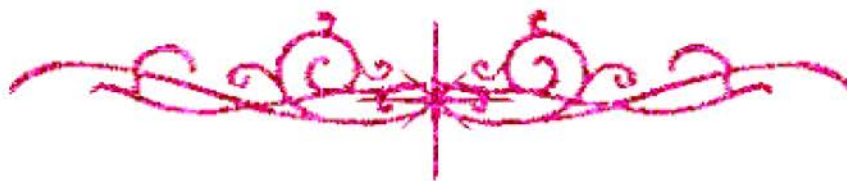


بسم الله الرحمن الرحيم





شبكة المعلومات الجامعية التوثيق الالكتروني والميكروفيلم



جامعة عين شمس

التوثيق الإلكتروني والميكروفيلم

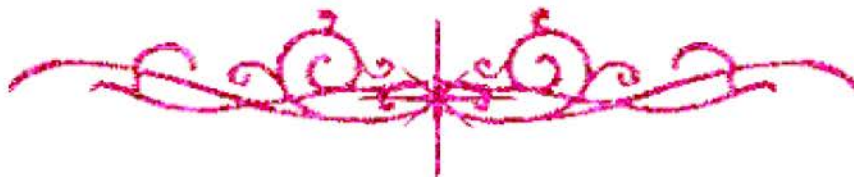
قسم

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





Cairo University

NUMERICAL INVESTIGATION OF VENTILATION METHODS FOR NiCd BATTERIES OF AN INDOOR SUBSTATION

By

Karim Tarek Abd El-Hamid Mohamed Abd El-Aziz

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
2021

NUMERICAL INVESTIGATION OF VENTILATION METHODS FOR NiCd BATTERIES OF AN INDOOR SUBSTATION

By

Karim Tarek Abd El-Hamid Mohamed Abd El-Aziz

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 the Supervision of

Prof. Dr. Mahmoud A. Fouad

Dr. Taher M. Halawa

.....
Professor of
Mechanical Power Engineering
Faculty of Engineering, Cairo University

.....
Assistant Professor
Mechanical Power Engineering
Faculty of Engineering, Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2021

NUMERICAL INVESTIGATION OF VENTILATION METHODS FOR NiCd BATTERIES OF AN INDOOR SUBSTATION

By

Karim Tarek Abd El-Hamid Mohamed Abd El-Aziz

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. Mahmoud Ahmed Fouad,
Professor, Mechanical Power Engineering Department
Faculty of Engineering, Cairo University

Thesis Main Advisor

Prof. Dr. Mostafa Abd-elhamid Rizk,
Professor, Mechanical Power Engineering Department
Faculty of Engineering, Cairo University

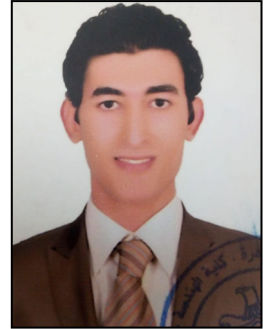
Internal Examiner

Prof. Dr. Mahmoud Abd-elftah Elkady,
Professor of Mechanical Power Engineering Department
Faculty of Engineering, Al-Azhar University

External Examiner

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2021

Engineer's Name: Karim Tarek Abd El- Hamid Mohamed Abd EL-Aziz
Date of Birth: 16/04/1992
Nationality: Egyptian
E-mail: engkarim.m.d@gmail.com
Phone: 0111-948-3000
Address: 24 Madina El Monora st. from Tahrir St. Giza, Egypt
Registration Date: 01/10/2016.
Awarding Date:/....../2021
Degree: Master of Science
Department: Mechanical Power Engineering



Supervisors:

Prof. Dr. Mahmoud A. Fouad
Dr. Taher M. Halawa

Examiners:

