

GEOMETRY OPTIMIZATION DRY ICE BLASTING NOZZLE FOR THE NOISE
REDUCTION USING EXPERIMENTAL VALIDATION

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In the name of God, The Most Gracious, The Most Merciful.

Specially for my beloved mother and father



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ABSTRACT

Dry ice blasting provides many advantages to surface cleaning in which the blasting medium sublimate during the surface impact will not leave a secondary contamination. However, on the negative side of dry ice blasting (DIB), it produces a high noise exposure. The noise exposure during a high blasting pressure may reach up to 130 dB which is considered a harmful noise level (standard 90 dB for eight working hours per day). At present, safety measures are taken according to administrative control that encapsulates the whole system with sound insulation. This limitation has made this research work a significant contribution to dry ice blasting industry. The main objectives of this project are to examine the dry ice blasting's flow characteristic on the influence of noise emission and to establish optimum parameters affecting the acoustic noise emission. The experimental validation on the effect of impact force and noise emission for optimum nozzle design is investigated. ANSYS fluent version 18.2 is employed in this study to simulate the fluid flow and acoustic noise in the nozzle. Six (6) different nozzle geometries are analyzed namely divergent length, convergent diameter, expansion ratio, gas inlet diameter, length ratio, and particle inlet angle. The optimum nozzle geometry is fabricated and validated throughout the experimental study on the effect of the impact force and sound pressure level for different pressures. The result shows that the optimum DIB nozzle geometry that satisfy the research objectives for gas inlet length, convergent diameter, particle inlet angle, divergent length, convergent length, gas inlet diameter, expansion ratio are 36 mm, 35 mm, 50°, 230 mm, 45mm, 6 mm and 1.00 respectively. This research is expected to provide a novelty design of dib nozzle geometry that able to protect the society from the hazardous working environment by engineering control.

ABSTRAK

Pembersihan menggunakan ais kering memberikan banyak kelebihan dan bersifat pro-alam sekitar yang mana bahan ais kering tersebut akan mengalami proses pemejalwapan ketika pembersihan, tanpa mengeluarkan kotoran sekunder. Walau bagaimanapun, kelemahan utama semburan menggunakan ais kering ini ialah bunyi bising yang terlalu kuat. Semburan dengan tekanan yang tinggi akan memberi kesan buruk kepada manusia jika bunyi bising tersebut mencapai sehingga 130 dB (kebiasaan 90 dB untuk 8 jam bekerja). Keselamatan yang sedia ada hanya bergantung kepada kawalan pentadbiran dengan mengasingkan bunyi bising. Kekurangan tersebut menjadikan kajian ini penting yang akan memberi sumbangan kepada industri ini. Objektif utama projek ini ialah untuk mengenalpasti karakter aliran ais kering terhadap bunyi bising dan mewujudkan parameter penting yang memberi kesan terhadap bunyi bising dan juga mengesahkan kajian dengan menjalankan ujikaji terhadap daya hentaman dan tahap bunyi bising. Analisa kajian ini menggunakan perisian “CFD, ANSYS Fluent” untuk membuat simulasi aliran cecair dan mengetahui tahap bunyi bising yang dihasilkan daripada nozel. Enam (6) geometri nozel dianalisa iaitu panjang pencapahan, diameter pertemuan, nisbah pengembangan, diameter kawasan masuk gas, nisbah panjang dan sudut masuk zarah digunakan untuk menyiasat kesan terhadap bunyi bising. Bentuk nozel yang optimum telah direkacipta untuk mengesahkan kajian simulasi terhadap kesan daya hentaman dan tahap bunyi bising pada tekanan yang berbeza-beza. Keputusan kajian menunjukkan bahawa bentuk nozel yang optimum yang dapat memenuhi objektif kajian untuk panjang gas masuk, diameter pertemuan, sudut masuk zarah, panjang pencapahan, panjang pertemuan, diameter kawasan masuk gas and nisbah pengembangan ialah 36 mm, 35 mm, 50°, 230 mm, 45mm, 6 mm and 1.00. Kajian ini dijangka akan memberi impak positif kepada masyarakat apabila bunyi bising di tempat kerja dikurangkan melalui kawalan kejuteraan.

