RESEARCH REPORT UMP GRANT

Laporan Prestasi Skim Geran UMP

Final	√	Progress		*Progress Period : Final*	*√ Please tick*

PROJECT DETAILS *(Keterangan Projek)*

A	**Grant No**	RDU1703252
	Faculty/CoE	FACULTY OF MANUFACTURING ENGINEERING
	Project Title	PERFORMANCE STUDY OF ORGANIC BASED MINIMUM QUANTITY LUBRICATION ON MACHINING DIFFICULT-TO-CUT MATERIAL
	Project Leader	DR. AHMAD SHAHIR BIN JAMALUDIN
	Project Member	1.NURUL HIDAYAH BINTI RAZAK 2.AHMAD NAJMUDDIN BIN IBRAHIM 3.MUHAMMED NAFIS BIN OSMAN ZAHID 4.NURRINA BINTI ROSLI 5.AHMAD RAZLAN BIN YUSOFF 6.AMIRIL SAHAB BIN ABDUL SANI 7.MOHD NIZAR BIN MHD RAZALI

PROJECT ACHIEVEMENT *(Pencapaian Projek)*

B

ACHIEVEMENT PERCENTAGE				
Project progress according to milestones achieved up to this period	**0 - 25%**	**26 - 50%**	**51 - 75%**	**76 - 100%**
Percentage (please state %)				√

EXPENDITURE *(Perbelanjaan)*

C

Budget Approved *Peruntukan diluluskan*	**Amount Spent** *Jumlah Perbelanjaan*	**Balance** *Baki*	**% of Amount Spent** *Peratusan Belanja*
RM 20500.00	**RM 20398.16**	**RM101.84**	**99.5%**

RESEARCH OUTPUT *(Output Penyelidikan)*

D

NO OF PUBLICATION

KPI FOR NO OF PUBLICATION

	ISI	Scopus	Index Proceedings	Others
KPI	**0**	**1**	**1**	**2**
Achievement	**0**	**2**	**2**	**1**

The contribution of funder (UMP, MOHE, MOSTI, Industry etc.) as the fund provider must be acknowledged at all times in all forms of publications. Please state the grant number (RDU/UIC) and grant name.

Number of articles/ manuscripts/books *(Please attach the First Page of Publication)*	**ISI**	**Scopus**
	1. 2.	1. Jamaludin, A. S.; Hosokawa, A.; Furumoto, T.; Koyano, T.; Hashimoto, Y. "Study on the

		effectiveness of Extreme Cold Mist MQL system on turning process of stainless steel AISI 316", IOP Conference Series: Materials Science and Engineering, Volume 319, Issue 1, pp. 012054 (2018). 2. Jamaludin A.S., Akira H., Furumoto T., Koyano T., Hashimoto Y. "High Precision Estimation on Physical Behavior for Cutting with Various Tool Rake Angle by Finite Element Method." Intelligent Manufacturing & Mechatronics. Lecture Notes in Mechanical Engineering. Springer, (2018) 3. AM Rosli, AS Jamaludin, MNM Razali, H Akira, T Furumoto, MS Osman "Bold Approach in Finite Element Simulation on Minimum Quantity Lubrication Effect during Machining" Journal of Modern Manufacturing Systems and Technology 2 (1), 33-41 (2019)
Conference Proceeding *(Please attach the First Page of Publication)*	**International**	**National**
	1. Study on the performance of Extreme Cold Mist MQL system on turning process of stainless steel AISI 316 (APCOM-IMEC 2017)	1. High Precision Estimation on Physical Behavior for Cutting with Various Tool Rake Angle by Finite Element Method (SIMM 2018)

HUMAN CAPITAL DEVELOPMENT

KPI FOR HUMAN CAPITAL DEVELOPMENT

	PhD Student	Master Student
KPI	**0**	**0**
Achievement	**0**	**2**

Human Capital Development	**Number**				**Others** (please specify)
	On-going		**Graduated**		
Citizen	Malaysian	Non Malaysian	Malaysian	Non Malaysian	
PhD Student					
Masters Student	2				
Undergraduate Student	2		2		
Total	4		2		

Name of Student: **ID Matric No:** **Faculty:** **Thesis title:** **Graduation Year:** **Name of Student:** **ID Matric No:** **Faculty:**	Nur Syamiza Binti Zamri FA14030 Fakulti Kejuruteraan Pembuatan **EFFECTIVE NOZZLE DESIGN ONTO HIGH PERFORMANCE HYBRID MINIMUM QUANTITY LUBRICANT (MQL) SUPPLY DURING METAL CUTTING** 2018 Ainur Munira binti Rosli FB14088 Fakulti

	Thesis title: **Graduation Year:** *** enter for more space*	Kejuruteraan Pembuatan **RELATIONSHIP OF CUTTING FLUID PROPERTIES TOWARDS THE EFFECTIVENESS OF MINIMUM QUANTITY LUBRICATION – STUDY ON VISCOSITY AND OIL MIST PARTICLES** 2018
	INTELECTUAL PROPERTIES	
	KPI FOR INTELECTUAL PROPERTIES Patent, Copyright, Trademark,Industrial Design: ___________	
	Patent, Copyright, Trademark, Industrial Design ect	
	OTHERS	
	KPI FOR OTHERS Prototype, Technology,Collaborations etc: ____________	
	Prototype, Technology, Collaborations etc	

ASSET *(Aset)*

E

Bil	Peralatan *(Equipment)*	Model	No Daftar Aset *(Asset Tagging No)*	Amount (RM)	Lokasi *(Location)*

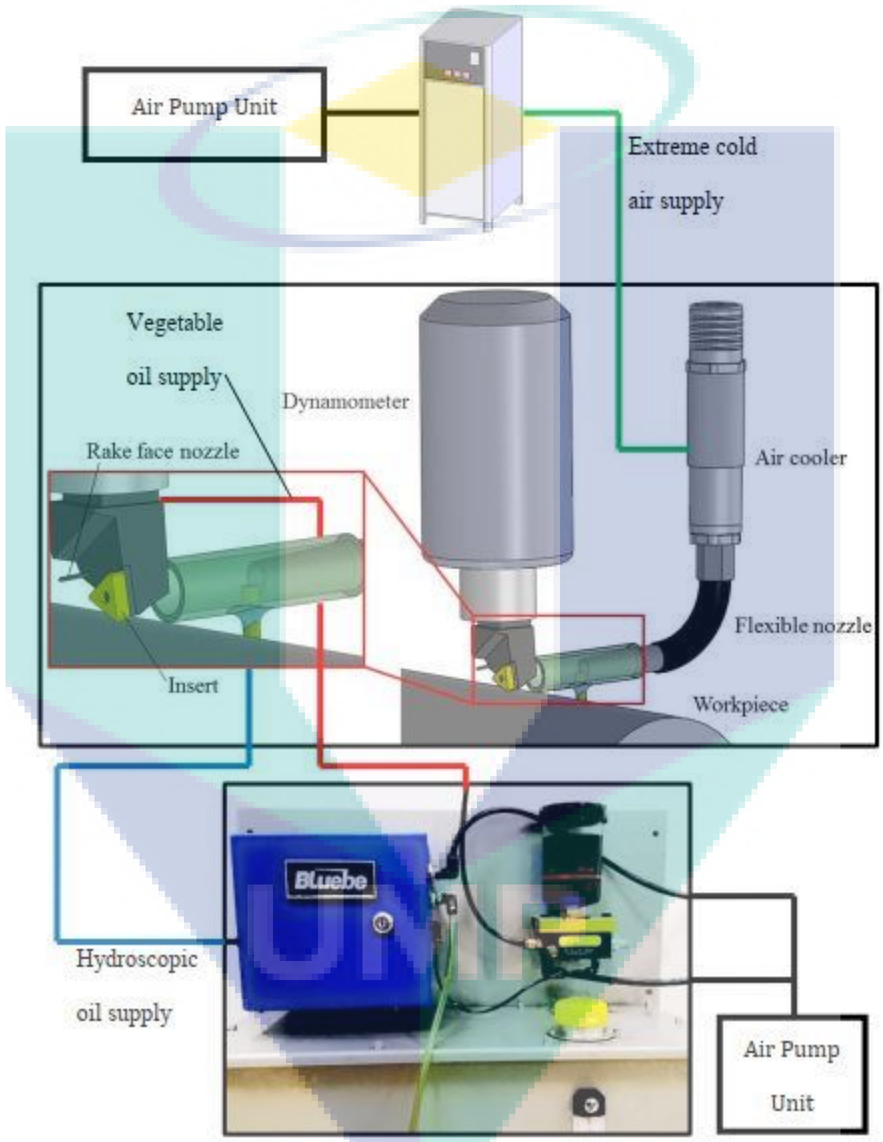
PRODUCT DESCRIPTION FOR UMP R&D DIRECTORY (SHORT & BRIEF) *Only for Final Report*

F

Minimal Quantity Lubrication (MQL) is a method in machining that distributes a particular volume of lubrication to the tool tip by mixing with the desired amount of air and an oil aerosol. Thus, a study on properties that made an effective cutting fluid is needed, where the viscosity and density properties of the cutting fluids, mist size of the fluids and its relationship with the fluids viscosity will be observed. A cutting fluid that capable to act as a coolant or lubricant at the same time is particularly important for metalworking activity is designed through combination of vegetable oil and water. Along with that, the study also assesses the design of MQL nozzles with variable internal geometries and to investigate the relationship of MQL nozzle design with the effectiveness of MQL application in terms of MQL flow behavior. In this study, a few samples consisting of combination of oil, water and emulsion is mixed and studied. The percentage of emulsion is kept constant at 10% while the percentage of water is varied from 0%, 10%, 30% and 50%. The samples are prepared using a mixing machine in the laboratory. Then, a viscosity test is carried out followed by a mist particle spray test using a MQL mist sprayer and a microscope with Motic software. A simulation is also done to simulate, observe and analyse the flow of oil mist. Using simulation software ANSYS, the internal geometry of nozzle is designed to know the flow behavior of fluid when it through the nozzle under the same pressure and type of fluid. There are five types of internal geometry of nozzle which are 30^o, 45^o, 0^o, -45^o, and -30^o. From the results of the viscosity test, it shows that the viscosity decreases with increase in percentage of water. The mist particle size proves to be larger when the viscosity is higher. Lastly, the simulation shows that the range of effectiveness of the Minimum Quantity Lubrication application is less than 20 mm away from the nozzle. The result obtained that the more effective nozzle when doing machining is by using the internal geometry 45^o. The simulation results point out that the focusing-flow nozzle is more efficient nozzle in doing machining process using MQL method which is the internal geometry 45^o is one of the focusing nozzle in this experiment. Besides, nozzle with internal geometry 45° has the oil mist shape of less disperse flow when flow out from the nozzle. It also has higher velocity of the oil mist flow. This study shows that, this flow behavior for internal geometry 45° more accurate to hit the cutting point and the tools that can cause faster cooling speed.

PRODUCT PICTURE FOR UMP R&D DIRECTORY *Only for Final Report*

G



SUMMARY OF RESEARCH FINDINGS (*Ringkasan Penemuan Projek Penyelidikan)*

H

1. Cutting fluid with the mixture of cutting oil and water is able to conduct temperature better and can be cooled down before supplied onto cutting zone.

2. However, the volume cutting fluid needed for the MQL to be able to lubricate the cutting zone is depending on the percentage of oil inside the mixture.

3. Cutting fluid with higher oil content has larger diameter of mist droplet size.

4. Based on the best results obtained from cutting force, finish surface roughness and tool flank temperature, it can be concluded that Extreme Cold Mist system is the best MQL system in the current study

PROBLEMS / CONSTRAINTS IF ANY *(Masalah/ Kekangan sekiranya ada)*	
I	

Date : 29/11/2019
Tarikh

Project Leader's Signature:
Tandatangan Ketua Projek

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COMMENTS, IF ANY/ ENDORSEMENT BY FACULTY *(Komen, sekiranya ada / Pengesahan oleh Fakulti)*	
J	**Recommend / Not Recommend / KIV / Need Ammendment**

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Name:
Nama:

Signature:
Tandatangan:

Date:
Tarikh:

**** Dean/TDR/Director/Deputy Director**

COMMENTS, IF ANY/ ENDORSEMENT BY RMC PNI *(Komen, sekiranya ada / Pengesahan oleh RMC PNI)*	
K	**Recommend / Not Recommend / KIV / Need Ammendment**

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Name:
Nama:

Signature:
Tandatangan:

Date:
Tarikh:

PERFORMANCE STUDY OF ORGANIC BASED MINIMUM QUANTITY LUBRICATION ON MACHINING DIFFICULT-TO-CUT MATERIAL

AHMAD SHAHIR BIN JAMALUDIN

RESEARCH VOTE NO:

RDU1703252

Faculty of Technology in Manufacturing and Mechatronic Engineering (FTKPM)

Universiti Malaysia Pahang

2019

ACKNOWLEDGEMENT

The author would like to acknowledge Universiti Malaysia Pahang for awarding the research grant RDU1703252 for this 2 years' length research study. A number of knowledge output had been discovered and several human capitals had been developed. The author hopes that the study will extend the exploration of knowledge into the machining field and useful to the society, especially in Malaysia.

ABSTRACT

Minimal Quantity Lubrication (MQL) is a method in machining that distributes a particular volume of lubrication to the tool tip by mixing with the desired amount of air and an oil aerosol. Thus, a study on properties that made an effective cutting fluid is needed, where the viscosity and density properties of the cutting fluids, mist size of the fluids and its relationship with the fluids viscosity will be observed. A cutting fluid that capable to act as a coolant or lubricant at the same time is particularly important for metalworking activity is designed through combination of vegetable oil and water. Along with that, the study also assesses the design of MQL nozzles with variable internal geometries and to investigate the relationship of MQL nozzle design with the effectiveness of MQL application in terms of MQL flow behavior. In this study, a few samples consisting of combination of oil, water and emulsion is mixed and studied. The percentage of emulsion is kept constant at 10% while the percentage of water is varied from 0%, 10%, 30% and 50%. The samples are prepared using a mixing machine in the laboratory. Then, a viscosity test is carried out followed by a mist particle spray test using a MQL mist sprayer and a microscope with Motic software. A simulation is also done to simulate, observe and analyse the flow of oil mist. Using simulation software ANSYS, the internal geometry of nozzle is designed to know the flow behavior of fluid when it through the nozzle under the same pressure and type of fluid. There are five types of internal geometry of nozzle which are 30°, 45°, 0°, -45°, and -30°. From the results of the viscosity test, it shows that the viscosity decreases with increase in percentage of water. The mist particle size proves to be larger when the viscosity is higher. Lastly, the simulation shows that the range of effectiveness of the Minimum Quantity Lubrication application is less than 20 mm away from the nozzle. The result obtained that the more effective nozzle when doing machining is by using the internal geometry 45°. The simulation results point out that the focusing-flow nozzle is more efficient nozzle in doing machining process using MQL method which is the internal geometry 45° is one of the focusing nozzle in this experiment. Besides, nozzle with internal geometry 45° has the oil mist shape of less disperse flow when flow out from the nozzle. It also has higher velocity of the oil mist flow. This study shows that, this flow behavior for internal geometry 45° more accurate to hit the cutting point and the tools that can cause faster cooling speed.

ABSTRAK

Pelinciran Kuantiti Minimum (MQL) adalah kaedah di dalam pemesinan yang menggunakan cecair pelincir berkuantiti yang tertentu ke hujung alat dengan mencampurkan bahan pelincir di dalam bentuk aerosol dengan udara termampat. Oleh itu, satu kajian mengenai sifat-sifat yang membuat cecair pemotong yang berkesan diperlukan, di mana kelikatan dan sifat ketumpatan cecair memotong, saiz kabus cecair dan hubungannya dengan kelikatan cecair akan dikaji. Cecair pemotongan yang mampu bertindak sebagai penyejuk atau pelincir pada masa yang sama adalah sangat penting untuk aktiviti pemesinan dan direka bentuk melalui gabungan minyak sayuran dan air. Tambahan lagi, kajian ini juga menilai reka bentuk muncung MQL yang mempunyai geometri dalaman berbeza serta mengkaji hubungan antara rekabentuk muncung MQL dengan keberkesanan aplikasi MQL dari segi perilaku aliran bahan tersebut. Dalam kajian ini, beberapa sampel yang terdiri daripada kombinasi minyak, air dan emulsi bercampur dan dikaji. Peratusan emulsi disimpan malar pada 10% manakala peratusan air bervariasi dari 0%, 10%, 30% dan 50%. Sampel disediakan menggunakan mesin pengadun di makmal. Kemudian, ujian kelikatan dilakukan diikuti oleh ujian semburan zarah kabut dengan menggunakan penyembur kabus MQL dan mikroskop dengan perisian Motic. Satu simulasi juga dilakukan untuk mensimulasikan, memerhatikan dan menganalisis aliran kabus minyak. Menggunakan perisian simulasi ANSYS, geometri dalaman muncung direka untuk mengetahui kelakuan aliran cecair apabila melalui muncung di bawah tekanan dan jenis bendalir yang sama. Terdapat 5 jenis geometri muncung dalaman iaitu 30˚, 45˚, 0˚, -45˚, dan -30˚. Dari hasil ujian kelikatan, ia menunjukkan bahawa kelikatan berkurangan dengan peningkatan peratusan air. Saiz zarah kabus terbukti menjadi lebih besar apabila kelikatan lebih tinggi. Tambahan lagi, simulasi menunjukkan bahawa keberkesanan penggunaan pelincir kurang dari 20 mm dari muncung. Hasilnya didapati bahawa muncung yang lebih berkesan apabila melakukan pemesinan adalah dengan menggunakan geometri dalaman 45˚. Keputusan simulasi menunjukkan bahawa muncung aliran fokus adalah muncung yang lebih cekap dalam melakukan proses pemesinan menggunakan kaedah MQL yang merupakan geometri dalaman 45˚ adalah salah satu muncung yang memfokuskan dalam eksperimen ini. Selain itu, muncung dengan geometri dalaman 45 ˚ mempunyai bentuk kabus minyak yang kurang menyebarkan aliran apabila mengalir keluar dari muncung. Ia juga mempunyai halaju yang lebih tinggi daripada aliran kabus minyak. Kajian ini menunjukkan bahawa kelakuan aliran ini untuk geometri dalaman 45˚ lebih tepat untuk memukul titik pemotongan dan alat yang boleh menyebabkan kelajuan penyejukan yang lebih pantas.