Prof. Dr. Mahmoud Ahmed Fouad (Thesis main advisor)
Prof. Dr. Mostafa Abd-elhamed Rizk (Internal examiner)
Prof. Dr. Mahmoud Abd-elftah Elkady (External examiner)
Professor of Mechanical Power Engineering Department,
Faculty of Engineering, Al-Azhar University

Title of Thesis:

**NUMERICAL INVESTIGATION OF VENTILATION METHODS FOR NiCd
BATTERIES OF AN INDOOR SUBSTATION**

Key Words: Ventilation / Indoor air quality / Hydrogen Emissions / NiCd Batteries
Energy Storage

Summary:

Performance of ventilation inside NiCd battery room was investigated numerically utilizing Ansys Fluent 19.0. The model was built and mesh by ANSYS design modeler yielding around 3.4 million elements after making good use of symmetry B.C. Validation was done against experimental published data and comparison between various turbulence models was performed. A parametric study is done to explore the impact of three various factors on the efficiency of the ventilation system. First, the relation between (ACH) utilized and the average hydrogen concentration. Second, the impact of changing inlets and outlet grilles location under fixed 20 (ACH) on hydrogen concentration. Third, the impact of storing batteries in double vertical racks on the ventilation performance, which offered the best ventilation performance utilizing wall type inlet grille at the lower wall section and outlet grille at the roof, while the batteries racks are surrounded by curtains to act as spot ventilation which offered the opportunity for choosing lower value of ACH (10) in order to reduce the equipment and energy cost which maintained an acceptable value of hydrogen concentration 0.66%.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree 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: Karim Tarek Abd El-Hamid Mohamed Abd El-Aziz

Date: / / 2021

Signature:

Acknowledgments

First, I would like to prostrate and praise THE ALMIGHTY ALLAH whose blessing, guide, and mercy have been behind whatever success may have been achieved in this work. I am eternally grateful that his blessings have come in the form of family and friends who have supported me in all my endeavors.

This Thesis would not be successfully completed without the generous support of many people. Firstly, I would like to express my deepest gratitude to my dearest supervisors, **Prof. Dr. Mahmoud A. Fouad and Dr. Taher M. Halawa** for their inspiration, guidance, and valuable advice throughout the preparation of this thesis. Without their kind support and tolerance, I can hardly complete this thesis.

Secondly, I would like to give my sincere thanks to my colleagues at work who helped me a lot.

And finally, I would like to thank my dear **Father Mr. Tarek Abd El-Hamid**, and my dear **Mother** for their encouragement, continuous support, and care during the whole period. Also, I would like to thank my friends and colleagues for helping me in finding data and their valuable suggestions.

Table of Contents

DISCLAIMER.....	I
ACKNOWLEDGMENTS	II
TABLE OF CONTENTS.....	III
LIST OF TABLES	VI
LIST OF FIGURES	VII
NOMENCLATURE	XI
GREEK LETTERS.....	XII
SUPERSCRIPTS AND SUBSCRIPTS.....	XIII
ABBREVIATIONS	XIV
ABSTRACT	XV
CHAPTER 1 : INTRODUCTION	1
1.1. GENERAL.....	1
1.2. BATTERY SAFETY HAZARDS AND CONSIDERATIONS.....	2
1.3. BATTERY TYPES.....	2
1.4. BATTERY APPLICATION.....	4
1.4.1. Classification by service application.....	4
1.4.2. Classification by enclosure	4
1.5. HEATING, VENTILATION AND AIR CONDITIONING DESIGN PERFORMANCE.....	5
1.5.1. Temperature	5
1.5.2. Air humidity	5
1.5.3. Air contaminants	6
1.6. HVAC DESIGN FOR SAFETY	6
1.6.1. Flammable/explosive gases.....	6
1.6.2. Hydrogen traps	6
1.6.3. Thermal runaway	6
1.6.4. Corrosive gases and acid vapour.....	7
1.7. HVAC SYSTEM DESIGN REQUIREMENTS	7
1.7.1. General	7
1.7.2. Indoor Air Quality (IAQ) In Battery Storage Rooms	7
1.7.3. HVAC System Design for ventilation.....	8
1.7.4. Types of ventilation systems.....	9
1.8. BATTERY STORAGE RACKS	10
1.9. THESIS OUTLINE.....	13
CHAPTER 2 : LITERATURE REVIEW	14
2.1. GENERAL.....	14
2.2. SPECIES DISTRIBUTION.....	14
2.3. VENTILATION METHODS	16
2.4. SCOPE OF PRESENT WORK.....	21