CONTENTS

CHAPTER	TTITLE	PAGE
	TITLE	i
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	LIST OF FIGURES	xiii
	LIST OF TABLES	xvii
	LIST OF SYMBOLS AND ABBREVIATIONS	x
	LIST OF APPENDICES	xx
CHAPTER 1	INTRODUCTION	1
	1.1 General	1
	1.2 Background	1
	1.3 Problem Statement	4
	1.4 Research Objectives	4
	1.5 Research Questions	5
	1.6 The Scope of Study and Limitation	5
	1.7 Outline of the Thesis	6

CHAPTER 2 LITERATURE REVIEW	8
2.1 Introduction	8
2.2 History of Dry Ice Blasting	8
2.3 Basic Principles of Dry Ice Blasting Operation	9
2.4 Phase Diagram of Carbon Dioxide as Dry Ice Pellets	10
2.5 Application of Dry Ice Blasting	11
2.6 Active Mechanism of Dry Ice Blasting	12
2.7 Performance of Dry Ice Cleaning	12
2.8 Factors Affecting Surface Cleaning for Dry Ice Blasting	13
2.8.1 Dry Ice Blasting Nozzle Geometry	13
2.8.2 Physical Property of Dry Ice Media	17
2.8.3 Stand off Distance	18
2.8.4 Impact of Particle Angle	18
2.8.5 Local Pressure on Surface	19
2.8.6 Temperature	19
2.8.7 Dwell Time	19
2.9 Noise Measurements	20
2.10 OSHA Regulations	21
2.11 Acoustic Noise of Dry Ice Blasting Nozzle Geometry	22
2.12 Simulation Optimization Method for Dry Ice Blasting	24
2.13 Selection of Optimization Method for Dry Ice Blasting	28
2.13.1 Response Surface Optimization Method	29
2.14 Measuring Guide for Sound Power	30
2.14.1 Method of Measuring Sound Power	31
2.14.2 Method of Measuring Sound Pressure - Based Sound Power	32
2.14.3 Method of Measuring Sound Intensity-Based Sound Power	33
2.14.4 Method of Measuring Sound Pressure - Based Methods	34

2.14.5	Method of Measuring Sound Intensity-Based Methods	43
2.14.6	Instrumentation for Sound Power Determination	48
2.15	Summary	49

CHAPTER 3 METHODOLOGY 51

3.1	Introduction	51
3.2	Overview of Flow Chart	52
3.3	Computational Fluid Dynamic Analysis	54
3.3.1	Application for Designing Three Dimensional Nozzle Geometry	54
3.3.2	Geometrical Modeling of Dry Ice Blasting Nozzle	54
3.3.3	Based Model of Dry Ice Blasting Nozzle Geometry	55
3.3.4	Nozzle Dimension of Dry Ice Blasting	56
3.3.5	Computational Fluid Dynamic Simulation	57
3.3.6	Meshing for Dry Ice Blasting Nozzle	58
3.3.7	Grid Independent Test	59
3.3.8	Mesh Quality Recommendations	60
3.3.9	Verification of Mesh Quality	61
3.3.10	Mesh Property in Ansys Mesh	62
3.3.11	Conditions of the Boundary	62
3.3.12	Parameter Setup in ANSYS Fluent	63
3.4	Design of Experiment for Response Surface Optimization	65
3.5	Design Point of Multiple Input Parameter	65
3.6	Parameter Parallel Chart	68
3.7	Geometrical Modeling and Simulation for Optimum Nozzle Geometry	69
3.7.1	Optimum Nozzle Dimension	70
3.7.2	Convergence Criterion in ANSYS Fluent	71
3.8	Fabricated Design Model	72
3.8.1	Based Model for Dry Ice Blasting Nozzle Geometry	73