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LIST OF ABBREVIATIONS

MIC	Microbial Induced Corrosion
EPS	Extracellular Polymeric Substance
EP	Extreme Pressure
VI	Viscosity Index
CF	Cutting Fluid
DAQ	Data Acquisition
CNC	Computer Numerical Control
CSSF	Commercial Semi Synthetic Fluid
MQL	Minimum Quantity Lubrication

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

As the manufacturing industry grows, the necessities for reduced expense, higher productivity and higher product quality are increasing. High productivity that is innately connected with elevated depth of cut, feed rate and cutting speed altogether prompt to a huge magnitude of heat generated and heighten the temperature within the cutting area. Therefore, the dimensional accuracy, tool life expectancy, and exterior wholeness of the products degrading. Nowadays, the cutting fluid is considered as a substantial component to the machining process in order to increase the productivity [1].

Cutting fluid acts as a coolant or lubricant, particularly for metalworking activity. There are several categories of cutting fluids, such as oils, oil-water emulsions, pastes, gels, and aerosols (mist). In the early 19th century, the usage off coolant starts to be utilized. It is discovered that with the use of water an increase when machining steel with high speed tools, 40% rise in cutting speed can be achieved [2].

However, although water has superior cooling ability, it is bad in lubrication and causes serious implications on the machine instrument and the workpiece itself. New development of cutting fluid is being furthered more in ensuring good cooling quality with lubrication properties. It is expected that, simultaneously improvement on the surface finish and reduction of cutting force, and power can be obtained during a particular machining process. [3]. Thus, it is needed to rely on the lubricating medium properties and the method solidity.

The lubrication characteristic in cutting fluid is needed to abbreviate the friction between the tribological partner. To create coating at the workpiece exterior by assimilation and chemisorption's processes, certain type of active additives are required [4].

Meanwhile, the cooling properties of the cutting fluid is needed for metal cutting process at higher cutting speed minimized distortion of the workpiece. This is due to, the coolant is needed in making sure the temperature is under the thermal softening limit of the cutting tools. Moreover, it also able to reduce the diffusion and adhesion of tool wear. As an example, a large amount of heat can be taken away by fluids by a high specific heat capacity type of cutting fluid. While fluid with low surface tension plays an important role in maintaining the proper wetting characteristics [1].

The cleaning capability of cutting fluids is required to ensure the contact zone during machining is free from chips and can be transported to the filtration system. This ensures the machining process is not disturbed by any stray chips that can distort the workpiece. Moreover, it is also important to hamper the grinding wheel pore impediment of flushing capabilities. These as the viscosity of the fluid depend on the cutting fluid properties such and the specific surface tension [2].

Basically, the properties and characteristics of the cutting fluid such as viscosity, specific surface tension, and thermal properties are important to choose the right cutting fluid that suits a particular machining processes. By studying the ideal properties for a cutting fluid, a new enhanced type of a cutting fluid can be developed and thus helps in improving the machining process and consequently our manufacturing industry.

1.4 PROBLEM STATEMENT

Cutting process generated large amount of heat and lower surface finish. The current application of cutting fluid can also be considered excessive. This will lead to higher cost, and more processing time when application of different type of cutting fluids are utilized. Thus, a study on the properties of cutting fluids is needed to helps in the new design of new cutting fluid that capable of lubricating and cooling.

1.5 OBJECTIVES

1. To measure cutting performance of difficult-to-cut material with the application of organic based Minimum Quantity Lubrication (MQL).
2. To optimize the application of organic based MQL during the cutting process of difficult-to-cut material

1.6 SCOPE OF STUDY

1. Designing experiments on the physical properties of the cutting fluid.
2. Investigate the relationship between viscosity and the mist particle size of the cutting fluids.

1.7 THESIS OUTLINE

This thesis comprises of five chapters, explained as follow:

CHAPTER 1 INTRODUCTION

This chapter consists of problem statements, objective of the study is being conduct, scope of the study, research background, research budget and thesis outline as a guideline of this study.

CHAPTER 2 LITERATURE REVIEW

This chapter will provide about the theory that has been use, properties of cutting fluid, its comparison, and type ofexperiment has been conduct.

CHAPTER 3 METHODOLOGY

This chapter will provide the flow chart of the whole process and explain about each of the process.

CHAPTER 4 RESULTS AND DISCUSSION

This chapter will provide all the data that have been collected during the experiment and analysis the data.

CHAPTER 5 CONCLUSION AND RECOMMENDATION

This chapter consists of the conclusion after all the experiments has been conducted and provide the recommendation for next experiment.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss in detail regarding to the design of new type of cutting fluid for lubricating and cooling purpose during machining process.

2.2 Type of cutting fluids and its function

In general, cutting fluids serve the purpose of lubrication or coolant during one cutting process. In some cases, application of cutting fluid is able to be utilized as a cleaning agent or medium, in removing the cutting chip from the perimeter of the cutting zone. The cutting fluid is able to diminish the friction between tribological partner by producing a film that increase lubrication.

It can be considered as important for the application of cooling and lubricating media in preventing thermal instigated form and preciseness and failure of workpiece and tool characteristics. Additionally, to extract chips from the impact area as well as to carry them to the filtration structure, the cleaning properties of cooling and lubricating media is required.

There are various types of cutting fluid that currently available in our manufacturing industry. However, the ideal combination between the tool material and the form of cutting fluid used has to be taken into consideration to avoid the risk of tool failure. The cutting fluid strategy also had to be choosen based on the cutting fluid and the cutting operation as shown in the figure below. As an example, ceramic cutting tool cannot be paired with high cooling capability fluid to prevent tool failure. On the other hand, during low cutting speed, lubrication would be more effective because it makes contact of the fluid at the tool chip contact much easier [3]. Cutting fluids can be divided into three main groups; water based, gas based and oil based.

Condition of aggregation (cooling and lubricating media examples)	Strategy: Flood	Strategy: MQL	Strategy: Dry	Function: Cooling	Function: Cleaning	Function: Lubricating
Solid						
CO_2 snow	◐	◐	○	↑	↘	↓
Graphite	○	◐	○	↓	↘	↗
Liquid						
Oils	●	●	○	↘	↗	↑
Emulsion / dilution	●	◐	○	↑	↑	↘
Liquid gases (LN_2, CO_2)	◐	◐	○	↑	↘	↓
Gaseous						
Compressed air	○	●	◐	→	→	↓
N_2, CO_2	○	◐	○	→	→	↓

Degree of fulfilment	Inferior ↓	↘	Average →	↗	Superior ↑
Degree of application	Low ○		Average ◐		High ●

Figure 2.1 Classification of the strategy application and their condition

Cutting fluid relevant machinery and equipment	Strategy: Flood	Flood (Multi-functional oil)	MQL	Dry (fluids to remove chips)	Dry
Filter System					
decentralised	●	●	◐	●	○
centralised	●	●	◐	●	○
Exhaust Air System					
decentralised	●	●	◐	◐	◐
centralised	●	●	◐	◐	◐
Cleaning (between machining processes)					
washing fluid	●	○	○	○	○
compressed air	○	○	●	◐	◐
Cleaning (between different processes)					
washing fluid	●	●	○	○	○
compressed air	○	○	●	◐	◐
Cleaning (end of the process chain)					
washing fluid	●	●	◐	◐	◐
compressed air	○	○	◐	◐	◐
Degree of necessity	Low ○		Average ◐		High ●

Figure 2.2 Classification on demand for additional machinery and equipment [2]

Water soluble fluids consist of water, oil, and an emulsifier to mix them together. Due to the presence of water, it is exposed to an aggregate of extra chemical and microbial transformations Water based cutting fluids is less stable compared with the oil based cutting fluid thus, it needs to be monitored regularly. A weekly monitoring interval for the fluids is recommended by the European employer's liability insurance association to control the efficiency of the fluids. Variables which should be experimented in advance prior to preparing the cutting fluids are the conductivity, pH value, water hardness, concentration of additives and microbial contamination in the soiled water. Figure 2.2.3 shows an example of microbial induced corrosion and bacteria forming extracellular polymeric substance and bio films at the surface.

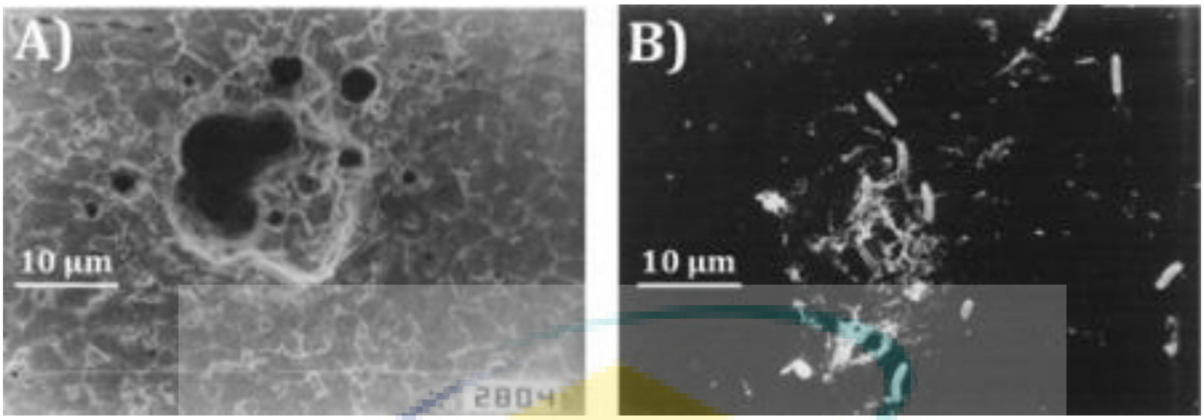

Figure 2.3 (A) MIC, Microbial induced corrosion (B) EPS

The aqueous based products are usually given in a concentrated condition, and mixed with water until it reached the desired concentration before it is utilized. Its good properties for cooling and lubricating makes emulsion type cutting fluids more preferable for high cutting speed and low pressure machining [1]. It is great in cooling because it contains water, while the inclination towards oxidation is reduced with the presence of oil. Under extreme conditions, extreme pressure additives are added.

The next type of cutting fluid is neat oils, the oil-based cutting fluid which is obtained from mineral, animal, vegetable and synthetic oils. The most popular one is petroleum-based mineral oil, where it has attractive lubricating characteristics. Additives such as fatty lubricants, EP additives, odorants, thickness modifier and polar additives are added to enhance naphthenic mineral oils and paraffin mineral oils.

Gas based lubricants are a gaseous shape at room temperature that is generally considered as environmentally cutting fluids. Gas based fluids are usually chemically inactive, thus they have impressive corrosion hindrance, which will prevent oxidation on the cutting tool or workpiece during high-temperature machining. They can also be utilized together with conventional cutting fluids to improve the lubrication process under the shape of mist or droplets. Previous researchers had applied the spraying of tiny drops of biodegradable oil in the air in low carbon steel high speed milling, thus reduced the tool flank wear in the cutting section up to 44%, along with cutting temperature and forces.

Table 2.2.1 shows the general comparison of several types cutting fluid that had been utilized by previous studies [1][4].

Table 2.1 Comparison of cutting fluids types

	Straight Oils	Soluble Oils	Semi Synthetics	Synthetics
1.	Made up from entirely oil or vegetable oils	A mixture of oil and water	Contains 30% or less concentration of soluble oil and contains inorganic material or other water-soluble compound	A chemical liquid containing inorganic or other chemical that are soluble in large quantity of water
2.	Primarily for operations where lubrication is required	Reduce effect of generated heat in cutting tool wear	Better maintenance than soluble oil	Offer superior cooling performance
3.	Corrosion resistance	Reduces tendency of water to cause oxidation	More effective lubricants	Transparent solution gives better view of cutting operations
4.	Very low heat transfer	Infestation by	Tarnishes easily	-

	capabilities	micro-organisms	when exposed to other machine fluids	
5.	Highly flammable	-	Can cause dermatitis risk to workers	-
6.	Low efficiency at high cutting speed	-	-	-
7.	Relatively high cost	-	-	-

2.3 Physical properties of cutting fluid

2.3.1 Density

The fundamental thermophysical characteristics used to size up heat transfer of cutting fluids is density. The influence of density plays a significant role in transfers of heat since buoyancy force and density changes is a form of convective heat transfer. It is believed by researchers that as density surges natural convection will also rises. [5]

Liew indicates that, according to Halelfadl in his journal, said that other than an increment of the thermal conductivity, the density, which dependent of temperature also flunctuates by increasing the volume ratio. The relative viscosity of cutting fluids is also affected by both the increase in its volume fraction and shear rate [4].

In fact, the most current research proved that the stability of particles in different compound is firmly interrelated to its electrokinetic properties. An elevated exterior charge density can yield a well spread suspension that will generate strong repulsive forces showed by the zeta potential. The stronger the zeta potential, the charge density will also be higher and the more stable the particles. [6]. Density of the lubricant should be almost similar with the density of water, which usually is measured using a density measurement tool, the pycnometer. [7]. Sharma stated that with increased viscosity and density of fluid, the heat extraction capability of cutting fluid will also increase thus, reducing the cutting zone temperature. [8].

2.3.2 Viscosity

Viscosity is the main attribute of a liquid that has an immediate relation with the heat transfer rate. Concerning viscosity of cutting fluids, it transitions as an effect of the appearance of additives (solid) in the base fluid and also concentration, size and type of the particles, temperature and shear rate effected this significantly. Usually, a lubricant that has high viscosity index (VI) value is a good lubricant. VI mirrors the expression of viscosity due to changes in temperature. A small change in viscosity over augmentation of temperature brings about high VI values.

The viscosity is also playing a major role in correlation to the Rehbinder effect, the surface energy and the Marangoni effect. Rehbinder stated that the Rehbinder effect is the weakening of the bond between the exterior foundation of a lattice due to surface active molecules adsorption.

The Marangoni effect is an outer interconnection which portrays the manners of fluids influenced by the surrounding area's temperature gradient. This outcome is caused by surface tension occurrence, as it is hinging on the temperature. This prompts thermo capillary fluid flow and volatilities in non-isothermal free exterior structures as theoretically shown below.

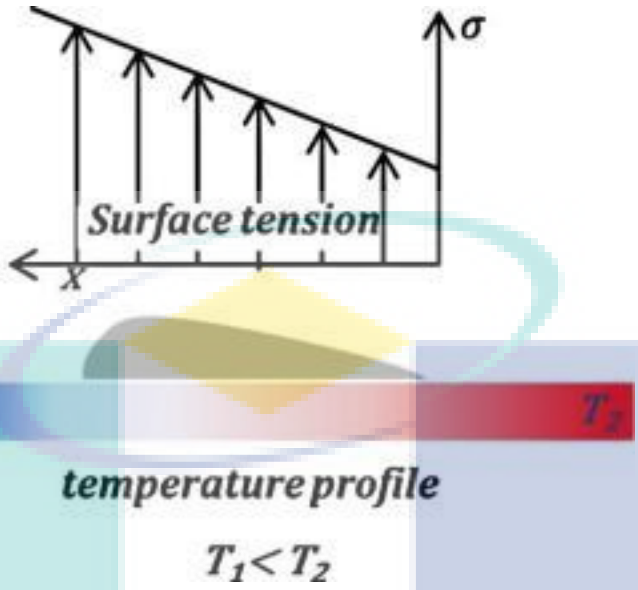

Figure 2.4 Surface tension in liquids (temperature)

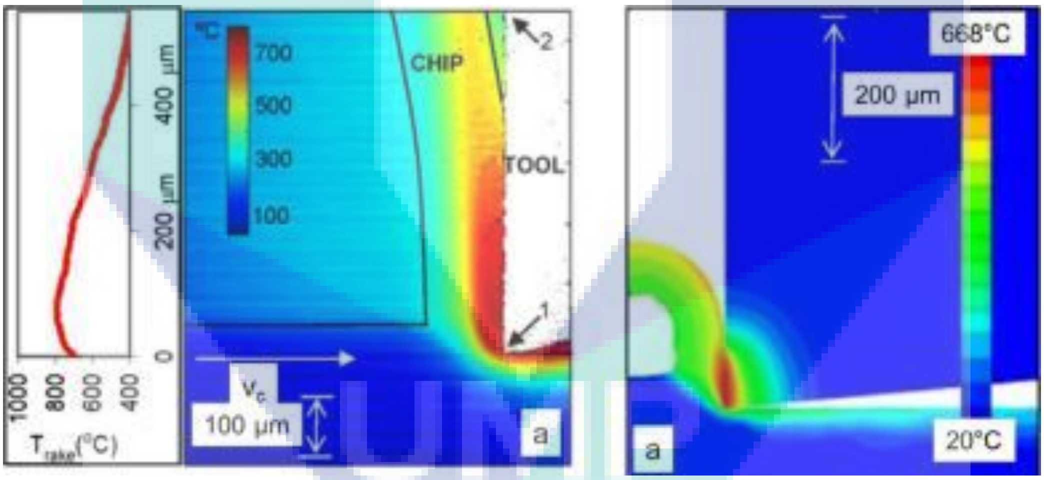

Figure 2.5 Spreading of temperature within the contact zone

The significant of the Marangoni effect can be establish due to in machining the impact area between tool and workpiece is the highest temperature area as shown in **Figure 2.5**. Based on the Marangoni effect, the cutting fluids carnally tends to get away from the area of the most temperatures to a much cooler region.

Viscosity is the main element that influences the ability of oils to sustain on par lubricating coating and the ability of the oils to flow. Water based cutting fluids have a inferior viscosity. For oil based cutting fluids, addition of additives such as polysulphides which is having high viscosity is a noticeable factor. Since a rise of concentration of an additive will results in higher viscosity of the cutting fluid. Positive effects from this may be due to fundamental reaction of the additive with the metal exterior and also polished formation of the adhered liquid on the surface of the metal.

The Viscosity Index VI, according to Brinksmeier, is a magnitude of scalar value which shows viscosity variation relating to the temperature alterations This is a parameter that is usually used on lubricants for engines or gears (mechanical systems). More viscosity index shows that the lubricants are able to sustain their constant viscosity throughout extensive temperature range.

The thermal conductivity improvement of widely arranged clusters is better than closely arranged clusters. [9]. Saasen explains this during an investigation on barite sag in oil-based drilling fluids with a conclusion that states that the crystalline structure will remains solid, as long as the Brownian motion is still followed. When the shear rate increased, the Brownian motion could not reconstruct the water droplets crystalline structure any longer. The individual droplets then have to redirect themselves, causing a chaotic motion and increment in viscosity leading to peak seen at very low shear rates. [10].

