnels; Ventilation; Visibility; FDS)

Summary:

Smoke is the deadliest factor in vehicular tunnels fire since smoke spreads in heading harmonize with passenger's evacuation way. It reduces visibility and can cause fatalities by suffocation. This research presents a numerical study of the effect of extracting the smoke system of ventilation on smoke spread inside the vehicular tunnel, solid curtain with transverse system 2018 by using FDS

DISCLAIMER

I hereby declare that this thesis is my own original work and that no part of it has been
Submitted for a degree of qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the
references section.

Name:

Date:

Signature:

ACKNOWLEDGMENT

Firstly, I would like to thank Almighty ALLAH, whom I owe everything WiththenameofGOD, Istartedthisresearch hopingthatitaccelerates thewheelof progressinthisfield.

Generousness and support through all my life.IwouldliketoexpressmysincereappreciationandinfinetthankstoProf. Essam E.Khalil, professor ofmechanical power-faculty ofengineering–Cairo U n i v e r s i t y , whogavemeagreatscientificsupportandguidancetomakeaprogressinmyresearch.Besides, havingsevereadmirationofhisgiganticexperienceandunlimitedco-operationandefforts ofhelpingmetointroducethisresearchinthebestway.

I extend my gratitude to Dr. Gamal Abdullmonaam El Hariry for hisgreat effort and valuable suggestions and noteworthy discussions

I would like also to thank Prof. Dr. Ahmed A. Medhat Ahmed Fahmy for his guidance and unremitting encouragement. I am grateful to him, and to all my respectful professors, for mentoring me throughout my graduate study

Thanks, are also to especially my colleagues Eng. Mohtady El Gawady , Eng.Maher Hussain El Zoghby and Eng Ramy Mahmoud for their encouragement andallmyteamandmyfriends:thankyouverymuchforwhatyouhavedoneforme.I thankyouallforthecompanionship thatmadethisjourneymucheasier.Infact,Idonot needtolistyournamesbecauseIamsurethatyouknowwho youare.

Finally,Icannotexpress;inwords;thesupportofmyparents and my brother for their motivationthrough finishing this thesis and their patience and care and for maintaining a perfectenvironment for study and research.

Contents

ACKNOWLEDGMENT	II
----------------------	----

CONTENTS	II
TABLE OF FIGURES	VI
TABLE OF TABLES	XI
NOMENCLATURE	XII
GREEK LETTERS	XIV
SUPERSCRIPTS AND SUBSCRIPTS	XV
ABBREVIATIONS.....	XVI
ABSTRACT.....	XVII
CHAPTER 1: INTRODUCTION	1
1.1 GENERAL.....	1
1.2 TUNNEL FIRES.....	1
۱.۳ HAZARD OF SMOKE	4
1.3.1 Reduce Visibility.....	4
۱.۳.۲ Toxicity	4
1.3.3 High temperature	4
۱.۴ FIRE HEAT RELEASE RATE	5
1.5 TUNNEL VENTILATION	5
1.6 TYPES OF VENTILATION SYSTEM.....	6
1.6.1 Longitudinal ventilation	6
1.6.2 Transverse ventilation.....	7
1.6.3 Semi-transverse ventilation	7
1.7 Road Tunnels Fire protection for road tunnels shall comply with the Application	8
1.8 TUNNEL CLOSURE AND TRAFFIC CONTROL	11
۱.۹ EMERGENCY VENTILATION	11
1.10 MAIN DESIGN FIRE PARAMETERS	12
۱.۱۱ JET FANS VENTILATION	14
۱.۱۲ SOLID CURTAINS.....	14
1.13 EXIT DOORS AND SIGNS	15
۱.۱۴ COMPUTER MODELING AND SIMULATION.....	18
1.15 THE SCOPE OF THIS STUDY.....	19
CHAPTER 2: LITERATURE REVIEW.....	20
2.1 INTRODUCTION	20
2.2 PREVIOUS RESEARCH WORK	20
2.2.1 Study on Hot Gases Flow in Case of Fire in a Road Tunnel	20
2.2.2 Experimental study of the effectiveness of air curtains of variable width and injection angle to block fire-induced smoke in a tunnel configuration	21
2.2.3 Experimental study on thermal and toxic hazards connected to fire scenarios in road tunnels	22
2.2.4 Experimental and Numerical Studies on Longitudinal Smoke Temperature Distribution Upstream and Downstream from the Fire in a Road Tunnel	23
2.2.5 A modified critical velocity for road tunnel fire smoke Management with dedicated smoke extraction configuration	24
2.2.6 Assessing the influence of fuel geometrical shape on fire dynamics simulator (FDS) predictions for a large-scale heavy goods vehicle tunnel fire experiment.....	26
2.2.7 CFD INVESTIGATION OF SMOKE MANAGEMENT IN VEHICULAR TUNNELS	27