3.8.2	Optimum Model for Dry Ice Blasting Nozzle Geometry	73
3.9	Fabrication of Base Design Models	74
3.10	Fabrication of Optimum Design Models	75
3.11	Testing Instrument	76
3.11.1	Force Impact Sensor	76
3.11.2	Programming Software - Arduino Development Environment (IDE)	78
3.11.3	Programming Source Code for Load Cell	79
3.11.4	Calibration Procedure of Force Impact Sensor	82
3.11.5	Selecting the Calibration Factor	83
3.11.6	Sound Analyzer	84
3.11.7	Sound Level Meter Interface	85
3.11.8	Calibration Procedure for Sound Level Meter	85
3.12	Equipment Setup of Dry Ice Blasting on Measuring Force Impact	86
3.12.1	Schematic Diagram of Dry Ice Blasting System on Measuring Force Impact	87
3.13	Experimental Setup of Dry Ice Blasting on Measuring Noise Level	89
3.13.1	Schematic Diagram of Dry Ice Blasting System on Measuring Noise Level	90
3.14	Summary	92
CHAPTER 4 RESULT AND DISCUSSION		93
4.1	Introduction	93
4.2	Verification of Dry Ice Blasting Nozzle Geometry	93
4.3	Maximum Particle Velocity against Divergent Length	97
4.4	Maximum Acoustic Power Level against Divergent Length	101
4.5	Relationship of Maximum Particle Velocity and Maximum Acoustic Power Level against the Divergent Length	105
4.6	Maximum Particle Velocity against Particle Inlet Angle	106

4.7	Maximum Acoustic Power Level against Particle Inlet Angle	109
4.8	Relationship of Maximum Particle Velocity and Maximum Acoustic Power Level against Particle Inlet Angle	113
4.9	Maximum Particle Velocity against Convergent Diameter	114
4.10	Maximum Acoustic Power Level against Convergent Diameter	117
4.11	Relationship of Maximum Particle Velocity and Maximum Acoustic Power Level against Convergent Diameter	120
4.12	Maximum Particle Velocity against Expansion Ratio	121
4.13	Maximum Acoustic Power Level against Expansion Ratio	124
4.14	Relationship of Maximum Particle Velocity and Maximum Acoustic Power Level against Expansion Ratio	127
4.15	Maximum Particle Velocity against Gas Inlet Diameter	128
4.16	Maximum Acoustic Power Level against Gas Inlet Diameter	131
4.17	Relationship of Maximum Particle Velocity and Maximum Acoustic Power Level against Gas Inlet Diameter	135
4.18	Maximum Particle Velocity against Length Ratio	136
4.19	Maximum Acoustic Power Level against Length Ratio	139
4.20	Relationship of Maximum Particle Velocity and Maximum Acoustic Power Level against Length Ratio	143
4.21	Local Sensitivity Analysis	144
4.22	Optimization using Response Surface for Acoustic Power Level	145
4.23	Optimization using Response Surface for Particle Velocity	147
4.24	Optimization using Response Surface for Impact Force	149
4.25	Candidate Point for Optimum Nozzle Geometry	151
4.25.1	Maximum Particle Velocity on the Optimum Nozzle Geometry	152
4.25.2	Maximum Acoustic Power Level on the Optimum Nozzle Geometry	152

4.25.3	Comparison of Simulation Result for Optimum and Reference Nozzle	153
4.26	Data Logging Force Impact on Various Pressure for Based Design	154
4.27	Data Logging of Force Impact on Various Pressure for Optimum Design	155
4.28	Data Logging Sound Pressure Level on Various Pressure for Based Design	155
4.29	Data Logging Sound Pressure Level on Various Pressure for Optimum Design	156
4.30	Experimental Result on the Effect of Force Impact with the Various Pressure	157
4.31	Experimental Result on the Sound Emission with the Various Pressure	158
4.32	Validation of Result of Impact Force	159
4.33	Validation Result of Sound Measurement	160
4.34	Summary	161
CHAPTER 5 RESULT AND DISCUSSION		162
5.1	Recommendation	164
REFERENCES		165
APPENDICES		173

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Active mechanism of dry ice blasting	2
1.2	Mood of CO ₂ released into the atmosphere	2
2.1	Phase diagram of CO ₂	10
2.2	Type of dry ice blasting nozzle	14
2.3	A-Weighted Decibel Scale in dBA	20
2.4	Sound Pressure Level with Distance	21
2.5	OSHA Table for Permissible Noise Exposure	22
2.6	A Simulation Model	24
2.7	Simulation optimization model	25
2.8	Simulation optimization method	26
2.9	Process flow of optimization method	30
2.10	Reference sound source measured with the use of a half-hemisphere microphone array	38
2.11	(a) Fixed positions of microphones on a hemisphere (b) Coaxial circular paths for a moving microphone or source (c) Meridional path for a moving microphone (d) Spiral path for the moving microphone	41
2.12	Measurement surfaces with measurement points indicated	45
2.13	Surfaces measurement with scanning paths	46
2.14	Orthogonal scanning paths on a partial rectangular surface	48
3.1	Process flowchart	53
3.2	Typical process of creating geometry	54
3.3	Modeling of reference model	55
3.4	Geometrical modelling of dry ice blasting nozzle	56