Kuram in his experimental test on viscosity of cutting fluid, measured the viscosity using a Brookfield LDV-E viscometer. This viscometer is fine-tuned with distilled water. He investigated on sunflower oil, canola oil, and a commercial semi synthetic cutting fluid. The characterization of the cutting fluid he investigated is shown in Table 1. He measured the pH values using a pH meter and changes the range from 8.92 to 9.18 to avoid too shallow pH values, which would be dangerous to the operator and difficult to be disposed. Then, he measured the density of the fluids using a pycnometer while ensuring the density of the cutting fluid to be consistent with water along 0.96-0.98 g/ml.

Refractive index is taken using Abbe refractometer. Lastly, the flash point is quantified with K16500 rapid flash closed-cup tester. In the flash point calculation, the sample is placed in the container and the temperature is raised with time during computation The flash point magnitude is taken from the value of the cutting fluids ignited. [7].

Table 2.2 Characterization of Vegetable Based Cutting Fluids

Metal cutting fluid[a]	pH (Emulsion 8%)	Density (g/ml)	Viscosity 40 °C (mm^2/s)	Viscosity, 40 °C (mm^2/s) (Emulsion 8%)	Flash point (°C)	Refractive index
SCF-II	8.92	0.96	91	4.1	217	1.4775
CCF-II	9.00	0.97	110	3.9	232	1.4770
CSSF	9.18	0.98	75	1.7	235	1.4825

[a] SCF-II: sunflower cutting fluid with 8% EP additive; CCF-II: canola cutting fluid with 8% EP additive; CSSF: Commercial semi-synthetic cutting fluid.

2.4 Chemical composition of cutting fluid

At the point when the metal is cut a clean incipient surface at atmospheric pressure, this causes it to be very reactive and quickly adsorbs either by chemisorption (strong) or physisorption (weak) any substances (liquids or gases) in sufficiently close range to itself. The adsorption onto a exterior where a bond (chemical) forms is called chemisorption, whereas physisorption includes lesser forces of adhesion. The performance of the cutting fluid could be effected when the time available for chemical equilibrium reached on the new metal surface varies, depending on the type of cutting process used.

Rowe and Murphy states that enhanced reactivity is needed when using a limited volume calibration as very little cutting fluid is utilized.(Rowe & Murphy, 1974), such heightened surface action may be denoted as follows: Enhanced reactivity = Exoelectron + Elevated temperature + High pressure.

Additives are mainly fatty alcohols, fatty acids and fatty esters. Fatty alcohols guarantee improved achievement of thefluids because they are not related with the annealing characteristics of the aluminium. These additives are added to provide lubricants with sufficient load carrying capacity and friction characteristics for cold rolling of aluminium, additives are supplemented to the reduced-viscosity mineral base oils.

The cutting fluid that is applied to the tool tip just before cutting can last for only a brief time as a protective film as its bond energy from chemisorption is typically 40 to 800 *kllmol* and the bond energies of aluminium are typically in the region of 0.0*15kllmol* to 57 *kllmol.* The metal- soaps that would originate are layers that would have a lower tendency to weld than metal. Catalysis (the acceleration of chemical reaction by a catalyst) can and often does happen, and initial cutting fluid might need to have a specific molecular arrangement for catalysis to occur in the metal at the interface of the tool and the shear-zone. This variation makes it possible for similar cutting fluids to produce different results during cutting.

Organometallic productions result from the response of the fatty additives with new enoxidase metal exterior that created during plastic degradation. These exteriors are very reactive and are called nascent surfaces. Fatty acid soaps are well known. It is clear that esters, ethers and alcohols react with fresh aluminium surfaces. It has been suggested that polymeric soap formation results from reaction with esters and fatty acids, and alkoxide formation from alcohols and ethers. Fatty alcohols can brings to a alike reaction of soap formation but to a lesser extent than fatty acids. In this case, it was assumed that part of the alcohol was transformed into an acid which can retaliate to make an ester and a combination of hybrid soaps of the general formula.

The negative-ion lubrication mechanism suggested by Kajdas, explains the build of aluminium alkoxides i.e. the Al(OR)y section of the hybrid soap from alcohols. This is referred on the low-energy electron emission method from the aluminium exterior. The action of the emitted electrons on alcohol particles creates negative and radical-negative ions, including R-CH2-CH2-0" ions which produces alkoxides by reaction with the positively charged sites on the plastically changed aluminium surface.

The reaction of the cutting fluid with the nascent metal surfaces stabilises them. The metal salts that produced functions as a little shear strength film that reduces friction and provides improved anti-weld properties, i.e. the resulting surface has better anti-weld properties than the unreacted freshly formed nascent metal surface. The result is a shorter welded-zone or contact length and there is therefore less shear, a lower cutting force and a reduced cutting temperature. When metal is cut in a vacuum a longer contact length is observed than when it is cut in air. When air is present the oxygen reacts with the nascent metal surface instead of the tool and this reduces the contact length. The oxide layer on the tool does not form at the hottest region on the tool but a little further away in the cooler region, because the oxygen in the air reacts preferably with the nascent metal surface and is thereby removed from the cutting edge region of the tool. Similar to the oxide layer producing a shorter contact length the cutting fluids also react with the nascent metal surface produced in metal cutting to bring about a reduced contact length, i.e. the size of the welded zone is reduced.

In a paper by Kajdas it is stated that metal surfaces that are protected with oxides, hydroxides and adsorbed organic contaminants are not chemically active enough. The mechanical action at solid surfaces tends to promote reactivity of the surfaces by exposing nascent high reactivity surfaces that can promote chemical reactions that are entirely different to those reactions that would be observed for static systems. Friction at the nascent surfaces' begins and quickens the chemical reactions that will usually only occur at hotter temperatures or not initiate at all. [11]

2.3.1 THERMAL PROPERTIES

Following the development in manufacturing industry, considerable endeavors have been devoted to study cutting fluid characteristics and capability as well as their usage in many industries and determining heat transfer coefficient [12].

Other than the utilization of pure fats and oils, primitive cutting fluids were combinations of water because of its better heat transfer coefficient and added element for the better of the fluids characteristics. A lot of effort is initiated especially for abrasive cutting processes, as these are very demanding regarding decreasing of friction-related heat or the cooling of the contact zone respectively [13].

Efforts to improve the thermal conductivity is the main idea to incline the heat transfer properties of conventional fluids [9]. Heat transfer base fluids, such as water, oil and ethylene glycol are considered as weak heat transfer fluids. So, it seems necessary to develop the above-mentioned fluids with high thermal conductivity and inclined heat transfer properties. Considering previous research and development focusing on heat transfer required by industries, major changes in heat transfer capabilities have been constrained due to low thermal conductivity of conventional fluids [12].

2.5 FUNDAMENTAL OF HEAT TRANSFER AND MECHANISM OF COOLING PHENOMENA

The heat transfer is a process in which completed through the transfer of energy from the warm medium to the colder one. The energy transfer from the higher temperature medium to the lower medium cause the stop transfer of energy when the two mediums reach the same temperature. The temperature difference results from the form of energy that is transferred from one system to another system.

Three fundamental of mechanism in heat transfer are conduction, convection and radiation. The transport of heat from the extra active molecules of substance to the together much less lively ones because of the interplay among the particle cause the conduction happened. The type of energy transfer between a solid surface and together liquid or gas that is moving, and involves the combined results of conduction is called as a convention . Radiation is the energy produced via depends of electromagnetic waves due to the modification inside the electronic arrangements of the atoms or moleculeS (Cengel, 2000).

So, it heat transfer and mechanism of cooling phenomena is involved during the process in machining. The lubricant is acting as the cold medium while the cutting tool and the workpiece is working as the warm medium. During the machining process, only convection and conduction mechanism occur because there is no radiation occur due to no electromagnetic waves involves.

2.3 MINIMUM QUANTITY LUBRICATION

Minimal Quantity Lubrication (MQL) is technique in machining that distributes a particular volume of lubrication to the tool tip. The lubricant will be mixed with forms the desired air or an oil aerosol combination and compressed air.

MQL is a supportable manufacturing method that changed conventional wet lubrication technique and dry machining. During the MQL method, by through the nozzle that will be through little pneumatically-operated pump, the lubricant will be sprayed on the friction surface (M.S. Najiha, M.M.Rahman, 2012). MQL uses a very little measure of a liquid to decrease the friction between a cutting tool and the work piece (Walker, 2013). MQL has being study for practical application and is considered as the better solution, especially to reduce amount of lubricant used (F.ItoigawaD.Takeuchi2017).

The idea of MQL have been recommended a decade before, as a mean for referring about the problems of environment insensitivity and working danger airborne cutting fluid particles. The decreasing of cutting fluid cause economic advantages by saving lubricants expenses. Besides, it decreased the tool, workpieces and machine cleaning time. The MQL method involves of misting a little amount about lubricant, usually of a flow rate about 50 to 500 cc/hour, in an air flow aimed at the clipping zone. Those lubricant will be sprayed by method for an outside supply system of single or more nozzles. When used of MQL, the volume of coolant is about 3-4 order of magnitude lower than using wet cooling (Boubekri & Shaikh, 2014).

In general, MQL is the used of less amount of cutting fluid that has been controlled to cold down the cutting tool and workpiece. As the result, the oil mist flow is less then conventional wet setting fluid.

2.3.1 Type of MQL System

MQL have two simple types of delivery systems which are through-tool and external spray. A reservoir or coolant tank that is connected with tubes equipped with one or more nozzles at the external spray system.

The system can be placed close to or at the machine .Then, the coolant flow and air can be adjusted independently .It is cheaper, movable, and suitable for almost all machining operations. Through-tool MQL systems are existing in two forms ; primarily based on the technique of making the air-oil mist. First, by externally mixed air and oil . Next, the tool is to the cutting zone and piped located over the spindle (Borse & Bansode, 2014).

In MQL process, the compressed air is used to spray oil out. There are two different mixing methods that can be used in MQL:

1) A mixing in the internal of nozzle, where the air pressure and oil are mixing together in the spindle and
2) A mixing at the outer of nozzle, in which the air pressure and oil are done mixing together the outside of the device .

Firstly, the oil mist is caused by the Venturi effect. The spindle is prepared with two channels, the first with oil and the different one with compressed air. At the end of the spindle, the oil mist is produced through the mixing of oil and air. In the second one, the combination of oil and air are received thru a mixing tool placed in a selected tank. Inside the tank device, the oil mist will be produced. After that, it will be sent through a channel through the spindle and the tool. In each instance, the floating oil mist will be decreased by using a vacuum oil mist collector which could cause health risks. (Duchosal, Leroy, Vecellio, Louste, & Ranganathan, 2013)

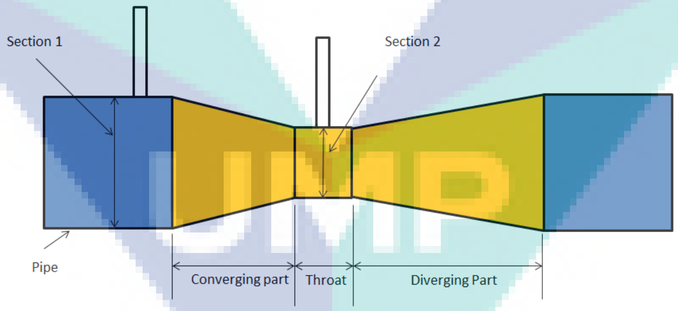

Figure 2.1: Venturi meter Source: Duchosal, Leroy, Vecellio, Louste, & Ranganathan (2013)

Overall, it seems like there are two type flow of MQL for nozzle which are internal and external. For internal, it is usually the nozzle of lubricant flow through the cutting tool . While for the external, lubricant flow in the tube of the nozzle, and the nozzle can be changed the position easily. Figure 2.1 shows the Venturi meter. The venture effect that used the Bernoulli principle also have been used during the MQL process to make the oil mist flow in the channel.

2.3.2 Working principle of MQL

The pressurized air moves the mist according to the wanted region. At the tip of the nozzle, the pressure regarding the atmosphere is required to move the mist, the place where air-lubricant mixing takes place. The lubricant through small pneumatically-operated pumps are supplied in the nozzle and the air-lubricant mixture is carried to the friction zones. The lubricant is driven through a capillary tube inside some other tube, through which the pressurized air is delivered, and mist is received to the tool-workpiece interface where this mixture is sprayed in the form of mist (M.S. Najiha, M.M.Rahman, 2012).

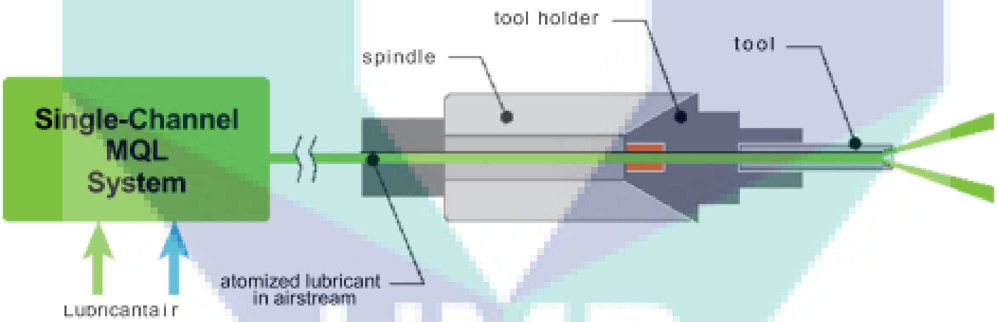

Figure 2.2: Single Channel MQL system (Walker, 2013)

From the Figure 2.2, it shows the parts in the MQL and how it flows in single-Channel MQL System.

2.3.3 Parts in MQL

There are parts that have in MQL systems, Figure 2.3 show the MQL apparatus while figure 2.4 shows the MQL equipment.

Figure 2.3: MQL apparatus (Accu-Lube) permanently to the mill (Source: DaSilva, 2007)

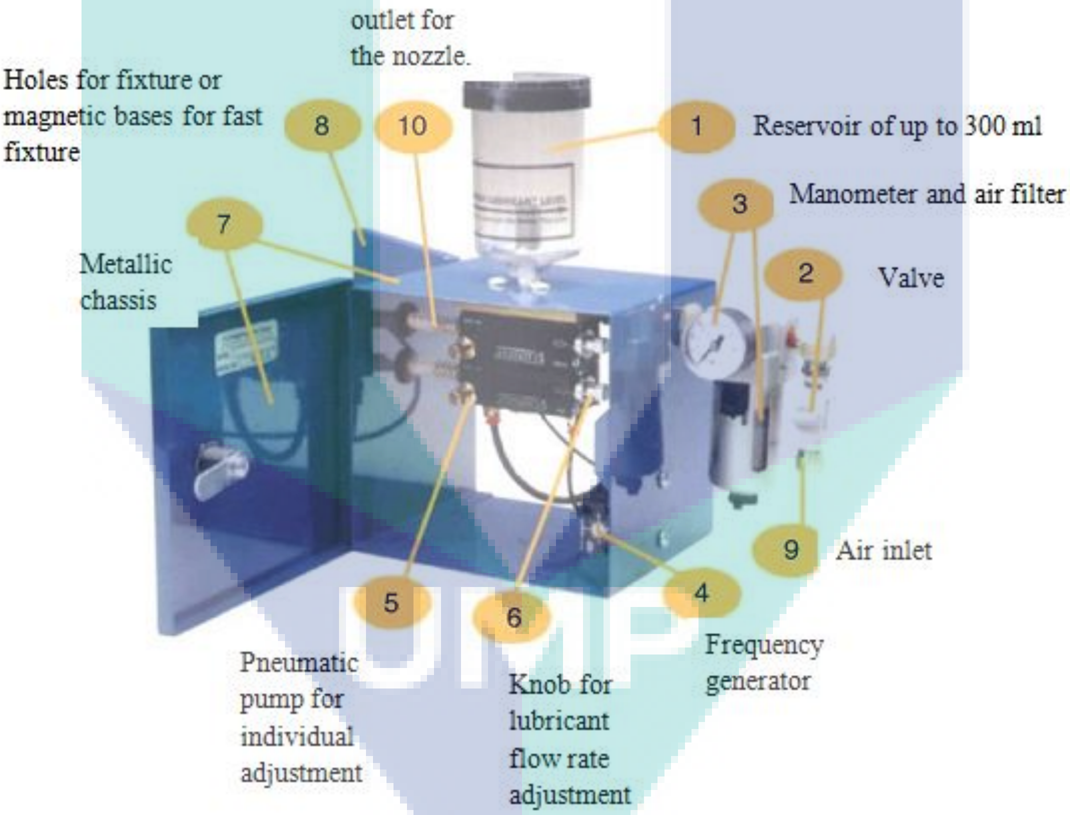

Figure 2.4: MQL equipment (DaSilva, 2007)

Effectiveness of lubrication and cooling of the rough grains on the work–tool interface in MQL approach managed to decrease range roughness values. The chips can slide easily and without trouble over the tool's surface because the efficient lubricant. It is resulting the better surface finished (da Silva et al., 2007).

2.3.4 Type of cutting fluid

Considering the fact that excellent lubricant properties are required in MQL, instead of using mineral oil, the synthetic ester oil and vegetable oil is used in MQL. MQL is consumption lubrication, that is, at the factor of application the majority of the lubricant implemented is evaporated. In real life, this evaporation and the compressed air flow will cool the workpiece by the use of the tool and the chips, the remaining heat is dissipated. In an preferably adjusted MQL system, the tool, workpiece and chips continue to be nearly dry (Boubekri & Shaikh, 2014).

Wakabayashi has introduced and describe about synthetic polyol ester potential as MQL fluids. This presents the potential additional for vegetable-based MQL oils, especially that respect to their optimal secondary potential characteristics. High biodegradability is displayed by all vegetable oil. Besides, depending on synthetic esters combined molecular structures of acids and alcohols, its offer full range of biodegradability. This characteristic, in junction with their suitable viscosities, encouraged (Wakabayashi et al., 2006) to identify these lubricants for advance testing.

Therefore, the potential of using synthetic polyol ester and vegetable based oil cause the MQL be the best approach compared to wet lubrication. Besides, the goods by using the vegetable cutting oil or ester oil are it safer for the workers and it is environmentally friendly compared to the use of chemical lubricant.

2.3.5 Characteristic of oil mist

The oil mist is categorized by the size, velocity, and volume flow rate of its particles. The specific measurement process is used for oil mist. First, for size, the laser diffraction granulometry is used. Second, the velocity of oil mist is measured by the particle image velocimetry. Last, the volume flow rate of oil mist particle can be measured by gravimetric method. According to the turbulent flow in the channel, type of oil has an important effect on the particle size and also on the particle size conservation.