CHAPTER 3 : GOVERNING EQUATIONS.....	22
3.1. INTRODUCTION.....	22
3.2. FLUID ELEMENT	22
3.3. MASS CONSERVATION EQUATION (CONTINUITY)	23
3.4. MOMENTUM CONSERVATION EQUATION	23
3.5. ENERGY CONSERVATION EQUATION.....	24
3.6. SPECIES TRANSPORT EQUATION.....	25
3.7. TURBULENCE MODELLING	26
3.7.1. Solution Behaviour for Turbulence Models.....	27
3.7.2. k - ϵ Models	27
3.7.2.1. Standard k - ϵ Model	27
3.7.2.2. Realizable k - ϵ Model.....	28
3.7.2.3. RNG k - ϵ Model	29
3.7.2.4. Definitions Applicable to k - ϵ Models.....	31
3.7.3. The k - ϵ Models	32
3.7.3.1. Standard Wall Functions.....	32
3.7.3.2. Momentum	32
3.7.3.3. Energy	33
3.7.3.4. Species.....	34
3.7.3.5. Turbulence.....	34
3.8. MATHEMATICAL MODEL.....	34
3.8.1. Boundary Conditions	35
3.9. CLOSURE.....	36
CHAPTER 4 : VALIDATION	37
4.1. INTRODUCTION.....	37
4.1.1. P. Gasper et al works.....	37
CHAPTER 5 : RESULTS AND DISCUSSION.....	40
5.1. GENERAL.....	40
5.2. CASE STUDIES DESCRIPTION	40
5.2.1. Parametric Cases	42
5.2.2. Grid Sensitivity	43
5.3. IMPACT OF VENTILATION RATE (ACH) ON HYDROGEN CONCENTRATION	44
5.3.1. Case 1 (ACH = 12)	44
5.3.2. Case 2 (ACH = 17)	49
5.3.3. Case 3 (ACH = 20)	52
5.3.4. Case 1, 2 and 3 results Summaries.....	56
5.4. IMPACT OF INLET AND OUTLET GRILLES LOCATION ON HYDROGEN	57
CONCENTRATION.....	57
5.4.1. Case 4.....	57
5.4.2. Case 5.....	61
5.4.3. Case 6.....	65
5.4.4. Case 7.....	69
5.4.5. Case 8.....	73
5.4.6. Case 3, 4, 5, 6, 7 and 8 results summaries	77
5.5. IMPACT OF STORAGE BATTERIES IN DOUBLE VERTICAL RACKS	80
WITH SINGLE STEPS.....	80

5.5.1.	Case 9	80
5.5.2.	Case 10	85
5.5.3.	Case 11	89
5.5.4.	Case 9, 10 and 11 results Summaries.....	93
5.6.	CASES SUMMARY	95
CHAPTER 6 : CONCLUSION AND RECOMMENDATIONS		96
6.1.	INTRODUCTION.....	96
6.2.	CONCLUSION	96
REFERENCES :.....		97