3.5	Geometrical dimension of the nozzle	57
3.6	Meshed model of dry ice blasting nozzle	59
3.7	Skewness and orthogonal mesh metric spectrum	61
3.8	Parameter Parallel Chart	68
3.9	Modeling of Optimum Nozzle Geometry using CATIA V5R20	69
3.10	Dimension of Optimum Nozzle Geometry	71
3.11	Residual convergence for CFD Simulation	72
3.12	Cross section of a fabricated model for based design	73
3.13	Cross section of a fabricated model for optimum design	74
3.14	Force impact sensor	77
3.15	Schematic diagram for a force impact sensor	78
3.16	Interface of the Arduino development environment	79
3.17	Programming source code for the load sensor cell	81
3.18	Calibration setup for force impact sensor	82
3.19	Sound analyzer brand TES 1358	84
3.20	Calibration process for a sound analyzer	86
3.21	Equipment setup for dual hose dry ice blasting system	87
3.22	Schematic diagram for dry ice blasting system	88
3.23	Equipment setup of dry ice blasting on measuring sound level	90
3.24	Schematic diagram of dry ice blasting on measuring the noise level	91
4.1	Simulation result on particle velocity magnitude for different input pressure (a) 0.2 MPa (b) 0.4 MPa (c) 0.6 MPa (d) 0.8 MPa	96
4.2	Simulation result on particle velocity magnitude for different divergent length (a) 190mm (b) 210mm (c) 230mm (d) 270mm (e) 290mm	100
4.3	Simulation result on acoustic power level for different divergent length (a) 190mm (b) 210mm (c) 230mm (d) 270mm (e) 290mm	104
4.4	Maximum particle velocity and maximum acoustic power level on the different divergent length	105
4.5	Simulation result on particle velocity magnitude for different particle inlet angle (a) 10° (b) 20° (c) 30° (d) 40° (e) 50° (f) 60°	109

4.6	Simulation result on acoustic power level for different particle inlet angle (a) 10° (b) 20° (c) 30° (d) 40° (e) 50° (f) 60°	112
4.7	Maximum particle velocity and maximum acoustic power level on a different angles of particle inlet	114
4.8	Simulation result on particle velocity magnitude for different convergent diameter (a) 20 mm (b) 25 mm (c) 30 mm (d) 35 mm	116
4.9	Simulation result on acoustic power level for different convergent diameter (a) 20 mm (b) 25 mm (c) 30 mm (d) 35 mm	119
4.10	Maximum particle velocity and maximum acoustic power level on the different convergent diameter	120
4.11	Simulation result on particle velocity magnitude for different expansion ratio (a) 1.00 (b) 1.75 (c) 2.50 (d) 3.25 (e) 4.00	123
4.12	Simulation result on acoustic power level for different expansion ratio (a) 1.00 (b) 1.75 (c) 2.50 (d) 3.25 (e) 4.00	126
4.13	Maximum particle velocity and maximum acoustic power level on the different expansion ratios	127
4.14	Simulation result on particle velocity magnitude for different gas inlet diameter (a) 1 mm (b) 2 mm (c) 3 mm (d) 4 mm (e) 5 mm (f) 6 mm	131
4.15	Simulation result on acoustic power level for different gas inlet diameter (a) 1 mm (b) 2 mm (c) 3 mm (d) 4 mm (e) 5 mm (f) 6 mm	134
4.16	Maximum particle velocity and maximum acoustic power level on different gas inlet diameters	135
4.17	Simulation result on particle velocity magnitude for different length ratio (a) 0.10 (b) 0.20 (c) 0.40 (d) 0.60 (e) 0.67 mm (f) 0.80	139
4.18	Simulation result on acoustic power level for different length ratio (a) 0.10 (b) 0.20 (c) 0.40 (d) 0.60 (e) 0.67 mm (f) 0.80	142
4.19	Maximum particle velocity and maximum acoustic power level on different length ratios	143
4.20	Local Sensitivity Bar Chart	145