It can be seen that when the oil is less viscous, it will be easier to reach small particle size and vice versa. Definitely, when the viscosity is lower, the atomization process will be easy that can cause the small particle easy to be reached. In the nozzle devices, the oil works in good condition which enable the oil breakup into the small size of the particles. Furthermore, the lower viscosity of MQL will be chosen for drilling process, because it can enter into the borehole. In contrast, high-viscosity oil decreases the concentration of oil in the oil mist, which produces small particles and is preferred for milling processes.

The particle size is influenced by oil viscosity in which, when the level of viscosity higher, the particle will be smaller. Extra air increases the possibility of inter particle collision also with the channel walls, which can cause an accumulation along the channel walls and therefore a reconditioning of the oil. This makes particles become larger and the spitting phenomenon occurs.

The level of oil consumption is influenced by on the mist settings, the oil type, and the channel geometries. The decreasing of mist flow rate can be done by reducing the cross section of the channel models. This is because of turbulancce phenomena and the wall, in strong conditions, when the level of viscosity higher, the mist will be more homogenous (Duchosal et al., 2013).

2.3.6 Design of MQL Nozzle

Type of design nozzle can be classified by three characteristics based on function, focusing and the nozzle geometry. Firstly, for function, we can determine whether the condition is for flooding or not flooding lubricant needed. Second, there are four types of focusing nozzle which is point nozzle, swell nozzle, free jet nozzle and spray nozzle. Lastly, by the geometry of the nozzle, there is needle nozzle, squeezed pipe and shoe nozzle. All have been concluded in Table 2.1. The coherence of the cutting fluid jet and its velocity is affected by the nozzle design.

Function	Volumne flow	Nozzle type	Focusing
Flooding	↑↑	Conventional (pipe/round nozzle)	Free jet nozzle
	↑	Slot nozzle	
	↑	Shoe nozzle	Nozzle without free jet
Not flooding	→	Spot jet / Point nozzle	
	→	Needle nozzle	
	↓↓	Spray nozzle	

Volumne flow: very high ↑↑ high ↑ medium → low ↓ very low ↓↓

Table 2.1: Function, type and geometry of nozzle (Madanchi, 2017)

Based on the experiment conducted by Madanchi, Winter, Thiede and Herrmann, they developed the different nozzle based on the design principle that have been described before. The overview of the shape of design nozzle is presented in Table 2.2. In this experiment, two types of jet slot nozzles were tested.

Nozzle I is the nozzle that change cross-sectional area over the nozzle while the nozzle II not change the cross section and have a straight nozzle length. Outlet size for both nozzles are 40.0 mm². In addition, designing and investigating of two not flooding point nozzles was applied. According to Rouse, nozzle I have been designed while nozzle II has again a straight nozzle length. The outlet nozzle size for both is 15.9 mm². Moreover, in according to grinding wheel, the geometry designed of a shoe nozzle was tested and have size of outlet of 411.8 mm².

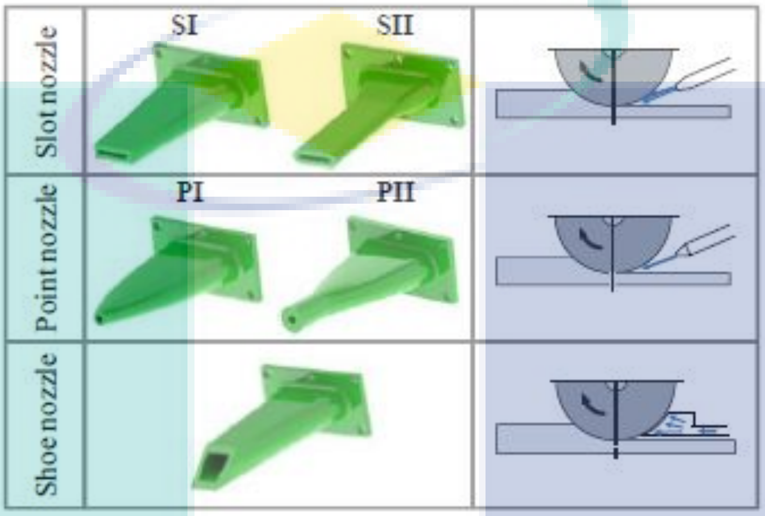

Table 2.2 : Shape of design nozzle (Source: Madanchi, 2017)

From the results, cutting fluid supply is influenced by three aspects which are design, position and nozzle type. A special design of nozzle has been used to concentrating small amounts of oil mist into the cutting interface. This is shown that, when the concentrated spraying of oil mist with a specially designed nozzle, it was quite effective in increasing tool life in the micro-liter lubrication range .The method used to spray oil mist to the cutting point influences the overall performance of MQL machining. To get a certain quality of oil consumption, three factor which are spray direction, pressure of compressed air and distance of nozzle from cutting tolls must be considered. (Obikawa, 2008)

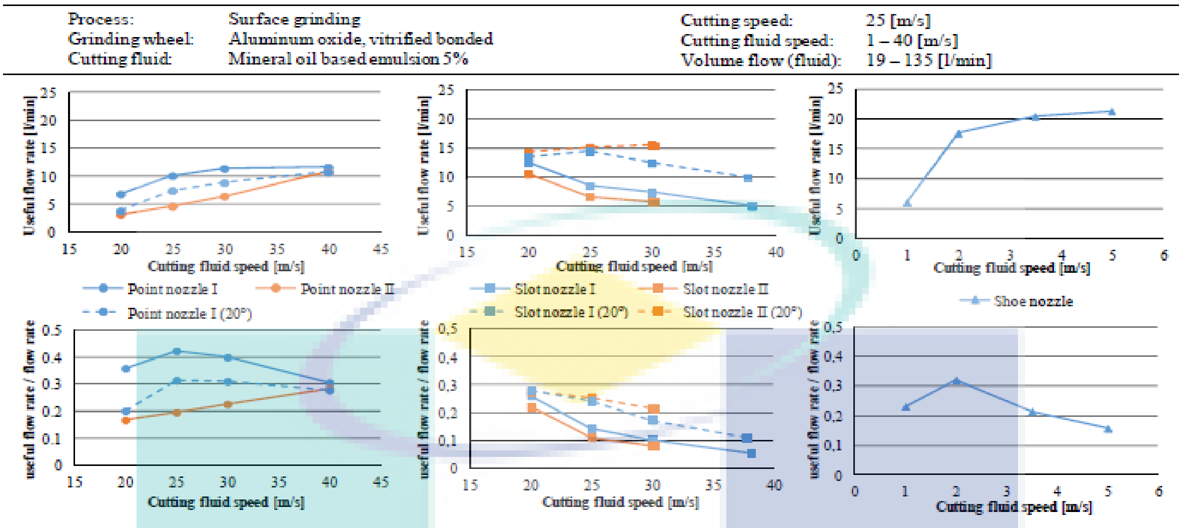

Figure 2.5: Result for the experiment conducted by Madanchi, Winter, Thiede and Herrmann

Source: (Madanchi, Winter, Thiede, & Herrmann, 2017)

Thus, the design of MQL nozzle must consider the factor why and when we want to use the MQL. The characteristics that can be followed to study this project is the function, focusing and the nozzle geometry.

2.3.7 Position of MQL Nozzle

Expanding spraying distance, those grinding forces, surface roughness, and harden layer depth are all increased. An investigated the oil mist velocity under those separate spreading distances, and experimental results showed that the mist velocity appeared the decrease tendency at a small spraying distance, while it trends flat at a large spraying distance. In the study, to overcome the boundary barrier, the velocity of mist is higher compared to the critical velocity and the mist can enter the grinding contact zone under the changed of spraying distance. When the spray distance increase, the mist velocity will be decreased. It is properly known that the decreased mist velocity leads to decrease in the relative velocity between the air and coolant (Huang, Ren, Li, Zhou, & Zhang, 2017).

With respect to the impact of oil mist, it is most influenced by the position the place the oil mist is supplied(Hadad & Sadeghi, 2013). Due to the relation between position of nozzle and cutting points, it is expected that when the distance increase, the oil mist concentration will be decrease .Then, a large portion of oil sprayed will be excess, if nozzle is not placed near the cutting point. The sprayed oil will act more effectively when the sprayed oil enters the boundary between the machine surface and tool side face. This is due to if the nozzle is placed close to the cutting point, and oil mist is sprayed as a located jet from the side of the tool side (Obikawa, Kamata, Asano, Nakayama, & Otieno, 2008). The positions of nozzle are shown as figure below:

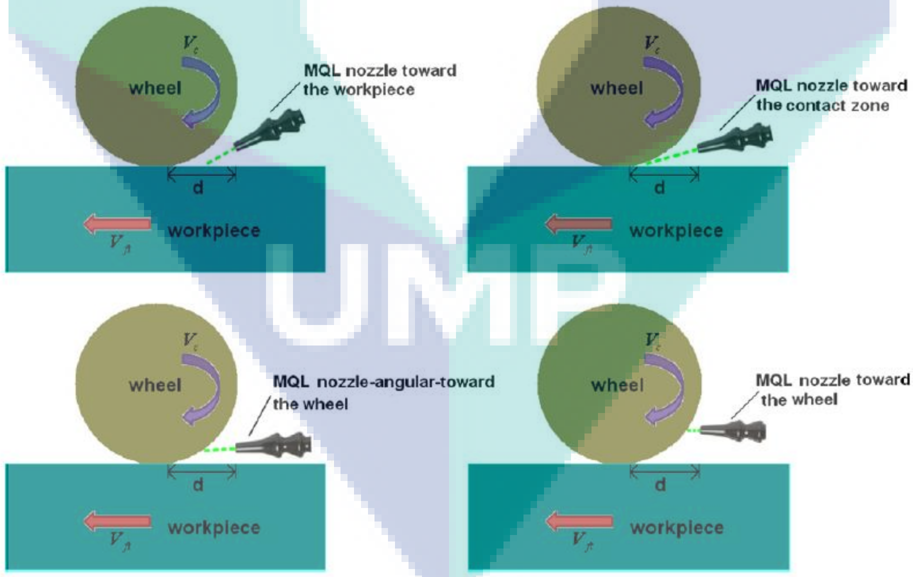

Figure 2.6: Different position of MQL nozzle (Source: Tawakoli, 2010)

The case in which MQL nozzle is placed angularly toward the wheel is the fine. It has been noted that the surface roughness and tangential forces are the highest when the MQL nozzle is set toward the workpiece. The MQL effectiveness increases, that is, the grinding forces and surface roughness decrease. When the wheel grain size increases, the roughness increases and grinding forces decrease. This phenomenon happens due to the higher thickness of the removed chips and lower touching the base area in case of coarse grains. Therefore, when grinding with the MQL technique, the usage of coarse grain wheels decreases grinding forces. By placing MQL nozzle angular near the wheel, the oil mist is shot up above the area of the reversed flow. Thus, in this instance, the wheel helps driving the oil mist into the grinding zone through which the spray jet overcomes any boundary layer effects. Furthermore, it is noted in this research that for the position of MQL nozzle toward the rack, the oil mist did not cling to the grinding wheel surface and flowed out around the wheel periphery due to the air barrier. Length of the MQL nozzle has also been proven to be decisive in order to enhance the oil mist penetration into the contact zone (Tawakoli, Hadad, & Sadeghi, 2010).

From the journal, it can be seen that the position of the nozzle also influences the effectiveness of the MQL in machining process. It can be concluded that when the nozzle distance increases, the velocity and concentration of oil mist will be decreased.

2.4 FINITE ELEMENT ANALYSIS ON MECHANISM OF MQL

Finite element analysis (FEA) can be used to predict about the product which responds to heat, forces acting on the product and any physical effect. FEA is using the on-screen method to do analysis. FEA will show the analysis of product whether it is can stand the force, can break or can act as the technique or method it was planned. There are many software used for the FEA such as Ansys, Autodesk Simulation and Nastran. During the metal cutting operation, a finite element is produced to analyze the temperature distribution in the tool and the work piece/chip, the result from FEA is shown in Figure 2.7. The model displayed increased temperature distribution in the tool, with the maximum temperature occurring at the tool–chip interface. A parametric study is held away to predict quantitatively the increased temperature level in the tool with increased cutting speed. The figure below shows the temperature distribution of cutting condition using FEA (Majumdar, Jayaramachandran, & Ganesan, 2005).

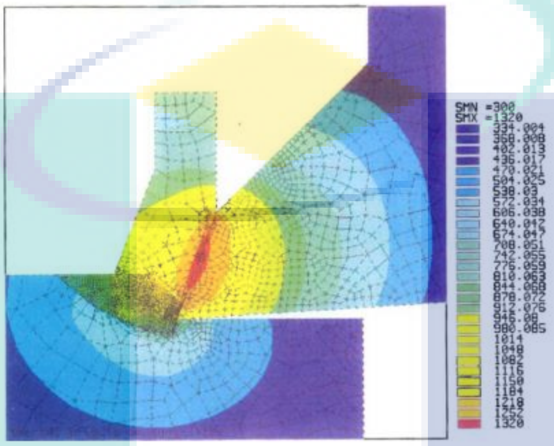

Figure 2.7: Temperature distribution for cutting condition using FEA (M.S. Najiha and M.M.Rahman, 2012)

The research followed either finite element method simulations or experimental observations for the machining under wet cutting situations (Hadad & Sadeghi, 2013). Orthogonal metal cutting process have been successfully modeling by using FEA. For analytical models, FEA deliver significantly reduced the simplifying. Nevertheless, a large number of input parameters are needed when used FEA in metal research. The parameters can be found via doing mechanical property tests and doing extensive experimental work. (Abukhshim, Mativenga, & Sheikh, 2006). From the previous study, it can be seen that FEA can be used in all engineering fields to predict the result from the experiment. By using FEA it is useful for this study to predict the behavior of the nozzle under design conditions by using software Analysis of Systems (ANSYS) software. The FEA software can give the analysis about the flow of oil mist after going out from the outlet of the nozzle.

2.5 CONCLUSION

The reading and research have been discussed in this chapter. The parameter and factor that influence the MQL characteristics also have been stated. From this chapter, the study can be done after getting the idea from the journal.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, methodology reviewed in chapter 2 is referred to achieve the objective in this research. The whole experiment flow will be mentioned and explained.

3.2 PREPARATION OF SPECIMEN

There are three types of fluid with different property applied in the study, which are vegetable oil, water and emulsifier. Hybrid MQL fluid is obtained through combination percentage shown as Table 1, before being stirred for 30 minutes using an electrical stirrer for each sample, while Table 2 shows general properties of each fluid type at room temperature

Table 3.1 : Combination percentage of hybrid MQL fluid (100ml)

Fluid	Oil (%)	Water (%)	Emulsifier (%)
A	100	0	0
B	80	10	10
C	60	30	10
D	40	50	10

Table 3.2: General properties of each fluid type at room temperature

Fluid	Oil (%)	Water (%)	Emulsifier (%)
Density ρ (g/cm^3)	0.93	1.0	1.0
Viscosity η (mm^2/s)	42.8	89.0	747.0
Heat transfer Coeffiecient *k* (W/m^2K)	50-350	330-400	NA

3.3 VISCOSITY TEST

A zahn cup will be used to measure the kinematic viscosity of the fluids. Zahn cup is usually used for one direction flow only and zahn cup 3 is specifically used for this experiment. For liquids that have varied flow conditions, a test using Rheometer is a much more suitable approach. A viscometer also can be used to measure the viscosity, however since it is not a complex liquid, a zahn cup should suffice. The kinematic viscosity unit is centistokes or mm^2/s. In this experiment, we choose to use the mm^2/s unit. The reading will be taken three times and the average value will be recorded. Figure 3.2.1 below shows the Zahn cup diagram.

Figure 3.2 Zahn Cup

3.4 MIST PARTICLE SIZE TEST

After the viscosity of the cutting fluids is sampled, the mist size is tested using a Minimum Quantity Lubrication mist sprayer. A MQL mist generator is designed for this study purpose as shown in **Figure 3.3** and its schematic diagram is shown in **Figure 3.4**. The pressure is set to 0.6MPa and the outlet is set to 1.5 turns for every spray with average flow rate of 80ml/hour. The mist is then sprayed on a microscope slide before the diameter of the mist particle is taken using the microscope as shown in **Figure 3.5** and the help from Motic software connected with the microscope.

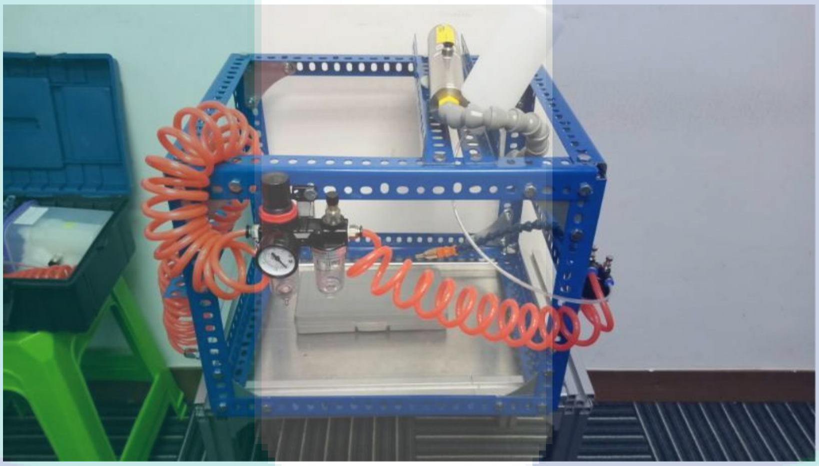

Figure 3.3 The Minimum Quantity Lubrication Mist Generator Set Up

Figure 3.5 The BA310 Compund Motic Microscope

3.5 SIMULATION

A simulation is done by utilising ANSYS^{TM} software to investigate the flow of the cutting fluids after being released from the nozzle. The simulation model and setup is shown as **Figure 3.4.1**. The results will able to show the relationship of hybrid MQL fluid characteristics towards its effectiveness in terms of mist size.

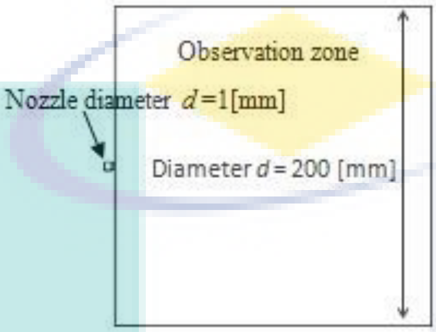

Figure 3.6 Simulation Model of Hybrid MQL Mist Flow

This study starts from study about the MQL system, how it works and its characteristics that lead to the efficiency of MQL in machining process. The finding is sorted by it's categorized and make a review about the research that have been done before. From the literature reviewed, we can find much idea about the MQL system. From the review it found that thera are many type of nozzle is used in the machining process. The problem is detected when there are many size of internal geometry used but which one is more effective is unknown. To see the effectiveness of nozzle, one experiment is conducted to make conclusion for effectiveness of the nozzle. The current and new internal geometry is invented during this study. The setting of MQL parameters based on the previous study is summarized in Table 3.1 to be used in this study.