2.2.8 NUMERICAL INVESTIGATION FOR SMOKE SPREAD IN AN UNDERGROUND SUBWAY STATION	28
2.2.9 NUMERICAL INVESTIGATION FOR CONTROL OF SMOKE IN DOMED MOSQUES	
29	
2.2.10 A numerical study on upstream maximum temperature in inclined urban road tunnel fires	30
2.2.11 Numerical investigation on the effect of ambient pressure on smoke movement and temperature distribution in tunnel fires	31
2.2.12 Numerical study on the optimization of smoke ventilation mode at the conjunction area between tunnel track and platform in emergency of a train fire at subway station	32
2.2.13 Theoretical and experimental study on longitudinal smoke temperature distribution in tunnel fires	33
2.2.14 Smoke development in full-scale sloped long and large curved tunnel fires under natural ventilation	34
2.2.15 Pool Fires	35
2.3 RELATIONS BETWEEN PREVIOUS WORK AND PRESENT WORK.....	35
CHAPTER 3: GOVERNING EQUATIONS.....	37
3.1 DESCRIPTION OF FDS.....	37
3.1.1 Combustion Model.....	37
3.1.2 Hydrodynamic Model	37
3.1.3 Radiation Transport	38
3.2 GOVERNING EQUATIONS	38
3.2.1 Mass and Species Transport.....	38
3.2.2 Momentum Transport	38
3.2.3 Energy Transport.....	39
3.3 EQUATION OF STATE	40
3.4 LARGE EDDY SIMULATION (LES).....	41
3.5 COMBUSTION (MIXTURE FRACTION MODEL)	42
3.6 RADIATION (RADIATION TRANSPORT EQUATION).....	42
3.7 THE HEAT CONDUCTION EQUATION FOR A SOLID.....	45
3.8 RADIATION HEAT TRANSFER TO SOLIDS.....	45
3.9 CONVECTIVE HEAT TRANSFER TO SOLIDS.....	45
CHAPTER 4: VALIDATION AND GRID SENSITIVITY ANALYSIS	47
4.1 COMPUTATIONAL DAIN AND GRID SENSITIVITY ANALYSIS	47
4.1.1 Tunnel description	47
4.1.2 Simulation Results.....	48
4.2 VALIDATION OF FDS	50
4.2.1 Tunnel description	50
4.2.2 Fire source.....	51
4.2.3 Ceiling Temperature Measurements	52
4.2.4 FDS simulations.....	53
4.2.5 FDS Simulation Results	53
4.3 SIMULATION CASES OF THE PRESENT STUDY	55
4.4 CONCLUSIONS	55
CHAPTER 5: RESULTS AND DISCUSSION	56
5.1 RESULTS OF DESIGN CASE 1.....	56
5.1.1 Smoke spread process	57