4.21	Response Surface Chart on Acoustic Power Level (a) Expansion Ratio and Convergent Diameter against Acoustic Power Level (b) Expansion Ratio and Convergent Length against Acoustic Power Level	147
4.22	Response Surface on Particle Velocity (a) Convergent Length and Convergent Diameter against Particle Velocity (b) Convergent Length and Expansion Ratio against Particle Velocity	149
4.23	Response Surface Chart on Impact Force Level (a) Expansion Ratio and Convergent Diameter against Impact Force (b) Expansion Ratio and Convergent Length against Impact Force	150
4.24	Maximum Particle Velocity on Optimum Nozzle Geometry	152
4.25	Maximum acoustic power on the Optimum Nozzle Geometry	153
4.26	Data logging of force impact against pressure for based design	154
4.27	Data logging of force impact against pressure for optimum design	155
4.28	Data logging of sound pressure level against pressure for based design	156
4.29	Data logging of sound pressure level against pressure for optimum design	157
4.30	Impact force of dry ice blasting against various pressures	158
4.31	Sound pressure level in dBA of dry ice blasting against various pressure	159



LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Application of Dry Ice Blasting	11
2.2	Method of optimization for simulation	27
2.3	Selection matrix for optimization method	28
2.4	List of sound power as per ISO standards	32
2.5	Precision method in a reverberant room	34
2.6	Engineering method in a hard-walled room	35
2.7	Engineering method in unique reverberation rooms	36
2.8	Engineering method in essentially free-field	37
2.9	Precision method in anechoic or semi-anechoic rooms	38
2.10	Survey method with no special test environment	41
2.11	Engineering or survey method in situ in a reverberant environment	42
2.12	Precision, engineering or survey discrete measurement points method	44
2.13	Engineering or survey scanning measurement method	45
2.14	Precision scanning measurement method	47
2.15	Summary of research gap	50
3.1	Dimension of Nozzle Geometry	56
3.2	Generated grid independent test	60
3.3	Skewness and orthogonal mesh metric for nozzle geometry	61
3.4	Generated mesh size	62
3.5	Input parameter used in this study	63
3.6	Input variable for design point	65
3.7	generated design point of multiple parameter	66
3.8	Dimension of Optimum Nozzle Geometry	70

3.9	Fabricated base model dimension	75
3.10	Fabricated optimum model dimension	75
3.11	Process of selecting the best calibration factor	83
4.1	Relative error on difference pressure inlets	94
4.2	Candidate point for multiple input parameter	151
4.3	Comparison of both reference and optimum nozzle geometry in terms of particle velocity magnitude and acoustic power level	153
4.4	Validation of Theoretical and Experimental Value of Impact Force	160
4.5	Validation of Theoretical and Experimental Value of Sound Measurement	161



LIST OF SYMBOLS AND ABBREVIATIONS

CO ₂	-	Carbon Dioxide
CFD	-	Computational Fluid Dynamic
CATIA	-	Computer Aided Three Dimensional Interactive Application
CFX	-	Central Florida Expressway
DIB	-	Dry Ice Blasting
D _{co}	-	Convergent Diameter
D _{ig}	-	Inlet Gas Diameter
ES	-	Evolutionary Strategies
FDE	-	Frequency Domain Experiments
GA	-	Genetic Algorithms
ISO	-	International Organization for Standardization
IEC	-	International Electrotechnical Commission
LR	-	Likelihood Ratio Estimators
L _{di}	-	Divergent Length
L _{ig}	-	Inlet Gas Length
NIOSH	-	National Institute for Occupational Safety and Health
OSHA	-	Occupational Safety and Health Administration
PELS	-	Permissible Exposure Limits
PA	-	Perturbation Analysis
RSM	-	Response Surface Methodology
SPL	-	Sound Pressure Level
SA	-	Simulated Annealing
TWA	-	Time Weighted Average
TS	-	Tabu Search
UTHM	-	Universiti Tun Hussein Onn Malaysia