Table 3.1: Experiment conditions using MQL

Environment	MQL
MQL oil flow rate (Q)	50 ml/h
Air Pressure (P)	300000 Pa
MQL oil	ρ=850 kg/m^3

3.2.2 The models of nozzle for MQL

From the experiment that have been investigated, a current internal geometry that have been used in MQL is straight-flow nozzle and focusing-flow nozzle. So this study want to know if which internal geometry is goods in doing MQL .

In CATIA, the nozzles design have been drawn to illustrate in 3D view. All five models of nozzle is sketch using the same step. Firstly, the drawing starts with the sketch angle of the nozzle, the angle depends on the internal geometry that will be created and the shaft is applied to make the sketch rotate and form the nozzle shape. The internal geometry angle of MQL models nozzle is measured starting from the X-axis.The positive angle will measured clockwise start from the X-axis and the negative angle is when the angle measured anti-clockwise from the X-axis as shown in Figure 3.2.

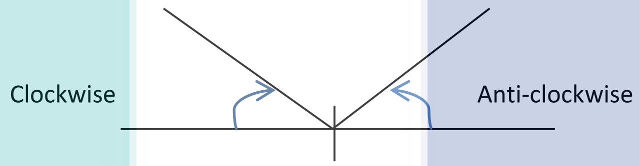

Figure 3.2: How the angle measured

The first picture for each angle represent the isometric view, while the second picture will be the view that have been designed to analyze using the ANSYS software. For this study, the air surrounding, in which the oil mist flow is drawn as a cylinder as boundry for simulation purpose as in Figure 3.3.

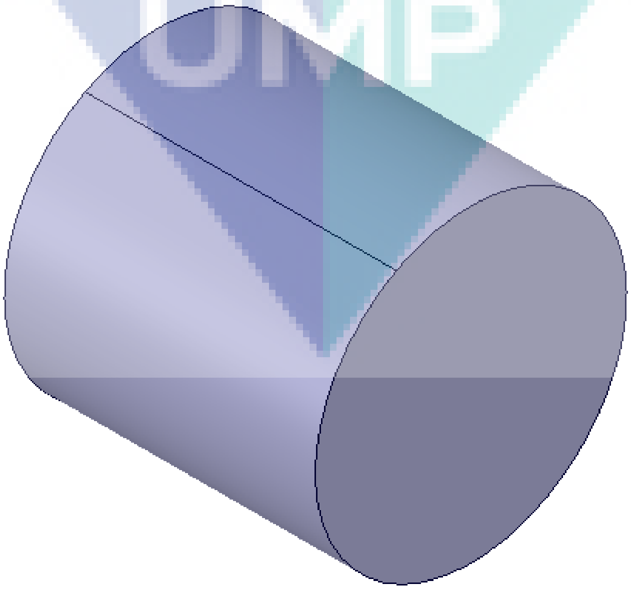

Figure 3.3: Cylinder as air boundary for Ansys Simulation

1) Model 1 = angle for internal geometry is 45^{o}

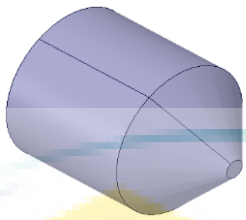

Figure 3.4 : Isometric view for internal geometry 45^{o}

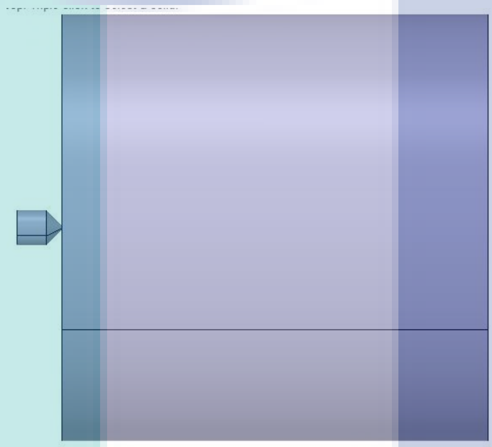

Figure 3.5 : The designed to analyze using the ANSYS software for 45^{o}

2) Model 2 = angle for internal geometry is 30^{o}

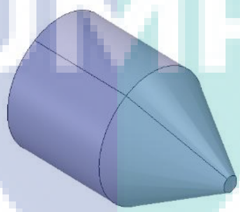

Figure 3.6: Isometric view for internal geometry 30^{o}

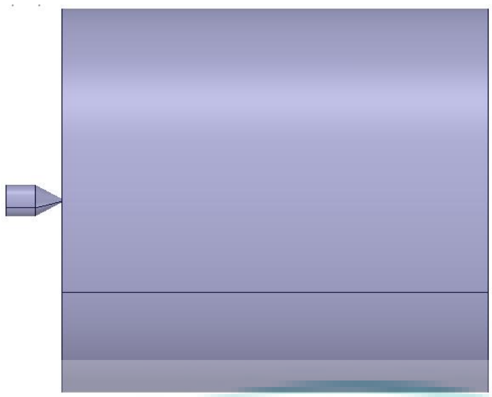

Figure 3.7: The designed to analyze using the ANSYS software for 30°

3) Model 3 = angle for internal geometry is 0°

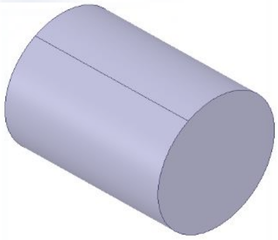

Figure 3.8: Isometric view for internal geometry 0°

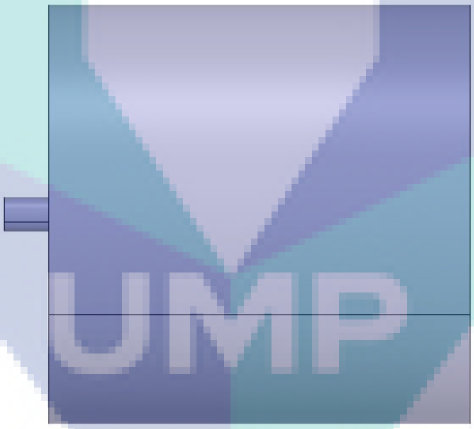

Figure 3.9: internal geometry design to analyze using the ANSYS software for 0°

4) Model 4 = angle for internal geometry is -30°

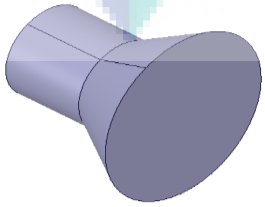

Figure 3.10: Isometric view for internal geometry -30°

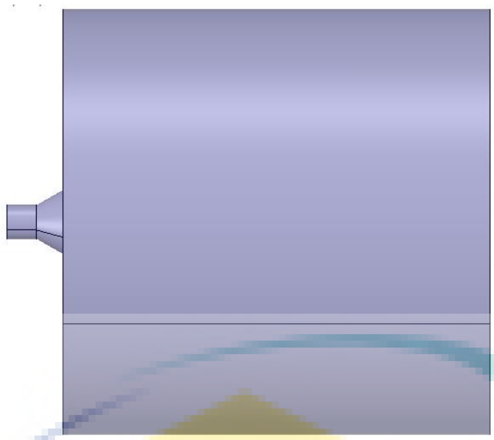

Figure 3.11: The designed to analyze using the ANSYS software for -30^o

5) Model 5 = angle for internal geometry is -45^o

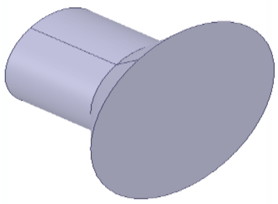

Figure 3.12: Isometric view for internal geometry -45^o

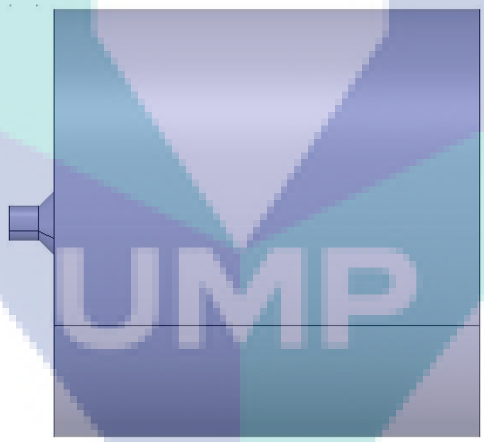

Figure 3.13: The designed to analyze using the ANSYS software for -45^o

From the design, the internal geometry with 30^o and 45^o is a convergent nozzle. The nozzle is decreasing the cross-sectional area respect to distance which sometimes called as focusing-flow nozzle. Next, the nozzle with internal angle 0^o is the straight flow nozzle. Lastly, -30^o and -45^o are the diverging nozzle.

3.2.3 3D Design: Software CATIA

After that, the designs that have been drafted are drawn in the Computer Aided Design (CAD) software which is Computer Aided Three-dimensional Interactive Application (CATIA) that developed by the French company named Dassault Systems. Five models of new nozzle for MQL are drawn with different internal angle are studied through this experiment. The result is compared are by using 30°, 45°, 0°, -45°, and -30°. All the 3D model designs and CNC codes generated is made using 3D drawing software CATIA. Figure 3.14 shows the 30° internal geometry that have been drawn in the CATIA.

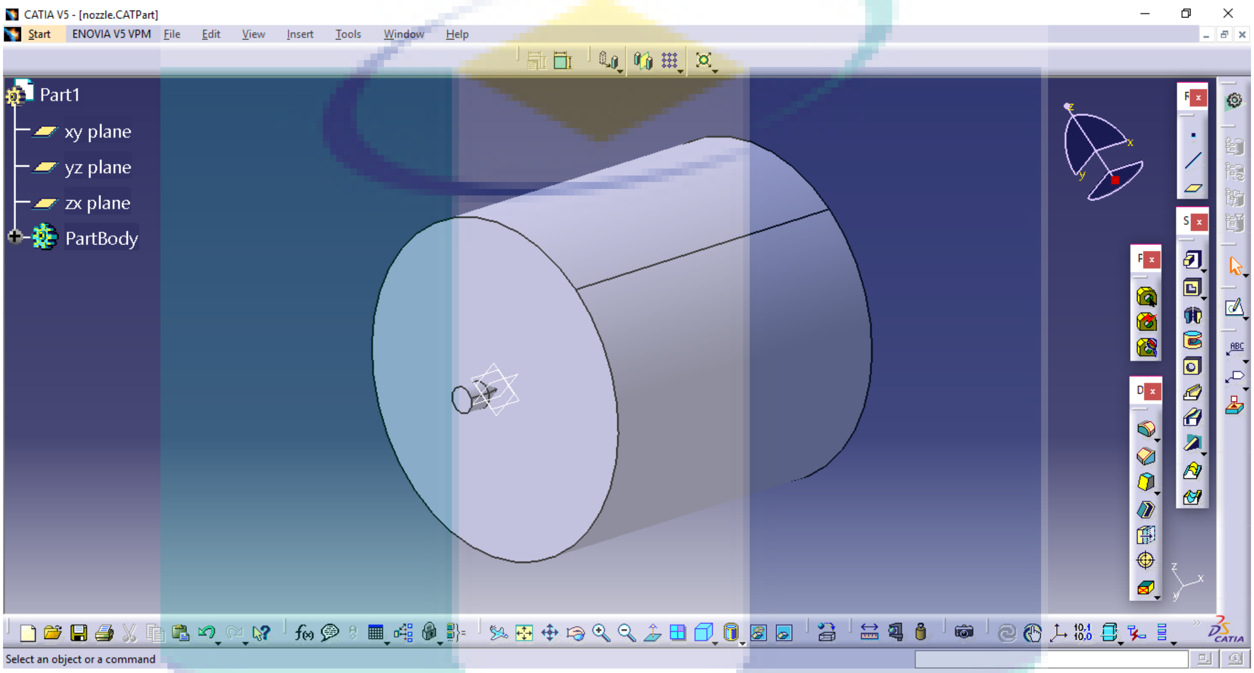

Figure 3.14: 3D design model in CATIA

3.2.4 Finite Element Analysis: Software ANSYS

Additonally, Finite Element Modelling (FEM), ANSYS is going to be utilized in predicting the behaviour of oil mist for this study. It is important to know the flow of the lubricant after release from the nozzle. In Ansys, the fluent part of analysis will be used. By using software Ansys, the flow of oil mist will be observed and analyses. The expected result will be concluded to compare with previous research. The steps in ANSYS software is illustrated in Figure 3.15 as shown in figure below.

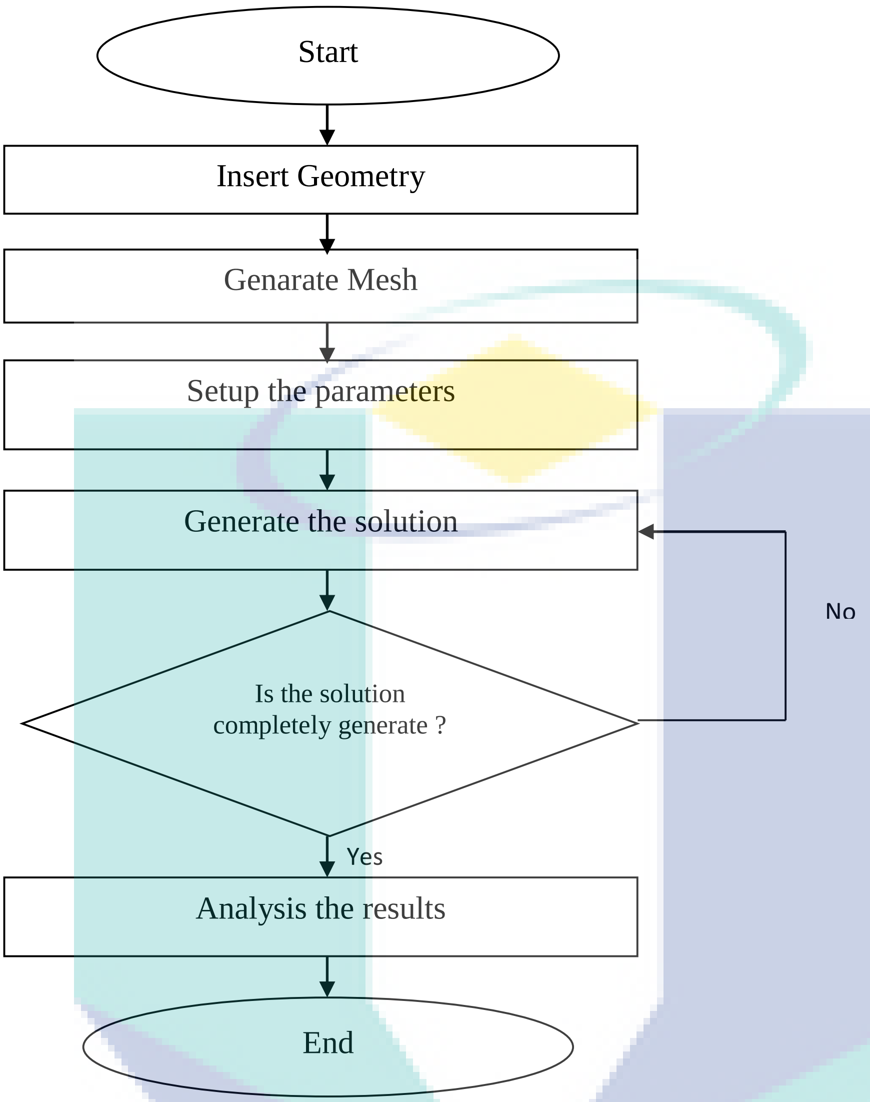

Figure 3.15: The flow work in ANSYS simulation.

The step one is insert geometry that have been drawn in CATIA software. In ANSYS, SpaceClaim interface is used to import the geometry from CATIA as shown in Figure 3.16. After that, mesh is generate to represent the geometry object as a set of finite element for computational analysis or modelling in ANSYS. The mesh is genarating by insert face sizing for each of the surface of model. The name section is added for surface Inlet and Outlet. The body for nozzle and cylinder also named as Body nozzle and Body Wall each. By clicking the button update, the mesh at the model will be generate automatically. Figure 3.17 shows the mesh at the model. Afterward, the parameter in Table 3.1 is inserted ANSYS and solution is generated. If the solution is completely generate, it will shown the graph and the oil mist flow as presented in Figure 3.18 and 3.19. If it is vise versa, the parameter must be set up again to move to the next step with is analysis the data.

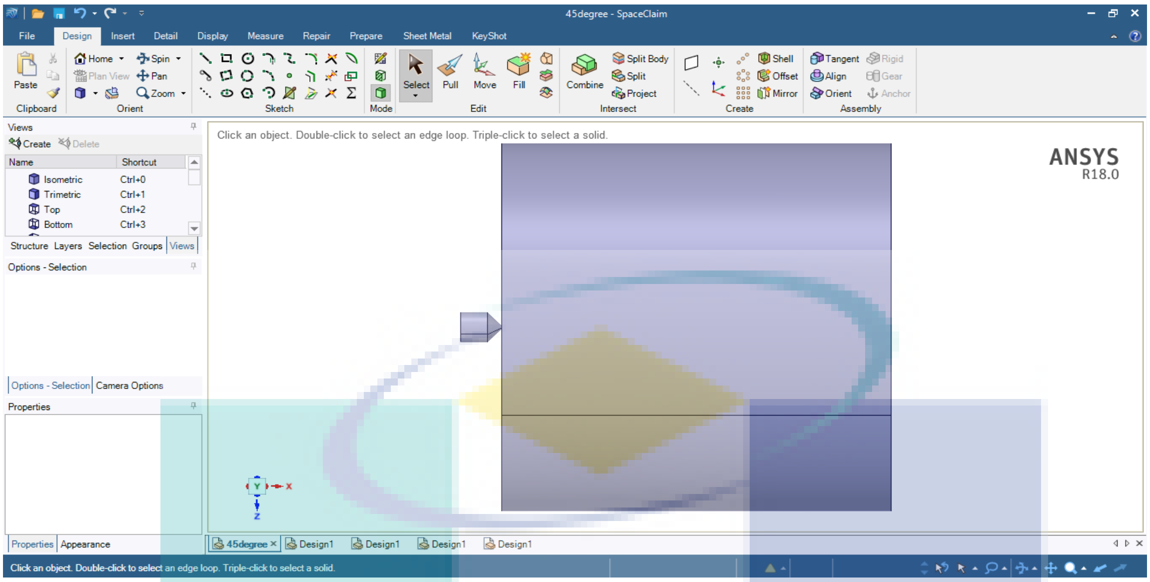

Figure 3.16: SpaceClaim interface for modelling.