5.1.2	Temperature distributions	58
5.1.3	Visibility distributions	59
5.1.4	CO concentration distributions	60
5.1.5	Velocity Distributions	62
5.2	RESULTS OF DESIGN CASE 2.....	63
5.2.1	Smoke spread process	64
5.2.2	Temperature distributions	66
5.2.3	Visibility distributions	67
5.2.4	CO concentration distributions	69
5.2.5	Velocity distribution.....	70
5.3	RESULTS OF DESIGN CASE 3.....	72
5.3.1	The smoke spread.....	72
5.3.2	Temperature distributions	74
5.3.3	Visibility distributions	75
5.3.4	CO concentration distributions	77
5.3.5	The velocity distribution.....	78
5.4	RESULTS OF DESIGN CASE 4.....	81
5.4.1	Smoke spread process	81
5.4.2	Temperature distributions	83
5.4.3	Visibility distributions	85
5.4.4	CO concentration distributions	88
5.4.5	Velocity Distributions	90
5.5	RESULTS OF DESIGN CASE 5.....	92
5.5.1	The smoke spread.....	93
5.5.2	Temperature distributions	95
5.5.3	Visibility distributions	97
5.5.4	CO concentration distributions	101
5.5.5	The velocity distribution.....	103
5.6	RESULTS OF DESIGN CASE 6.....	105
5.6.1	Smoke spread process	105
5.6.2	Temperature distributions	108
5.6.3	Visibility distributions	110
5.6.4	CO concentration distributions	112
5.6.5	Velocity Distributions	114
5.7	RESULTS OF DESIGN CASE 7.....	116
5.7.1	Smoke spread process	117
5.7.2	Temperature distributions	119
5.7.3	Visibility distributions	120
5.7.4	CO concentration distributions	122
5.7.5	Velocity Distributions	123
5.8	RESULTS OF DESIGN CASE 8.....	124
5.8.1	The smoke spread.....	125
5.8.2	Temperature distributions	126
5.8.3	Visibility distributions	127
5.8.4	CO concentration distributions	129
5.8.5	The velocity distribution.....	130
5.9	RESULTS OF DESIGN CASE 9.....	131
5.9.1	Smoke spread process	132
5.9.2	Temperature distributions	133
5.9.3	Visibility distributions	134

5.9.4 CO concentration distributions	135
5.9.5 Velocity Distributions	136
CHAPTER 6: CONCLUSIONS AND SUGGESTED FUTURE WORKS	139
6.1 INTRODUCTION	139
6.2 CONCLUSIONS	139
6.3 SUGGESTED FUTURE WORKS	139
REFERENCES	141
APPENDIX.....	144

Table of Figures

FIGURE 1.1 : LÆRDAL ROAD TUNNEL, SOGN OG FJORDANE, NORWAY [1]	1
FIGURE 1.2 : EMISSION STANDARDS FOR NEW HEAVY-DUTY DIESEL ENGINES, RELATIVE TO EURO I [4]	6
FIGURE 1.3 : LONGITUDINAL & TRANSVERSE & SEMI TRANSVERSE VENTILATION [4]	7
FIGURE 1.4 : JET FANS USED FOR VENTILATING AD-NORWAY-UNDERWATER-TUNNEL, NORWAY [6]	14
FIGURE 1.5 : SOLID CURTAIN IN CEILING OF THE TUNNEL [7]	15
FIGURE 1.6 : EXIT SIGN [8]	16
FIGURE 1.7 : EMERGENCY EXIT DOORS	17
FIGURE 2.1 : CONFIGURATION OF THE GENERATORS AND TRAYS DURING BOTH HOT SMOKE TESTS (LEFT—TWO TRAYS.....)	21
FIGURE 2.2 : PHOTO OF THE TEST SECTION AND THE INSTRUMENTATION BEFORE TESTING	22
FIGURE 2.3 : SCHEMATIC LAYOUT OF LABORATORY SCALED TUNNEL AND DETECTION/SAMPLING EQUIPMENT (A ¼ FIRE SECTION; B ¼ 60 CM DOWNSTREAM SECTION; IN EACH SECTION 7 THERMOCOUPLES: 2 EXTERNAL (PT-100) AND 5 INSIDE AT DIFFERENT DISTANCES FROM THE TUNNEL CEILING)	23
FIGURE 2.4 : SCHEMATIC OF THE TUNNEL FOR TESTS: (A) TUNNEL ENTRY; (B) SCHEMATIC DIAGRAM OF THE CROSS-SECTION; AND (C) PLANE VIEW OF THE TUNNEL.....	24
FIGURE 2.5 : SMOKE EXHAUST WITH 4 WALL DAMPERS, LONGITUDINAL VENTILATION $U = 2.0$ M/S.....	26
FIGURE 2.6 : FLAME EXTENSION IMAGES AT DIFFERENT FIRE DEVELOPMENT STAGES FOR THE FOUR SCENARIOS.....	27
FIGURE 2.7 : VEHICULAR TUNNEL SMOKE	28
FIGURE 2.8 : THE MODELED GEOMETRY.....	29
FIGURE 2.9 : MOSQUE	30
FIGURE 2.10 : SCHEMATIC VIEW OF FDS MODEL TUNNEL.....	31
FIGURE 2.11 : ARRANGEMENTS OF THE MEASURING POINTS.	32
FIGURE 2.12 : A SCHEMATIC DRAWING OF THE SUBWAY STATION.	33