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A-1	Dry ice pellets hopper	174
A-2	Internal dimension of base design nozzle	175
A-3	Internal dimension of optimum design nozzle	175
A-4	Connections and accessories for dry ice blasting system	176
A-5	Dry ice blasting hose of size 3/4 inch	177
A-6	Compressed air hose of size 1/2 inch	177
A-7	Air compressor of 8 bars	178
A-8	3 mm diameter of dry ice pellet of 10 kg	178
A-9	Nozzle stand holder	179
B-1	Arduino Uno as a microcontroller	181
B-2	Aluminum plate for an impact force sensor	181
B-3	Load cell sensor of maximum 10 kg	182
B-4	Breadboard 8.5 cm x 5.5 cm	182
B-5	HX711 ADC module for load sensor converter	183
B-6	I2C 1602 Serial LCD for Arduino microcontroller	183
B-7	Standard USB B type cable	184
B-8	Laptop brand HP intel inside core i5	184
C-1	Sound analyzer brand TES 1358	186
C-2	Tripod stand for holding sound analyzer	187
C-3	Standard acoustic calibrator brand CAL 200	188
C-4	Air velocity meter TA440	189
D-1	Calibration Certificate of Sound Calibrator	191

CHAPTER 1

INTRODUCTION

1.1 General

Chapter 1 explores a research background of noise emission in dry ice blasting industry. It starts with the mechanism of dry ice blasting surface cleaning that consists of three (3) mechanisms which are sublimation, mechanical and thermal effect. These active mechanisms represent the processes for surface removal. This section also outlines the effect of noise emission, the factor affecting the noise level, and a current method to control noise exposure. The main issues on noise emission from the dry ice blasting process are also discussed in problem statements, objectives and scope of the study, limitations, and significance of the study subtopics.

1.2 Background

Dry ice blasting is in fact a carbon dioxide (CO₂) cleaning process in its solid form. During the process, dry ice pellets are accelerated by pressurized air stream and the nozzle is directed toward contaminated surfaces. The process of dry ice blasting is can be according to three combined mechanisms; thermal, mechanical and sublimation effect. The left picture shows the thermal mechanism of dry ice blasting, the middle picture shows the mechanical effect when dry ice pellets hit the surface, and the right picture shows the effect of sublimation process where the dry ice pellets expand their volume and crack the contaminant on the surface. See Figure 1.1 for the three (3) active mechanisms of dry ice blasting.

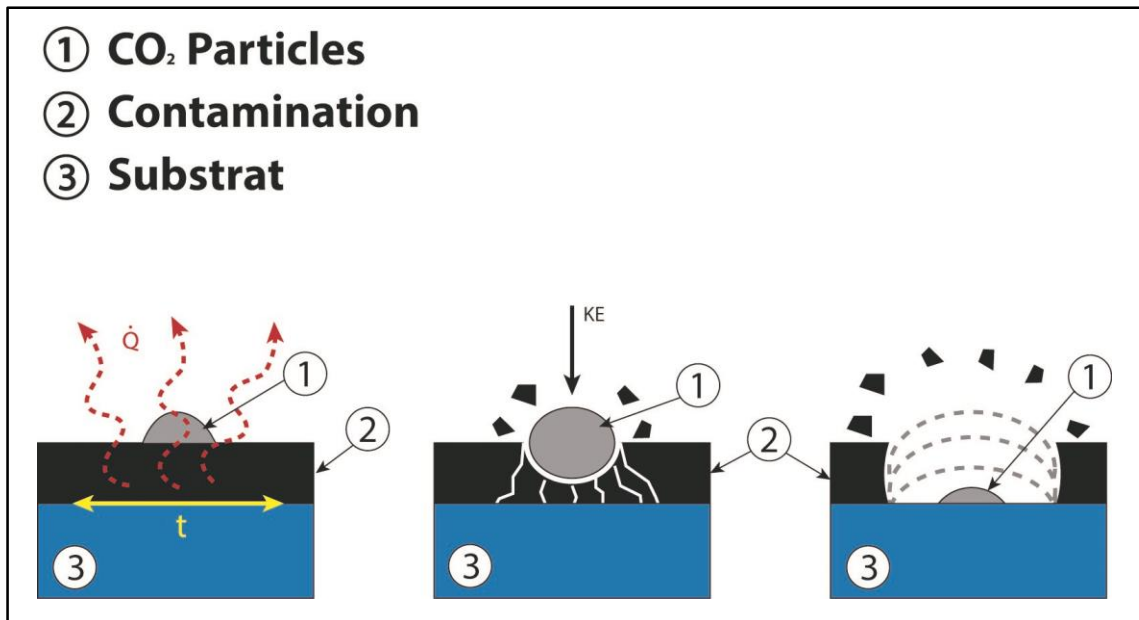


Figure 1.1: Active mechanism of dry ice blasting (Uhlmann & El Mernissi, 2008)