List of Tables

Table 5.1. BOUNDARY CONDITIONS	42
Table 5.2. ALL CASES STUDIES IN THE CURRENT RESEARCH	42

List of Figures

Figure 1.1: The Wastage cause by the explosion in battery area in California, USA [1]	1
Figure 1.2: The Wastage cause by the explosion in battery area in California, USA [1].....	2
Figure 1.3: Displacement flow within a space [4]	9
Figure 1.4: Entrainment flow within a space [4]	9
Figure 1.5: Underfloor Air Distribution to Occupied Space above [4]	10
Figure 1.6: Batteries Storage Racks, Single Rack – Double Step	11
Figure 1.7: Batteries Storage Racks, Single Rack – Triple Step	11
Figure 1.8: Batteries Storage Racks, Single Rack – Quadruple Step	12
Figure 1.9: Batteries Storage Racks, Double Rack – Double Step	12
Figure 2.1: Schematics of five settings utilized in the numerical study [Y]	10
Figure 2.2: Schemes of air distribution and OPCs location in a test chamber: (1) one-way mixing air supply; (2) four-way mixing air supply; (3) displacement air supply,[8]	16
Figure 2.3: Schematic diagram of the experimental chamber, [10]	17
Figure 2.4: Schematic diagram of the experimental room, [11]	18
Figure 2.5: CFD model arrangements, [13]	19
Figure 2.6: Spatial contours and particle traces with LEV system in operation., [13]	19
Figure 2.7: Layout 1 – Workstations located in the middle with partition in between., [14]	20
Figure 2.8: Layout 2 – Workstations located in the middle with partition in the middle.,[14]...	20
Figure 2.9: Gasper Experimental model layout and boundary conditions., [15]	21
Figure 3.1: Fluid element for conservation laws., [16]	22
Figure 3.2: Stress components on the three faces of the fluid element	24
Figure 3.3: Numerical Model by ANSYS Design Modeler 19.0	35
Figure 4.1: The Validation model built by ANSYS 19.0	37
Figure 4.2: The sketch of physical investigated by Gasper et al., [15]	37
Figure 4.3: Velocity contours at mid – inlet plan ($W/2 = 0.36$ m) of the validation model built by ANSYS 19.0	38
Figure 4.4: Temperature contours at mid – inlet plan ($W/2 = 0.36$ m) of the validation model built by ANSYS 19.0	38
Figure 4.5: Comparing velocity distribution at $x/l = 0.447$; $y/(0.5w) = 0.944$	39
Figure 4.6: Comparing velocity distribution at $Z/H = 0.5$; $y/(0.5w) = 0.944$	39
Figure 5.1: Numerical Model by ANSYS Design Modeler 19.0	41
Figure 5.2: Numerical Model by ANSYS Design Modeler 19.0 showing symmetry boundary	41
Figure 5.3: Comparing Hydrogen Concentration % distribution at the middle of the room ($x=2.5$ m, $y=1.25$ m) while using different grid sizes for case 3	43
Figure 5.4: Comparing velocity distribution at the middle of the room ($x=2.5$ m, $y=1.25$ m) while using different grid sizes for case 3	44
Figure 5.5: Numerical Model by ANSYS Design Modeler 19.0 for case 1,2 &3	45
Figure 5.6: Contour of H_2 Concentration (%) at $X=1.9$ m (Case – 1)	45
Figure 5.7: Contour of H_2 Concentration (%) at $X=2.5$ m (Case – 1)	46
Figure 5.8: Contour of H_2 Concentration (%) at $X=3.375$ m (Case – 1)	46
Figure 5.9: Contour of H_2 Concentration (%) at $Y=0.475$ m (Case – 1)	47
Figure 5.10: Contour of H_2 Concentration (%) at $Y=0.9125$ m (Case – 1)	47
Figure 5.11: Contour of H_2 Concentration (%) at $Y=1.7$ m (Case – 1)	48