FIGURE 2.13 : SMALL SCALE MODEL TUNNEL APPARATUS.	34
FIGURE 2.14 : TOP VIEW OF THE TUNNEL LAYOUT (UNIT: M).	35
FIGURE 4.1 : SCHEMATIC DIAGRAM OF THE ARRANGEMENT OF FIRE SOURCE, VENTS	47
FIGURE 4.2 : COMPARISON FOR NUMERICAL TEMPERATURE DISTRIBUTIONS AT 4.95 M ABOVE THE TUNNEL FLOOR	49
FIGURE 4.3 : COMPARISON FOR NUMERICAL VISIBILITY DISTRIBUTIONS AT 1.7 M ABOVE THE FLOOR LEVEL.....	49
FIGURE 4.4 : COMPARISON FOR NUMERICAL CO CONCENTRATION DISTRIBUTIONS AT 1.7 M ABOVE THE FLOOR LEVEL	50
FIGURE 4.5 : PHYSICAL MODEL FOR SIMULATIONS [35]	51
FIGURE 4.6 : A PARTIAL VIEW OF THE FULL-SCALE TUNNEL FIRE EXPERIMENTAL SETUP [35]	51
FIGURE 4.7 TYPICAL HRR AS A FUNCTION OF TIME FROM THE ETHANOL POOL FIRES FOR FOUR PANS BASED ON THE MEASURED MASS LOSS RATE [35] .	52
FIGURE 4.8 : COMPARISON OF TEMPERATURE VARIATION BETWEEN SIMULATION AND EXPERIMENTAL RESULTS	54
FIGURE 4.9 : COMPARISON OF HRR VARIATION BETWEEN SIMULATION AND EXPERIMENTAL RESULTS	54
FIGURE 5.1 : SCHEMATIC DIAGRAM OF THE ARRANGEMENT OF FIRE SOURCE AND VENTS IN CASE 1.	57
FIGURE 5.2 : SMOKE SPREAD PROCESS IN Z CASE 1 AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	57
FIGURE 5.3 : SMOKE SPREAD PROCESS IN Y CASE 1 AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	58
FIGURE 5.4 : TEMPERATURE CONTOURS DISTRIBUTIONS ALONG THE Z=1.7M TUNNEL IN CASE 1 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	58
FIGURE 5.5 : TEMPERATURE CONTOURS DISTRIBUTIONS ALONG THE Y=5M TUNNEL IN CASE 1 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	59
FIGURE 5.6 : NUMERICAL VISIBILITY DISTRIBUTIONS IN CASE 1 AT HUMAN LEVEL AT Z=1.7M ALONG THE TUNNEL IN CASE 1 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	59
FIGURE 5.7 : NUMERICAL VISIBILITY DISTRIBUTIONS IN CASE 1 AT HUMAN LEVEL AT Z=2.2M ALONG THE TUNNEL IN CASE 1 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	60
FIGURE 5.8 : VISIBILITY DISTRIBUTIONS AT Y=5M ALONG THE TUNNEL IN CASE 1 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	60
FIGURE 5.9 : NUMERICAL CO CONCENTRATION DISTRIBUTIONS CASE 1 AT HUMAN LEVEL AT Z=1.7M ALONG THE TUNNEL IN CASE 1 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	61