The thermal effect happens because of the differences in thermal coefficient happening between surface contaminant and substrate which cause the embrittle of contaminant. A supersonic speeds hitting on the surface by blasting medium creates a kinetic energy which eventually creates a mechanical effect.

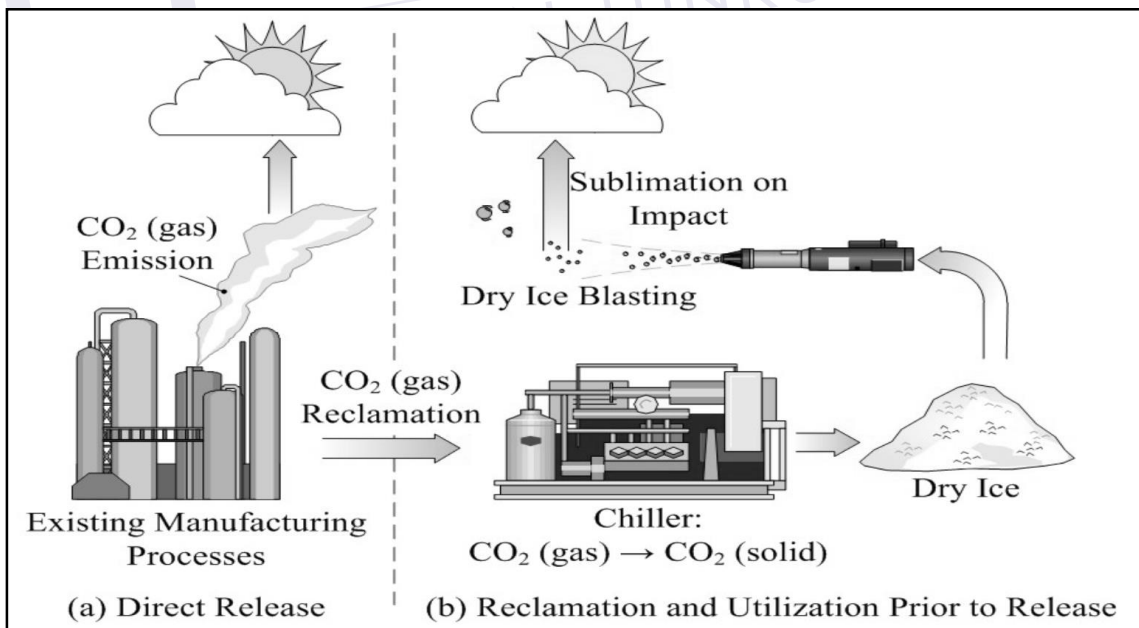


Figure 1.2: Mood of CO₂ released into the atmosphere (Millman & Giancaspro, 2012)

Despite of advantages and zero hazardous to the environment, dry ice blasting for cleaning contaminated surfaces as can be seen in Figure 1.2 is reported to produce high noise exposures up to 130 dBA that is considered as harmful for humans (Uhlmann & El Mernissi, 2008). To make things worse, the noise could occur in low-frequency areas that are undetectable by humans' ears (Uhlmann & Hollan, 2015). The level of noise emission generated by dry ice blasting is influenced by the nozzle geometry, type of nozzle, shape and surface texture of the surface being blast, the amount of dampness presented in the compacted air supply, the moistness of the day, stand-off distance and location at which the reading is taken. Set surfaces raise noise levels because of stream screech. High humidity raises noise levels because of excellent sound transmission over the dry air, and furthermore due to the addition of dampness to the ready air supply, noise levels rise because the dampness is solidified into precious ice stones and removed with the impacted stream (Uhlmann & Hollan, 2015). Current safety measures rely heavily on organizational measures which do not segregate the levels of noise but instead encapsulating the entire system by sound insulation. The measure is also on personal discretion using safety hearing protection. Noise or any annoying sound is the most well-known word pertaining to dangers in any working environment. 30 million labourers in the United States, gauged by National Institute for Occupational Safety and Health (NIOSH) are exposed to perilous noise. Long exposures to abnormal levels and amounts of noise may cause loss of hearing, promote pressures physically and mentally, diminish efficiency, interfere a communication, and lead to mischances and wounds due to lack of awareness on cautioning signals (Occupational Safety and Health Administration, 2019). This project presented possible technical safety measures to reduce noise emission from dry ice blasting nozzles. Analysis using CFD gained the first insight into the noise emission's flow characteristic particularly in the blasting nozzle design area. Nozzle geometry concerning the turbulent intensity model was presented. Appropriate design measures and critical parameters influence noise reduction were also investigated in this study.