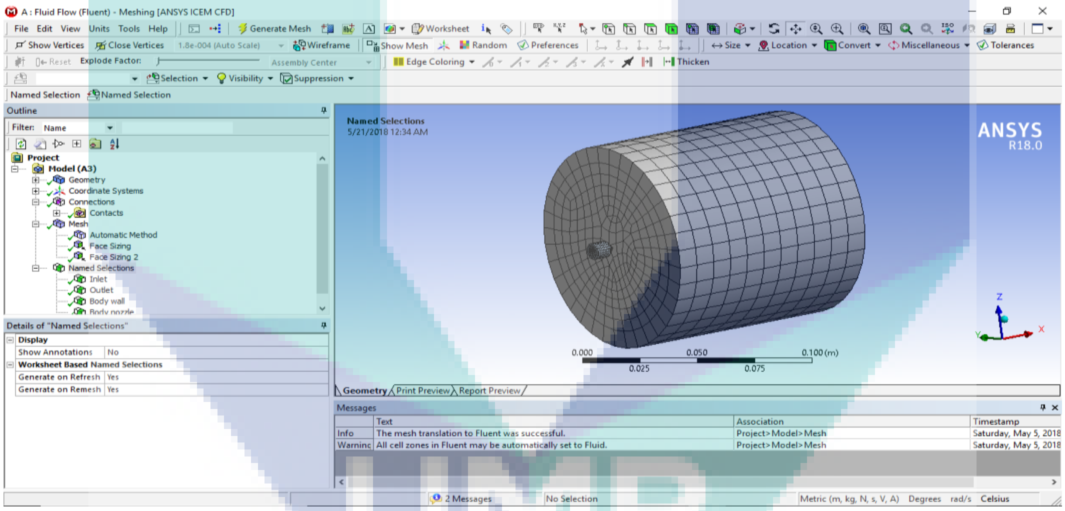

Figure 3.17: Meshing

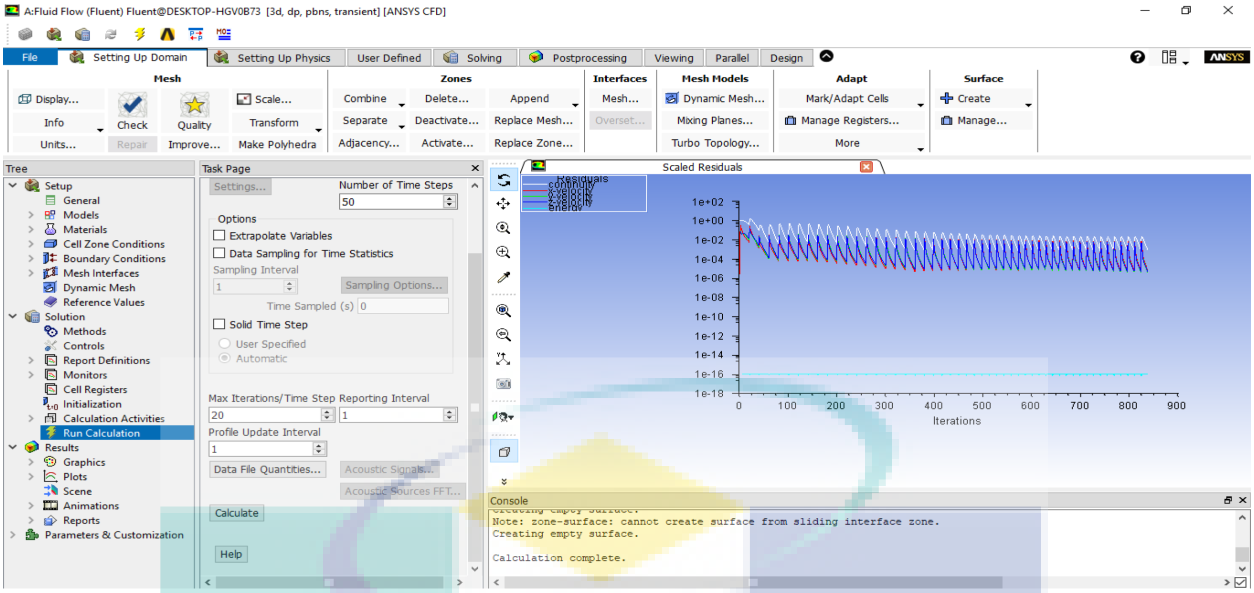

Figure 3.18: Graph for Solution in ANSYS

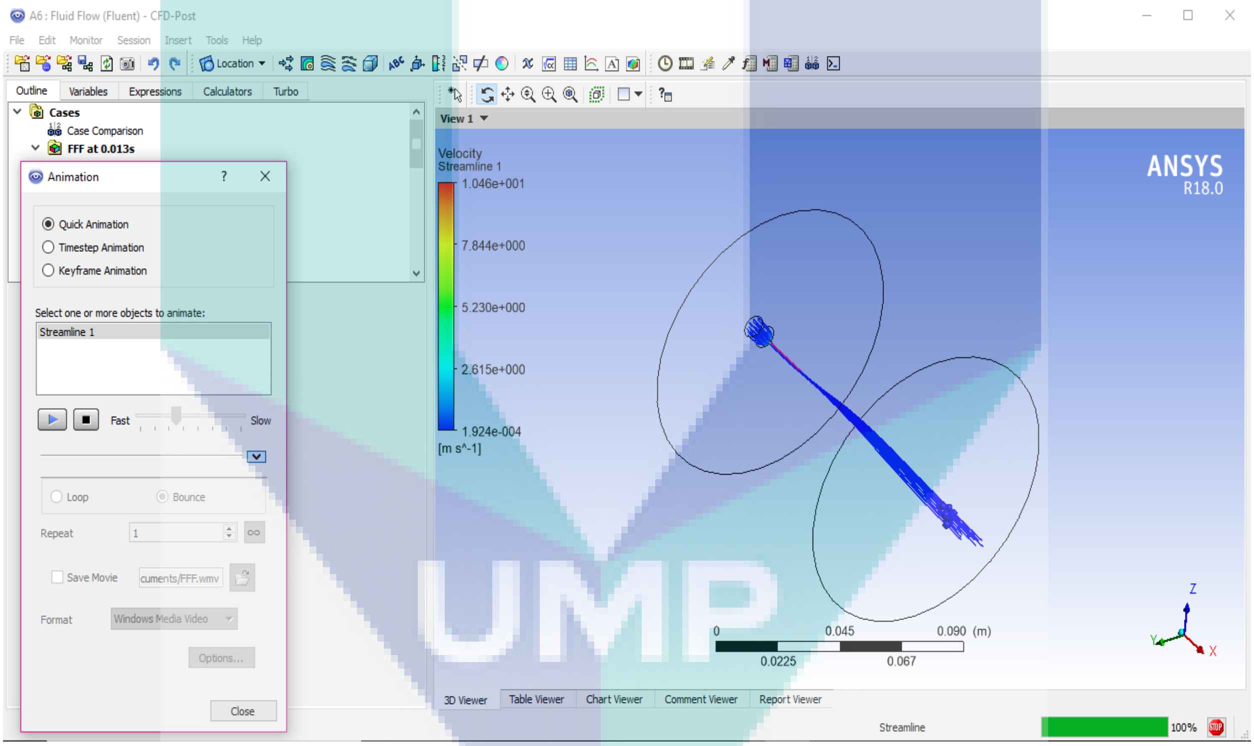

Figure 3.19: Shape of oil mist in ANSYS

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter will discuss about the data collection from the experiment in the project. This chapter further elaborates and analyse all the data and result obtained from conducting the experiment and simulation stated in chapter 3.

4.2 VISCOSITY TEST

Based on table 4.2.1 below, the table is based on the result of viscosity in mm^2/s that is obtained from the Zahn cup. The theoretical density from calculation, and measured density from the mass and volume of the liquids. Then, two figure is produced to show the progression of the viscosity and the density.

Table 4.1: The table of viscosity and density test, and the fluid properties

Num.	Type	Mass (g)	Volume (ml)	Theoretical Density (g/cm^3)	Measured Density (g/cm^3)	Average Zahn cup time (s)	Viscosity (mm^2/s)
1.	100% oil	90.60	100	0.91	0.91	10.6	36.27
2.	10%E 10%W 80%O	74.62	100	0.93	0.75	9.5	23.4
3.	10%E 30%W 60%O	81.49	100	0.95	0.81	8.5	11.7
4.	10%E 50%W 40%O	90.00	100	0.96	0.90	7.7	2.34

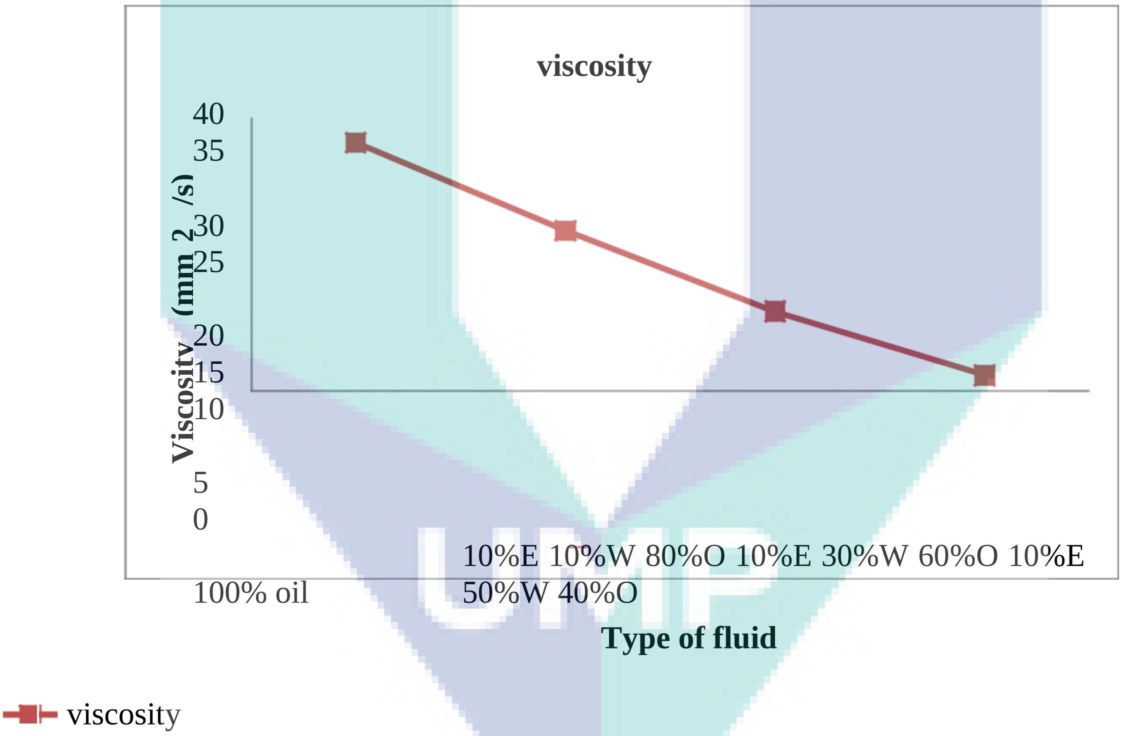

Figure 4.1 The graph of viscosity and type of the fluid

Figure 4.1 shows viscosity comparison between each hybrid MQL liquid obtained from the mixture of oil, water and emulsion. It can be observed from the result that the viscosity of the mixture is decreasing as the oil contents decreases and water content increases. It can be understood that, the hybrid MQL liquid will gradually lost its lubrication capability as the viscosity decreases, related to the oil contents, but it might gain the cooling capability as percentage of water contents increases.

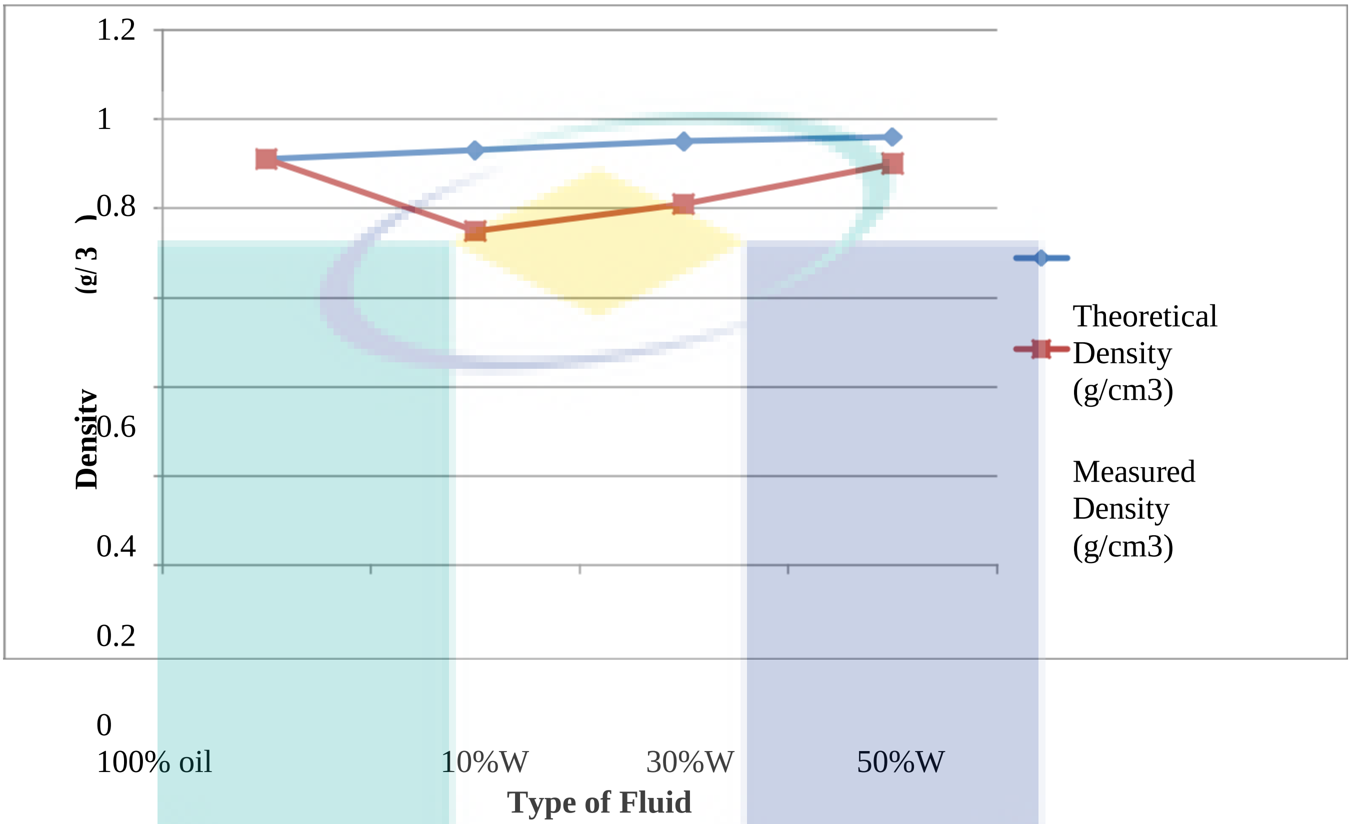

Figure 4.2 The graph of density and type of the fluid

Based on the figure above, It shows the density comparison of each of the hybrid MQL liquid obtained from the study, meanwhile the line is plotted based on the water contents, as it is well known that water has higher density compared to oil. Although not much information can be related to the density of hybrid MQL liquid, it is assumed that MQL mist with higher density have the ability to be supplied with higher accuracy and longer distance due to higher molecule momentum. However, this assumption will need to be prven through simulation or further study on fluid dynamic of the hybrid MQL liquid.

Additionally, a slight different is obtained from the measured density and theoretical density, where the measured density is lower that the theoretical density. It is assumed that the slight different obtained from the results is due to bubbling phenomenon obtained from mechanically mixed together emulsion, oil and water, where the rotational speed of mechanical mixture arms was not taken into consideration. It is assumed that, the phenomenon of bubbling might increase the capability of the hybrid MQL liquid to act as an extreme low temperature mist as the bubble can in containing the extreme low temperature air longer onto the surface of the material or tool.

4.3 MIST DROPLET SIZE TEST

Table 4.2: Mist droplet size reading of two fluid

Num.	Type	Reading 1	Reading 2	Reading 3	Average Size (mm)
1.	100% oil	246.85 X 10^{-3}mm	253.02 X 10^{-3}mm	223.60 X 10^{-3}mm	241.16 X 10^{-3}mm
2.	10%E 50%W 40%O	40.73 X 10^{-3}mm	42.49 X 10^{-3}mm	69.49 X 10^{-3}mm	50.90 X 10^{-3}mm

Table 4.2 shown the average mist size of two selected fluids which are the 100% oil and 100%E 50%W40%O. Based on the result, the average size of mist of the first liquid is much larger compared to the second liquid. This is because the viscosity of the 100% oil is higher thus, resulting in larger mist droplet size. It can be observed that, the molecule size decreases as the oil contents decreases and water contents increases. It is assumed that this phenomenon is related to the viscosity whereas it is assumed that higher viscosity fluid, the mist molecules bond is stronger and tend to generate mist droplets in larger size.

Obtaining larger size mist droplets shows that, the mist might have higher lubrication capability, where it can be explained as in **Figure 4.5,** where effective height of higher viscosity liquid is larger compared to low viscosity liquid when contact happens**.** Plus**,** even if the droplet is pressed to be the same height, it can be assumed that, the amount of mist particles with higher viscosity and larger mist droplets size in a unit of contact area is higher compared to lower viscosity and smaller mist droplets size. Additionally, if the liquid itself is compressible, the liquid will react like a resistor or spring, thus decreases the direct contact pressure between that two surfaces.