Figure 5.12: Streamline of velocity magnitude in m/s (Case – 1)	48
Figure 5.13: Contour of H2 Concentration (%) at X=1.9 m (Case – 2)	49
Figure 5.14: Contour of H2 Concentration (%) at X=2.5 m (Case – 2)	49
Figure 5.15: Contour of H2 Concentration (%) at X=3.375 m (Case – 2)	50
Figure 5.16: Contour of H2 Concentration (%) at Y=0.475 m (Case – 2)	50
Figure 5.17: Contour of H2 Concentration (%) at Y=0.9125 m (Case – 2)	51
Figure 5.18: Contour of H2 Concentration (%) at Y=1.7 m (Case – 2)	51
Figure 5.19: Streamline of velocity magnitude in m/s (Case – 2)	52
Figure 5.20: Contour of H2 Concentration (%) at X=1.9 m (Case – 3)	52
Figure 5.21: Contour of H2 Concentration (%) at X=2.5 m (Case – 3)	53
Figure 5.22: Contour of H2 Concentration (%) at X=3.375 m (Case – 3)	53
Figure 5.23: Contour of H2 Concentration (%) at Y=0.475 m (Case – 3)	54
Figure 5.24: Contour of H2 Concentration (%) at Y=0.9125 m (Case – 3)	54
Figure 5.25: Contour of H2 Concentration (%) at Y=1.7 m (Case – 3)	55
Figure 5.26: Streamline of velocity magnitude in m/s (Case – 3)	55
Figure 5.27: Average H2 Concentration at different Ventilation rate for Case 1, 2 and 3	56
Figure 5.28: Numerical Model by ANSYS Design Modeler 19.0 showing symmetry boundary – Case 4	57
Figure 5.29: Contour of H2 Concentration (%) at X=1.9 m (Case – 4)	58
Figure 5.30: Contour of H2 Concentration (%) at X=2.5 m (Case – 4)	58
Figure 5.31: Contour of H2 Concentration (%) at X=3.375 m (Case – 4)	59
Figure 5.32: Contour of H2 Concentration (%) at Y=0.475 m (Case – 4)	59
Figure 5.33: Contour of H2 Concentration (%) at Y=0.9125 m (Case – 4)	60
Figure 5.34: Contour of H2 Concentration (%) at Y=1.7 m (Case – 4)	60
Figure 5.35: Streamline of velocity magnitude in m/s (Case – 4)	61
Figure 5.36: Numerical Model by ANSYS Design Modeler 19.0 showing symmetry boundary – Case 5	61
Figure 5.37: Contour of H2 Concentration (%) at X=1.9 m (Case – 5)	62
Figure 5.38: Contour of H2 Concentration (%) at X=2.5 m (Case – 5)	62
Figure 5.39: Contour of H2 Concentration (%) at X=3.375 m (Case – 5)	63
Figure 5.40: Contour of H2 Concentration (%) at Y=0.475 m (Case – 5)	63
Figure 5.41: Contour of H2 Concentration (%) at Y=0.9125 m (Case – 5)	64
Figure 5.42: Contour of H2 Concentration (%) at Y=1.7 m (Case – 5)	64
Figure 5.43: Streamline of velocity magnitude in m/s (Case – 5)	65
Figure 5.44: Numerical Model by ANSYS Design Modeler 19.0 showing symmetry boundary – Case 6	65
Figure 5.45: Contour of H2 Concentration (%) at X=1.9 m (Case – 6)	66
Figure 5.46: Contour of H2 Concentration (%) at X=2.5 m (Case – 6)	66
Figure 5.47: Contour of H2 Concentration (%) at X=3.375 m (Case – 6)	67
Figure 5.48: Contour of H2 Concentration (%) at Y=0.475 m (Case – 6)	67
Figure 5.49: Contour of H2 Concentration (%) at Y=0.9125 m (Case – 6)	68
Figure 5.50: Contour of H2 Concentration (%) at Y=1.7 m (Case – 6)	68
Figure 5.51: Streamline of velocity magnitude in m/s (Case – 6)	69
Figure 5.52: Numerical Pattern by ANSYS Design Modeler 19.0 appearing symmetry boundary – Case 7	69