1.3 Problem Statement

Dry ice technology has been used widely in many industries ranging from cleaning electrical component to big blasting jobs due to its versatility. However, high noise emission coming from a nozzle during dry ice blasting process would be its primary disadvantage. The worst case scenario, at a high blasting pressure, a harmful noise level of up to 130 dBA might be experienced (Uhlmann & El Mernissi, 2008). The situation significantly impairs a human being when the noise emission occurs in the low-frequency area that human ears cannot detect the frequency. Current safety measures rely heavily on organizational measures which do not segregate the levels of noise but instead encapsulating the entire system by sound insulation. The measure is also on workers' own discretion using safety hearing protection. Although there have been many researchers conducted the study on the parameter optimization on the performance of dry ice blasting technology, but they took for granted the effects of noise generation from dry ice blasting nozzle geometry. This limitation has made this research work a significant contribution to dry ice blasting industry as noise emission critically needs to be reduced. Therefore, the engineering approach to safety measures is implemented in this research.

1.4 Research Objectives

This study was to fulfill the below stated objectives:

1. To obtain the flow characteristic in terms of particle velocity magnitude and acoustic power level for different nozzle geometries.
2. To investigate optimum parameters that affect both performances of acoustic noise emission and dry ice pellets velocity.
3. To validate the simulation result with experimental work for an optimum nozzle design based on the sound pressure level and impact force.

This project was expected to provide industry players or users of dry ice blasting with a technology that increases the performance and provide information on the economic feasibility and environmental impact and health effect with respect to it.

1.5 Research Questions

1. What is the flow characteristic of dry ice blasting that concerning noise level
2. Does dry ice blasting nozzle geometry influence the acoustic noise level?
3. What is the optimum parameter of nozzle geometry that affects performance dry ice blasting in terms of noise and velocity magnitude?
4. Does experiment show good agreement with the simulation result?

1.6 The Scope of Study and Limitation

This current study ought to study the improvement of existing dry ice blasting nozzle design in terms of particle velocity magnitude and acoustic power level. The type of nozzle selection a double hose convergent-divergent nozzle geometry. The simulation was meant to investigate the flow characteristic as the experiment was difficult to be performed inside the nozzle geometry. Six (6) different nozzle parameters were simulated namely expansion ratio, gas inlet diameter, divergent length, length ratio, convergent diameter, and inlet angle to determine the flow characteristic pertaining acoustic noise emission. These parameters were simulated using a constant pressure of 6 bar and 1.2 kg/s as boundary conditions. A constant pressure of 6 bar was used because the previous researcher was conducted the study done by Dong et. al in 2013 using 6 bar pressure throughout their simulation process. Thus, their simulation result can be comparable with the optimum design nozzle geometry. On the other hand, for the experimental part, the compressed air pressure was set as 2 bar, 3 bar, 4 bar, 5 bar, and 6 bar. These sets of values were referred from previous researcher study done Spur et. al in 1999. In addition, validation study comparing simulation with experimental result can be done by focusing on only 6 bar pressure. Apart from that, this study did not consider the design optimization on the compressor and the equipment of dry ice blasting, also sublimation process of dry ice blasting after the impact. The method of selection for the optimum parameter is based on the Response Surface Method for finding the optimization result. On the other hand, the duration of measuring impact force and sound pressure level was ten (10) seconds on every experiment. The working distance between the load cell sensor to the aperture of

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