FIGURE 5.10 : NUMERICAL CO CONCENTRATION DISTRIBUTIONS CASE 1 AT HUMAN LEVEL AT Y=5M ALONG THE TUNNEL IN CASE 1 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	61
FIGURE 5.11 : VELOCITY DISTRIBUTIONS CASE 1 AT HUMAN LEVEL AT Z=1.7M ALONG THE TUNNEL IN CASE 1 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	62
FIGURE 5.12 : VELOCITY DISTRIBUTIONS CASE 1 AT HUMAN LEVEL AT Y=5M ALONG THE TUNNEL IN CASE 1 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	63
FIGURE 5.13 : SCHEMATIC DIAGRAM OF THE ARRANGEMENT OF FIRE SOURCE, VENTS AND SOLID CURTAINS IN CASE 2	64
FIGURE 5.14 : SMOKE SPREAD PROCESS IN Z IN CASE 2 AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	65
FIGURE 5.15 : SMOKE SPREAD PROCESS IN Y IN CASE 2 AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	65
FIGURE 5.16 : TEMPERATURE CONTOURS DISTRIBUTIONS ALONG THE Z=1.7M TUNNEL IN CASE 2 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	66
FIGURE 5.17 : TEMPERATURE CONTOURS DISTRIBUTIONS ALONG THE Y=5 TUNNEL IN CASE 2 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	67
FIGURE 5.18 : VISIBILITY CONTOURS DISTRIBUTIONS ALONG THE TUNNEL IN CASE 2 AT Z=1.7M SIDE VIEW (AT 50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	68
FIGURE 5.19 : VISIBILITY CONTOURS DISTRIBUTIONS ALONG THE TUNNEL IN CASE 2 AT Z=2.2M SIDE VIEW (AT 50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	68
FIGURE 5.20 : VISIBILITY CONTOURS DISTRIBUTIONS ALONG THE TUNNEL IN CASE 2 AT Y=5M SIDE VIEW (AT 50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	69
FIGURE 5.21 : NUMERICAL CO CONCENTRATION DISTRIBUTIONS CASE 2 AT Z=1.7M ALONG THE TUNNEL IN CASE 2 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	70
FIGURE 5.22 : NUMERICAL CO CONCENTRATION DISTRIBUTIONS CASE 2 AT Y=5M ALONG THE TUNNEL IN CASE 2 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	70
FIGURE 5.23 : VELOCITY DISTRIBUTIONS CASE 2 AT HUMAN LEVEL AT Z=1.7M ALONG THE TUNNEL IN CASE 2 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	71