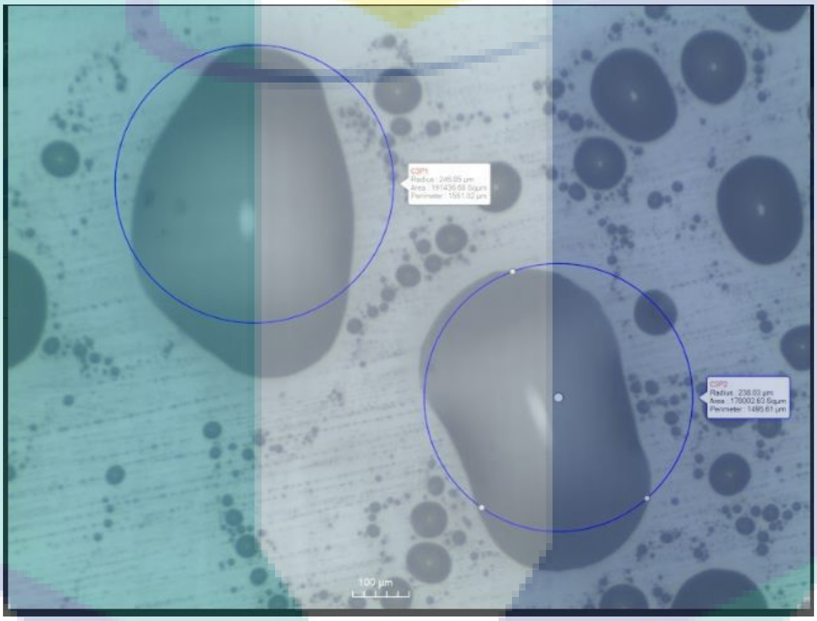

Figure 4.3: Mist droplet of 100% oil

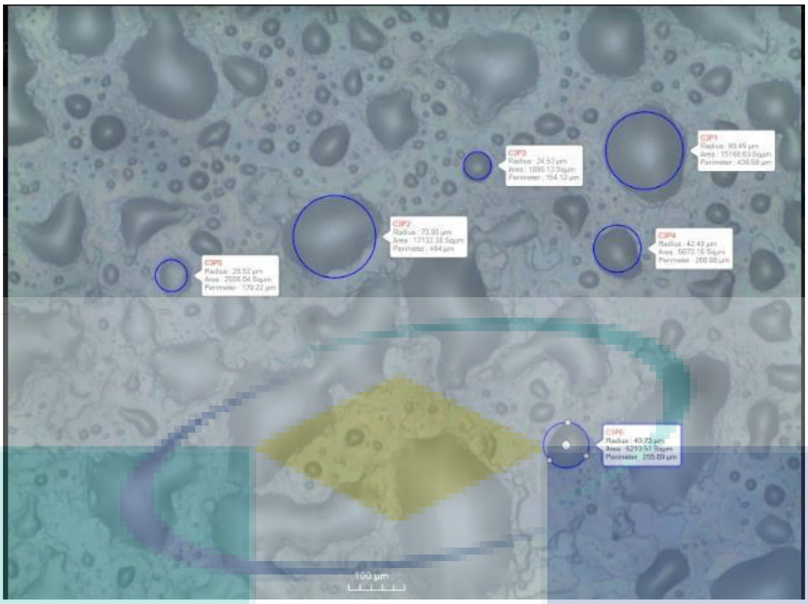

Figure 4.4 The mist droplet of 10%E 50%W 40%O

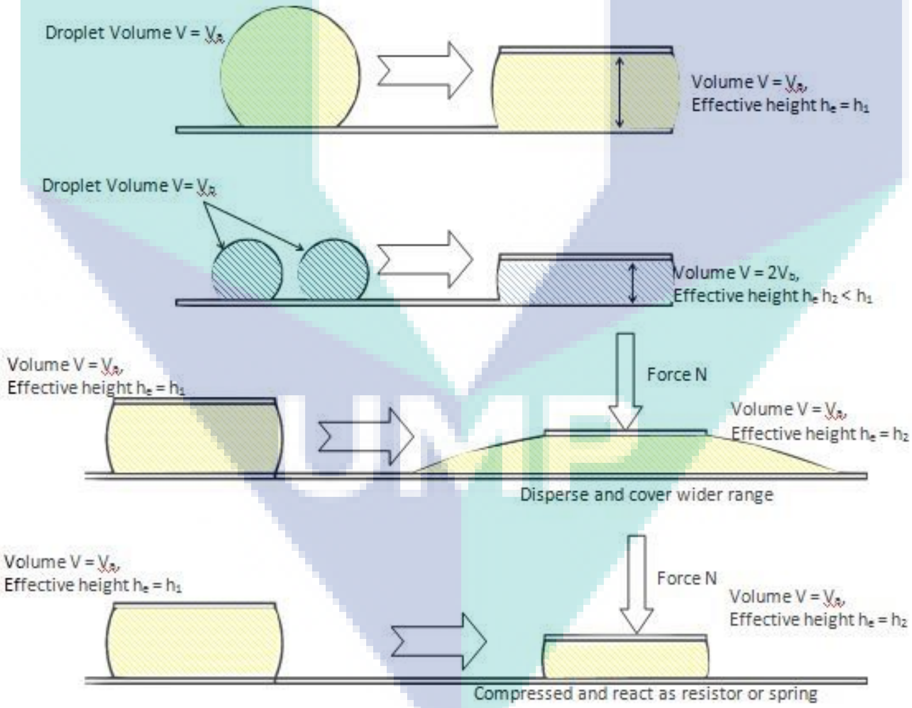

Figure 4.5 Effect of Droplets Size onto Contact Between Two Surfaces

4.4 SIMULATION

Furthermore, **Figure 4.6** shows simulation results for fluid flow of hybrid MQL fluid. From the figure, it is observed that the particle dispersed with high velocity. This is due to the pressure and energy that is high enough. However, the velocity is gradually decreases as the particles are moving away from the nozzle. According to **Figure 4.7**, it can be considered that the range of effective MQL application is less than 20 [mm] away.

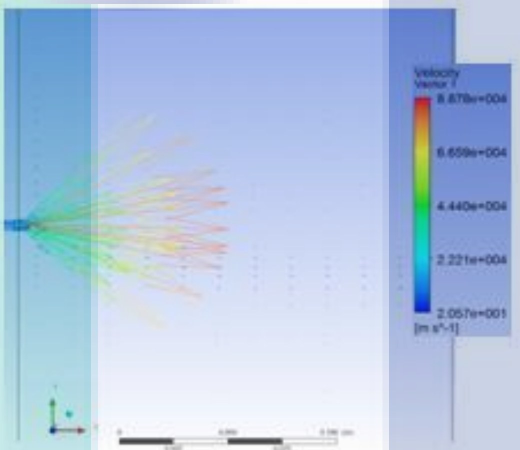

Figure 4.6 Mist Behaviour Estimated by FEM

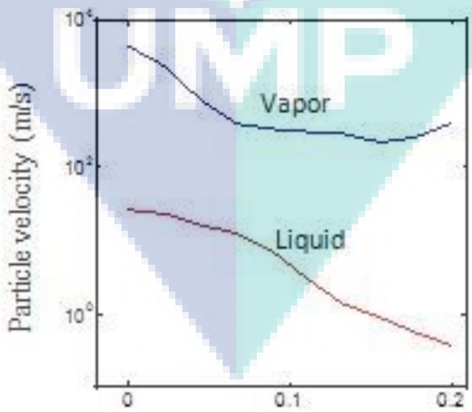

Figure 4.7 Particles Velocity Behavior Estimated by FEM for Various Mist Condition

The fluid velocity is obtained from the simulation in ANSYS and the data is compile to see the result for different type of models. Table 4.1 shows all type of nozzle and the distance of oil mist from the nozzle. The allocation for every point is plotted in Microsoft Excel to make a graph.

Table 4.1. Velocity for 5 types of nozzle

Distance, X[m]	**45º**	**30º**	**0º**	**-30º**	**-45º**
0.00E+00	1.04E+01	1.54E+01	2.31E-01	9.87E-02	1.56E-01
1.11E-02	2.34E-01	1.07E-01	4.22E-02	2.33E-02	1.87E-02
2.22E-02	9.80E-02	8.21E-03	8.47E-03	4.93E-03	4.32E-03
3.33E-02	1.31E-02	4.37E-03	3.55E-03	2.60E-03	2.46E-03
4.44E-02	4.65E-03	2.01E-03	2.00E-03	1.83E-03	1.80E-03
5.56E-02	2.58E-03	1.66E-03	1.66E-03	1.61E-03	1.59E-03
6.67E-02	1.92E-03	1.54E-03	1.54E-03	1.52E-03	1.51E-03
7.78E-02	1.65E-03	1.59E-03	1.59E-03	1.58E-03	1.58E-03
8.89E-02	1.52E-03	1.22E-03	1.22E-03	1.22E-03	1.22E-03
1.00E-01	1.45E-03	1.45E-03	1.45E-03	1.45E-03	1.45E-03

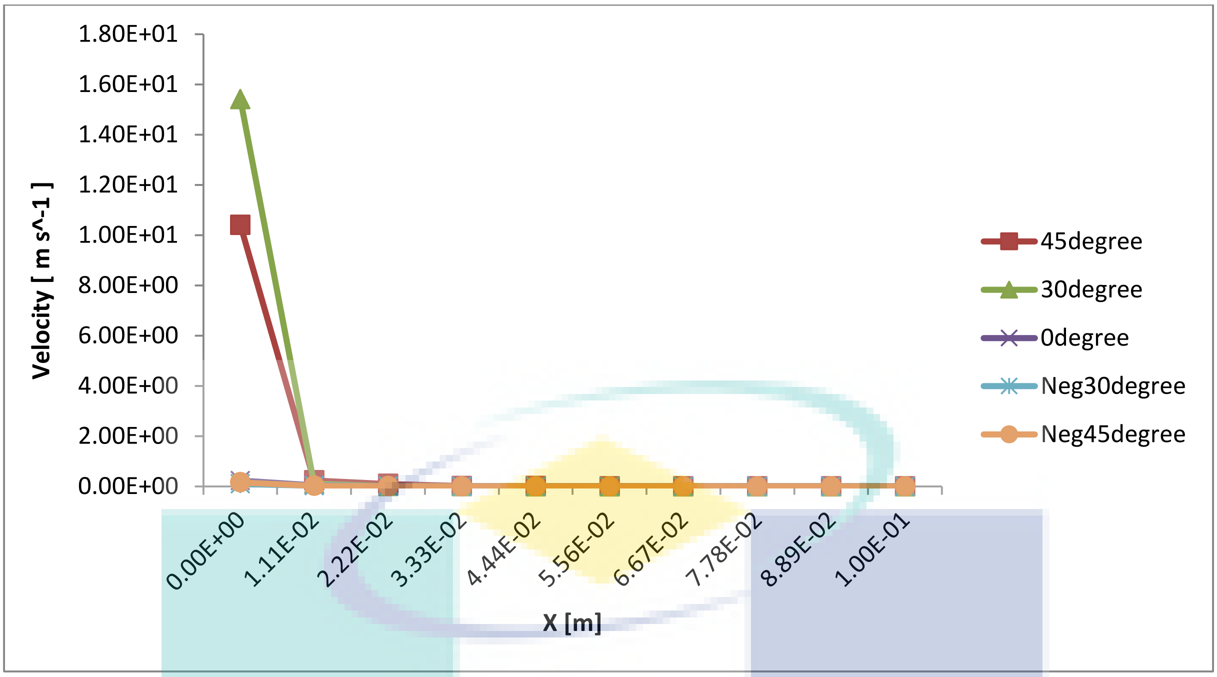

Figure 4.1: Velocity for 5 types of nozzle.

Referring to graph in Figure 4.1, the velocity for nozzle with internal geometry 30^o is the highest than the other nozzles when going out from the nozzle. The second highest velocity is nozzle with internal geometry 45^o. However, the nozzle with internal geometry 0^o, -30^o, and -45^o have almost the same velocity from flow out of the nozzle until the distance 1.00E-01m. The nozzle with internal geometry 30^o are decreasing rapidly from 1.54E+01ms^{-1} at distance 0.00E+00m to 1.07E-01ms^{-1} at distance 1.11E-02m and continuing decrease slowly until 1.45E-03ms^{-1} at distance 1.00E-01m. Then, for nozzle with internal geometry 45^o, the highest velocity when flow out from the nozzle is 1.04E+01ms^{-1} at 0.00E+00m. It also decrease rapidly to 2.34E-01ms^{-1} at 1.11E-02m. On the other hand, the nozzle with internal geometry 0^o, -30^o, and -45^o show different pattern. The velocity for the the nozzle with internal geometry 0^o, -30^o, and -45^o are steady when flow out from the nozzle.

In conclusion, the graph in Figure 4.1 compares the velocity various type of internal geometry of nozzle for MQL method in machining. It can clearly seen that the velocity for all type of nozzle declining throughout the distance.

4.3 PRESSURE

The fluid pressure is took from the simulation in ANSYS and the data is compile to see the result for different type of models. Table 4.2 shows all type of nozzle and the distance of oil mist from the nozzle. The pressure is obtained when the oil mist flow out from the nozzle. The distribution for every point is plotted in Microsoft Excel to make a graph.

Table 4.2 Pressure for 5 types of nozzle.

Distance, X[m]	**45º**	**30º**	**0º**	**-30º**	**-45º**
0.00E+00	3.10E-01	4.00E-01	-9.28E-05	1.37E-05	-2.49E-05
1.11E-02	4.50E+01	1.22E+02	7.51E-03	4.19E-03	1.18E-02
2.22E-02	4.54E+01	1.22E+02	8.47E-03	4.59E-03	1.24E-02
3.33E-02	4.54E+01	1.23E+02	8.08E-03	4.53E-03	1.23E-02
4.44E-02	4.54E+01	1.23E+02	7.90E-03	4.50E-03	1.23E-02
5.56E-02	4.54E+01	1.23E+02	7.86E-03	4.50E-03	1.23E-02
6.67E-02	4.54E+01	1.23E+02	7.84E-03	4.50E-03	1.23E-02
7.78E-02	4.54E+01	1.23E+02	7.83E-03	4.49E-03	1.23E-02
8.89E-02	4.54E+01	1.23E+02	7.83E-03	4.49E-03	1.23E-02
1.00E-01	4.54E+01	1.23E+02	7.83E-03	4.49E-03	1.23E-02

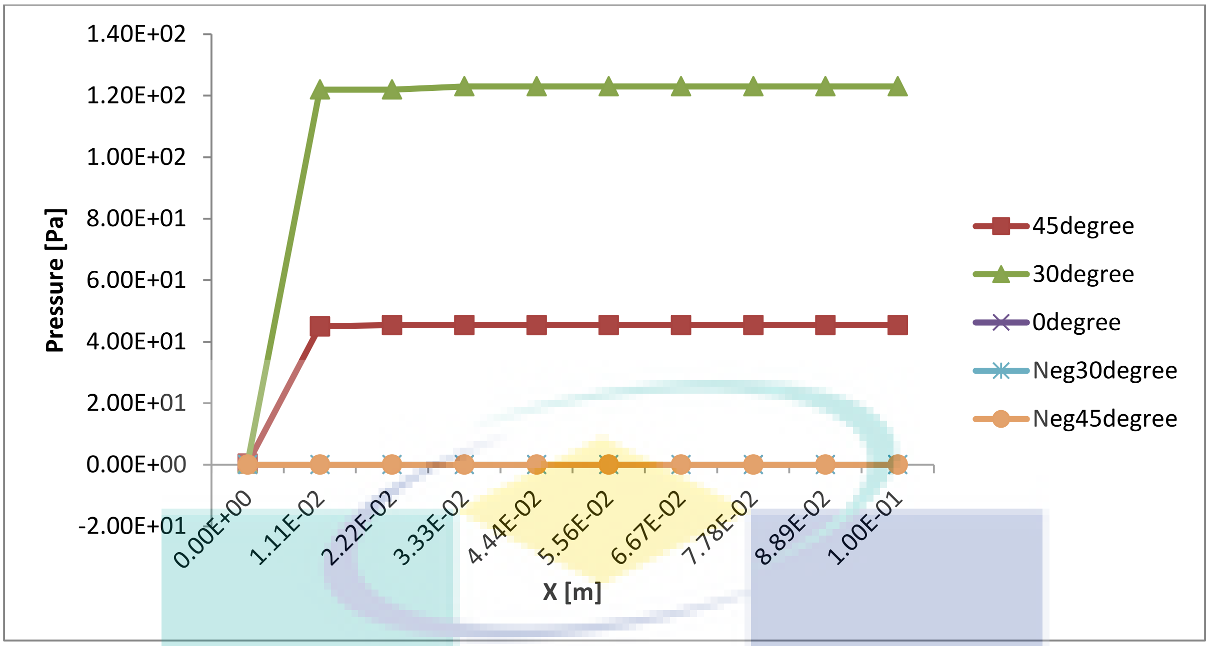

Figure 4.2: Pressure for 5 types of nozzle.

Discussing about graph in Figure 4.2, the overll pressure for nozzle with internal geometry 30° is the highest than the other nozzles when going out from the nozzle. Initially, the nozzle with internal geometry 30° are increase rapidly from 4.00E-01Pa at distance 0.00E+00m to 1.22E+02Pa at distance 1.11E-02m. From distance 3.33E-02m, the pressure remain constant at 1.23E+02Pa until distance 1.00E-01m. Moreover, the second highest pressure is nozzle with internal geometry 45°. The lowest velocity for 45° is 3.10E-01Pa when flow out from the nozzle at 0.00E+00m. It also increase rapidly to 4.50E+01Pa at 1.11E-02m.After that, increase to 4.54E+01Pa at 2.22E-02m and remain conatant until 1.00E-01m. However, the nozzle with internal geometry 0°, -30°, and -45° have almost the same pressure from flow out of the nozzle until the distance 0.00E+00m. The pressure for the the nozzle with internal geometry 0°, -30°, and -45° are steady when flow out from the nozzle.

4.4 RELATIONSHIP BETWEEN VELOCITY AND PRESSURE

The graph for velocity and pressure show that, when the velocity decrease the pressure will be increasing. From the design, the internal geometry with 30^o and 45^o is a convergent nozzle. The area of internal nozzle starts with big and become smaller cross-section. By entering the small cross-section, the velocity is increase because the oil mist move faster. Pressure is the some energy which is in random motion. When through the high velocity, the pressure will be dropped. So, for internal geometry 0^o, -30^o and -45^o the velocity is not change due to the straight flow nozzle and divergeing nozzle.

4.5 SHAPE OF OIL MIST FLOW IN THE AIR THROUGH DIFFERENT NOZZLE.

In the fluent analysis, all nozzle with different internal geometry are simulated after all parameters are entered in the data base ANSYS. The flow behavior for the oil mist moving is observed. From the fluent analysis, the shapes of oil mist flow in the air and particle moving is presented in Figure 4.3 until 4.7.