FIGURE 5.24 : VELOCITY DISTRIBUTIONS CASE 2 AT HUMAN LEVEL AT Y=5M ALONG THE TUNNEL IN CASE 2 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	71
FIGURE 5.25 : SCHEMATIC DIAGRAM OF THE ARRANGEMENT OF FIRE SOURCE, VENTS AND THE SOLID CURTAIN	72
FIGURE 5.26 : SMOKE SPREAD PROCESS IN Z CASE 3 AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	73
FIGURE 5.27 : SMOKE SPREAD PROCESS IN Y CASE 3 AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	73
FIGURE 5.28 : TEMPERATURE CONTOURS DISTRIBUTIONS ALONG THE Z=1.7M TUNNEL IN CASE 3 AT TOP VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	74
FIGURE 5.29 : TEMPERATURE CONTOURS DISTRIBUTIONS ALONG THE Y=5 TUNNEL IN CASE 3 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	75
FIGURE 5.30 : VISIBILITY CONTOURS DISTRIBUTIONS ALONG THE TUNNEL IN CASE 3 AT Z=1.7M TOP VIEW (AT 50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	76
FIGURE 5.31 : VISIBILITY CONTOURS DISTRIBUTIONS ALONG THE TUNNEL IN CASE 3 AT Z=2.2M TOP VIEW (AT 50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	76
FIGURE 5.32 : VISIBILITY CONTOURS DISTRIBUTIONS ALONG THE TUNNEL IN CASE 3 AT Y=5M SIDE VIEW (AT 50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	77
FIGURE 5.33 : NUMERICAL CO CONCENTRATION DISTRIBUTIONS CASE 3 AT Z=1.7M ALONG THE AT TOP VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	78
FIGURE 5.34 : NUMERICAL CO CONCENTRATION DISTRIBUTIONS CASE 3 AT Y=5M ALONG THE TUNNEL IN CASE 3 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	78
FIGURE 5.35 : VELOCITY DISTRIBUTIONS CASE 3 AT HUMAN LEVEL AT Z=1.7M ALONG THE TUNNEL IN CASE 3 AT TOP VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	79
FIGURE 5.36 : VELOCITY DISTRIBUTIONS CASE 3 AT HUMAN LEVEL AT Y=5M ALONG THE TUNNEL IN CASE 3 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	79
FIGURE 5.37 : SCHEMATIC DIAGRAM OF THE ARRANGEMENT OF FIRE SOURCE AND VENTS	81
FIGURE 5.38 : SMOKE SPREAD PROCESS IN Z CASE 4 AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	82
FIGURE 5.39 : SMOKE SPREAD PROCESS IN Y CASE 4 AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	83
FIGURE 5.40 : TEMPERATURE CONTOURS DISTRIBUTIONS ALONG THE Z=1.7M TUNNEL IN CASE 4 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	84
FIGURE 5.41 : TEMPERATURE CONTOURS DISTRIBUTIONS ALONG THE Y=5M TUNNEL IN CASE 4 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	85
FIGURE 5.42 : NUMERICAL VISIBILITY DISTRIBUTIONS IN CASE 4 AT HUMAN LEVEL AT Z=1.7M ALONG THE TUNNEL IN CASE 4 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	86
FIGURE 5.43 : NUMERICAL VISIBILITY DISTRIBUTIONS IN CASE 4 AT HUMAN LEVEL AT Z=2.2M ALONG THE TUNNEL IN CASE 4 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	87
FIGURE 5.44 : VISIBILITY DISTRIBUTIONS AT Y=5M ALONG THE TUNNEL IN CASE 4 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	88
FIGURE 5.45 : NUMERICAL CO CONCENTRATION DISTRIBUTIONS CASE 4 AT HUMAN LEVEL AT Z=1.7M ALONG THE TUNNEL IN CASE 4 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	89
FIGURE 5.46 : NUMERICAL CO CONCENTRATION DISTRIBUTIONS CASE 4 AT HUMAN LEVEL AT Y=5M ALONG THE TUNNEL IN CASE 4 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	90
FIGURE 5.47 : VELOCITY DISTRIBUTIONS CASE 4 AT HUMAN LEVEL AT Z=1.7M ALONG THE TUNNEL AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	91
FIGURE 5.48 : VELOCITY DISTRIBUTIONS CASE 4 AT HUMAN LEVEL AT Y=5M ALONG THE TUNNEL IN CASE 4 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	92
FIGURE 5.49 : SCHEMATIC DIAGRAM OF THE ARRANGEMENT OF FIRE SOURCE, VENTS AND THE SOLID CURTAIN	93
FIGURE 5.50 : SMOKE SPREAD PROCESS IN Z=1.7M CASE 5 AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	94
FIGURE 5.51 : SMOKE SPREAD PROCESS IN Y=5M CASE 5 AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	95
FIGURE 5.52 : TEMPERATURE CONTOURS DISTRIBUTIONS ALONG THE Z=1.7M TUNNEL IN CASE 5 AT TOP VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	96
FIGURE 5.53 : TEMPERATURE CONTOURS DISTRIBUTIONS ALONG THE Y=5 TUNNEL IN CASE 5 AT SIDE VIEW AT (50 s, 100 s, 200 s, 300 s, 400 s, 500 s AND 600 s)	97