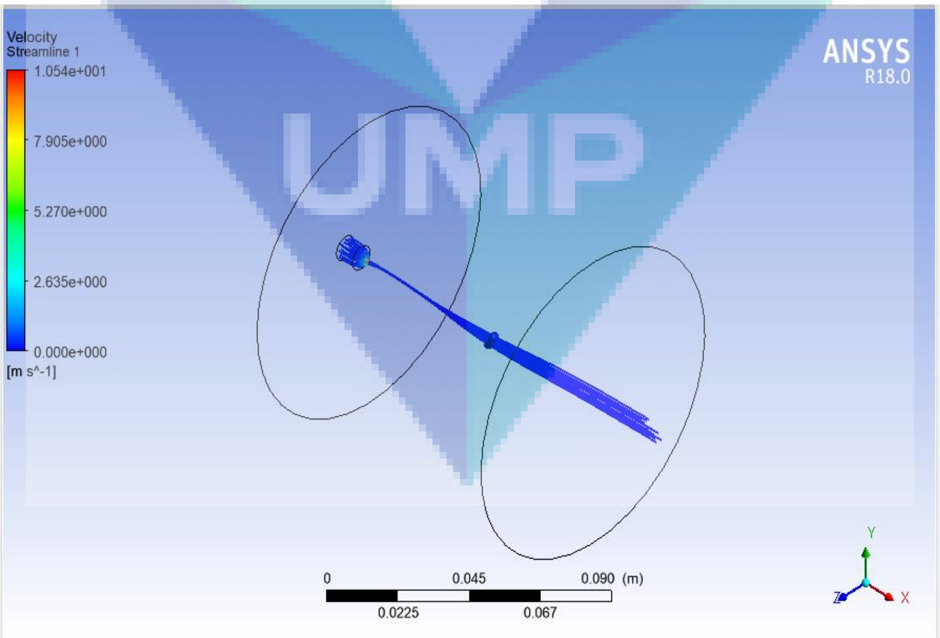

Figure 4.3: The shape of oil mist flow in the air from the nozzle with internal geometry 45^o

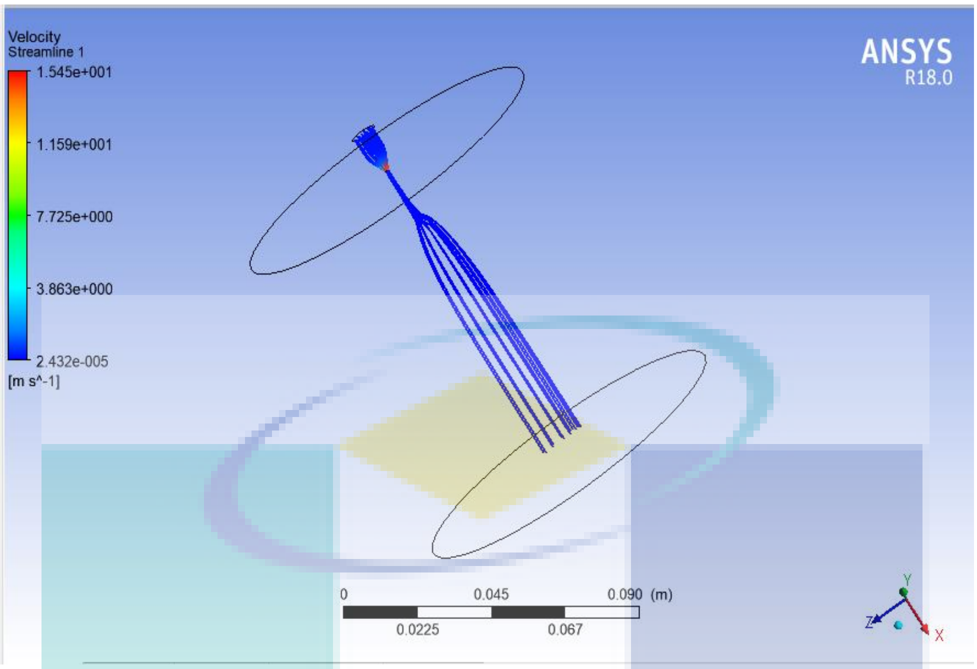

Figure 4.4: The shape of oil mist flow in the air from the nozzle with internal geometry 30°

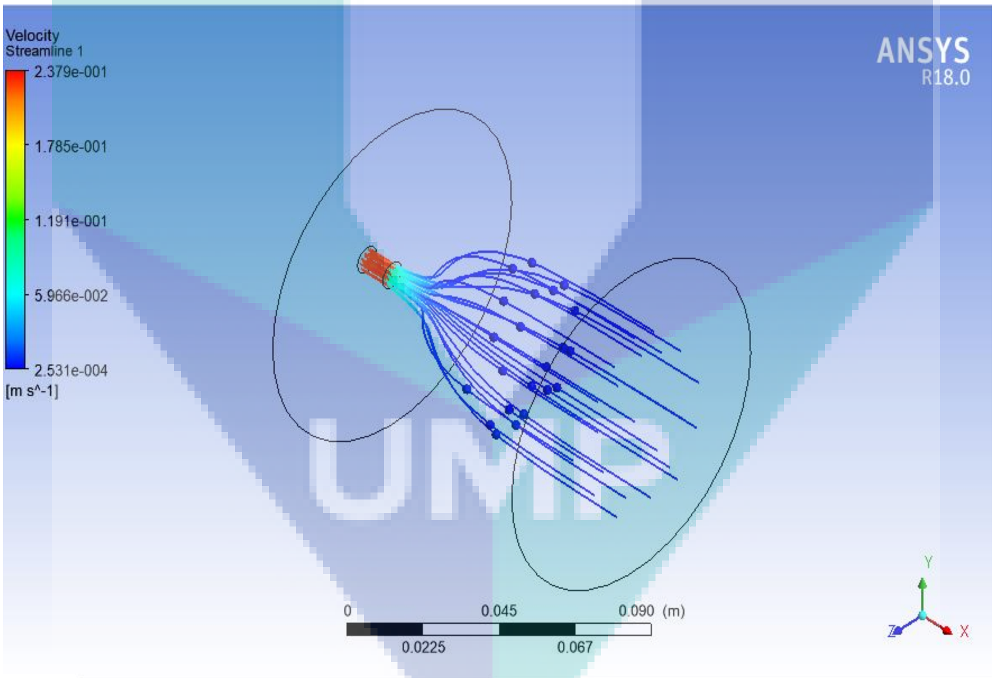

Figure 4.5: The shape of oil mist flow in the air from the nozzle with internal geometry 0°

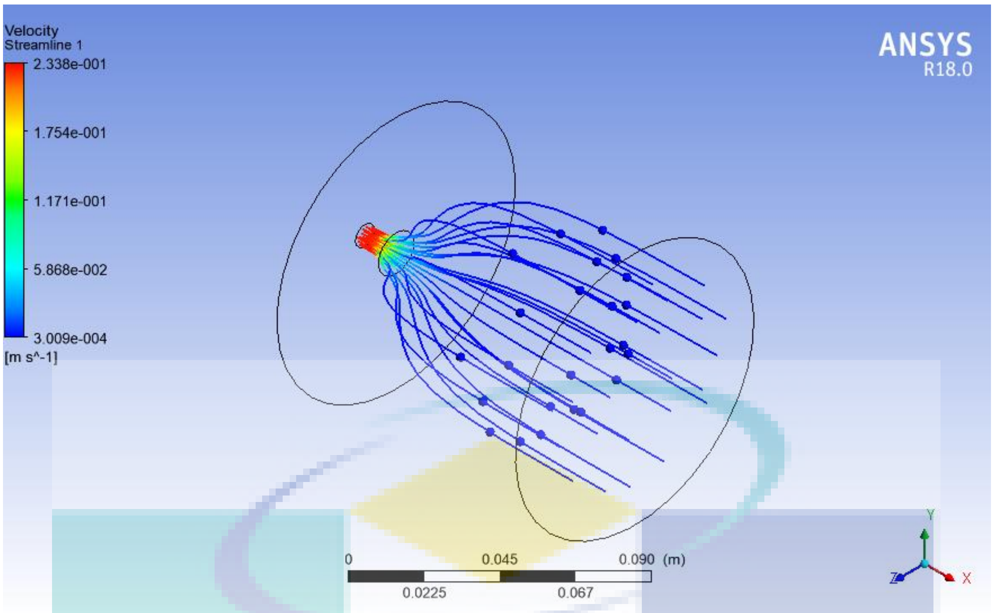

Figure 4.6: The shape of oil mist flow in the air from the nozzle with internal geometry -30°

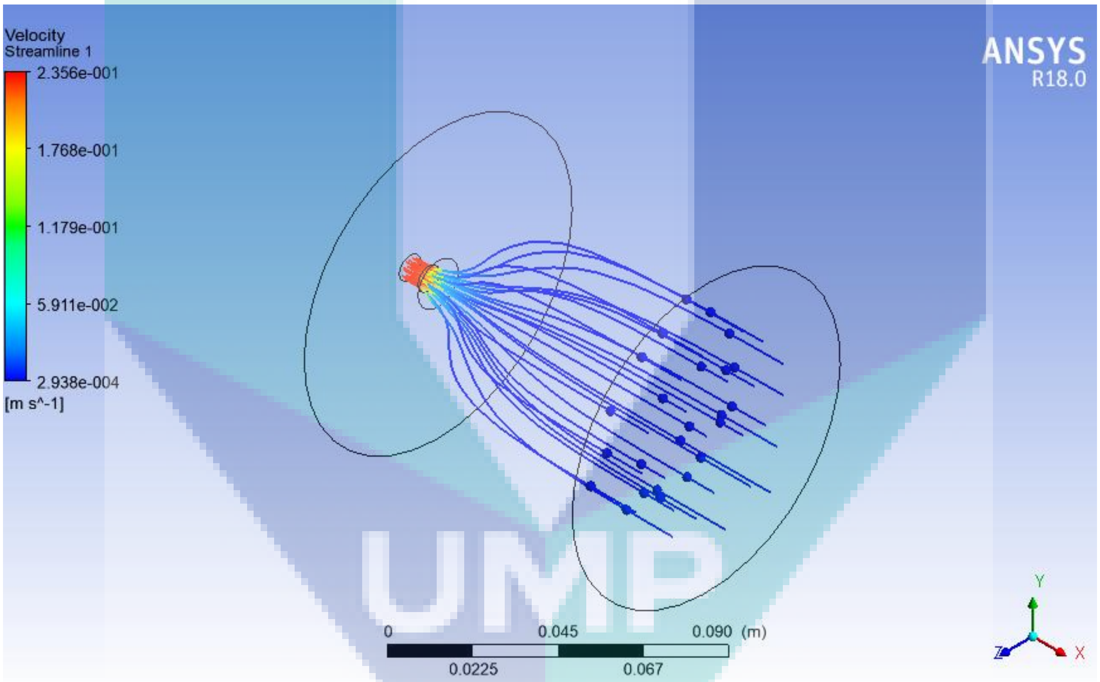

Figure 4.7: The shape of oil mist flow in the air from the nozzle with internal geometry -45°

From the Figure 4.3, it can be seen that, the particle of oil mist flow for nozzle with internal geometry 45° close to each other when leave the nozzle and start to disperse very slowly in the air. The dispersion is slowly until the end of the cylinder. This is because the diameter end of nozzle decreases over the nozzle and the particles of oil mist collide to the wall of 45°.

The streamline for the 45^o shows the nozzle the lowest dispersity. Lower dispersity means higher accuracy, more MQL mist is able to reach the cutting zone. However, for internal angle 30^o, the shape is same with internal angle 45^o. But, the dispersion of particle is wider than the internal angle 45^o with respect to time. This is because the wall 30^o more decline compared to 45^o.

Next, for internal angle 0^o, the shape of the nozzle is a cylinder and oil mist disperse faster that internal geometry 30^o. The oil mist also moving far away from one another with respect to time. The oil mist flow out through the -35^o and -45^o also have almost the same shape of oil mist moving with the 0^o. This is because the internal angle is negative and the wall at the end incline and the oil mist is not colliding with the end of nozzle wall. Additional air increases the risk of interparticle collision as well as collision with the channel walls, which can cause an accumulation along the channel walls and therefore a reconditioning of the oil. This creates larger particles and leads to the spitting phenomenon. . (Duchosal, Leroy, Vecellio, Louste, & Ranganathan, 2013)

Therefore, the nozzle with internal geometry 45^o is more efficient. This is because it have the second highest velocity and very less disperse in term of shape of oil mist. The oil mist flow is more accurate to hits the cutting point and the tools. With the more oil mist hit the same point, it can cool the cutting tool and workpiece faster. But, if there are big area to cool down, there are three nozzle that can be used which are nozzle with internal geometry 0^o, -35^o and -45^o. This is because of oil mist particle hits the workpiece in the large area. So its helps to cool down but more time needed due to the less amount of oil mist at one point.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.2 Summary

The samples of 100% oil, 10%E 10%W 80%O, 10%E 30%W 60%O and 10%E 50%W 40%O had been mixed and its viscosity and density properties had been analyzed. The mist droplet size and its relation to viscosity of the cutting fluids had been studied. Thus the objectives of this research are achieved.

The viscosity test conducted proven that the viscosity of the cutting fluids decreases and the density increases as the water contents increases. Due to mixture of different types of particles, the bond between the particles become weaker making the viscosity decreases. Regarding the mist droplet size, the 100% oil has larger droplet size than the sample with 10%E 0%W 40%O.

The decrease in viscosity affects the mist particle more than its density. This is also related to the weaker bonds between the particles causing the mist droplet to have smaller size. Smaller mist droplet is usually related to high heat transfer. This is due to less energy is needed to break the bond. Thus, fluids with smaller mist droplet particle has higher cooling abilities.

Lastly, the simulation shows the physical trajectory direction of the mist when sprayed from the nozzle. The pressure become higher when it reaches impact point while the velocity becomes lower before both stabilizes. The effective distance of Hybrid MQL application is less than 20[mm] away from the nozzle.

5.3 RECOMMENDATION

Based on the results of this research, further study on the properties of a hybrid MQL in other chemical or physical aspects should be done. Other than that, A different kind of hybrid or cutting fluid additives could be experimented to find the perfect combination. This will further helps in advancement of the cutting fluid technology and thus the manufacturing industry. The testing of the performance of the hybrid MQL can also be done using appropriate performance measurement tools such as tribometer for surface roughness and thermocouple experiment for effect of cooling.

Machining process by using the Conventional method is now invented to Minimum Quantity Lubrication (MQL) method. Nozzle is one of important part in MQL that can cause the effectiveness during cutting process. In this study, we proposed and analyse the internal geometry of nozzle. There are five type of nozzle which are 30^o, 45^o, 0^o, -45^o, and -30^o. The simulation results point out that the focusing-flow nozzle is more efficient nozzle in doing machining process using MQL method. Nozzle with internal geometry 45^o is less disperse and high velocity nozzle is the good one. This is because, the oil mist flow out from nozzle is more accurate to hits the cutting point and the tools that can cause faster cooling speed.

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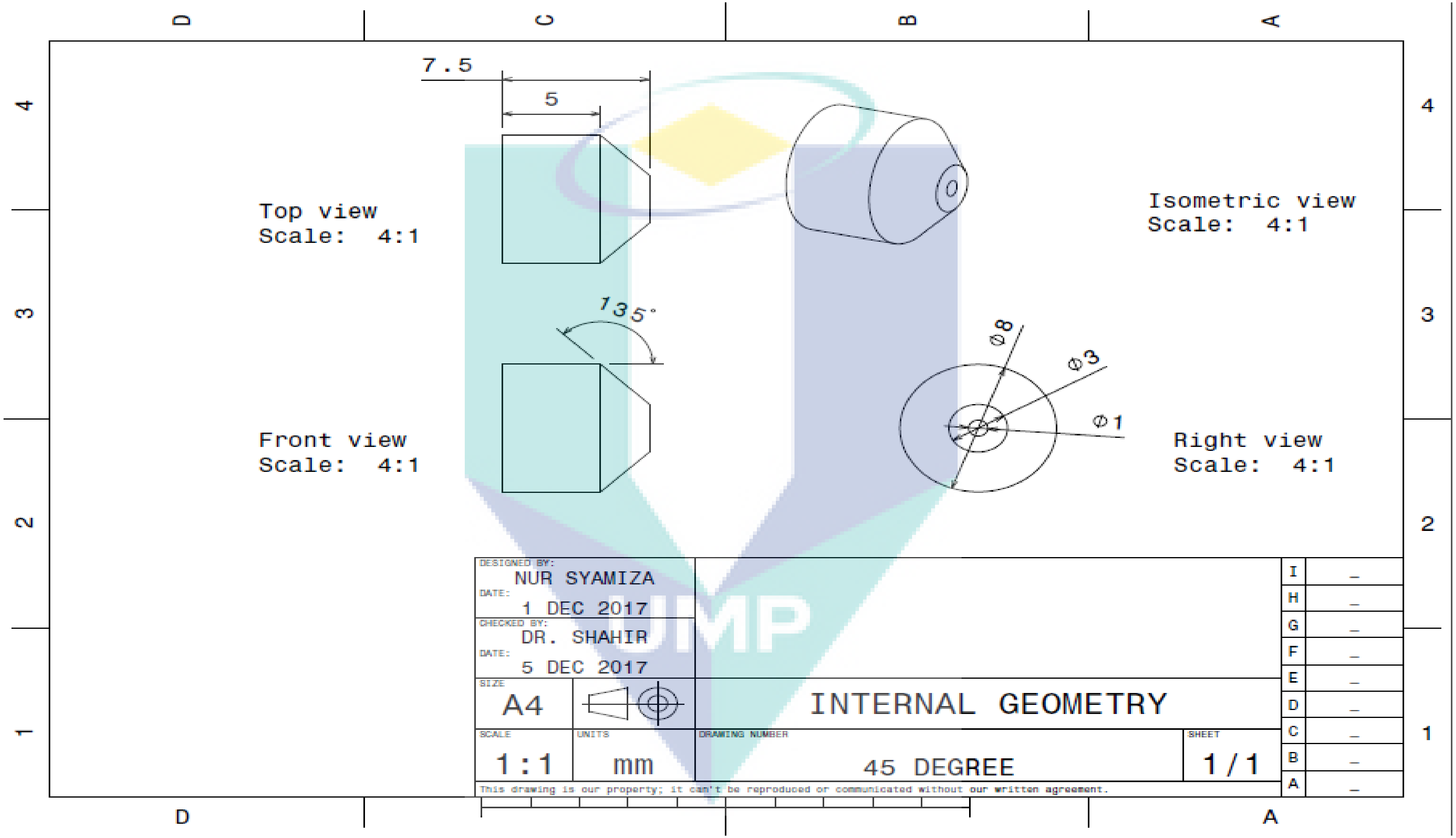
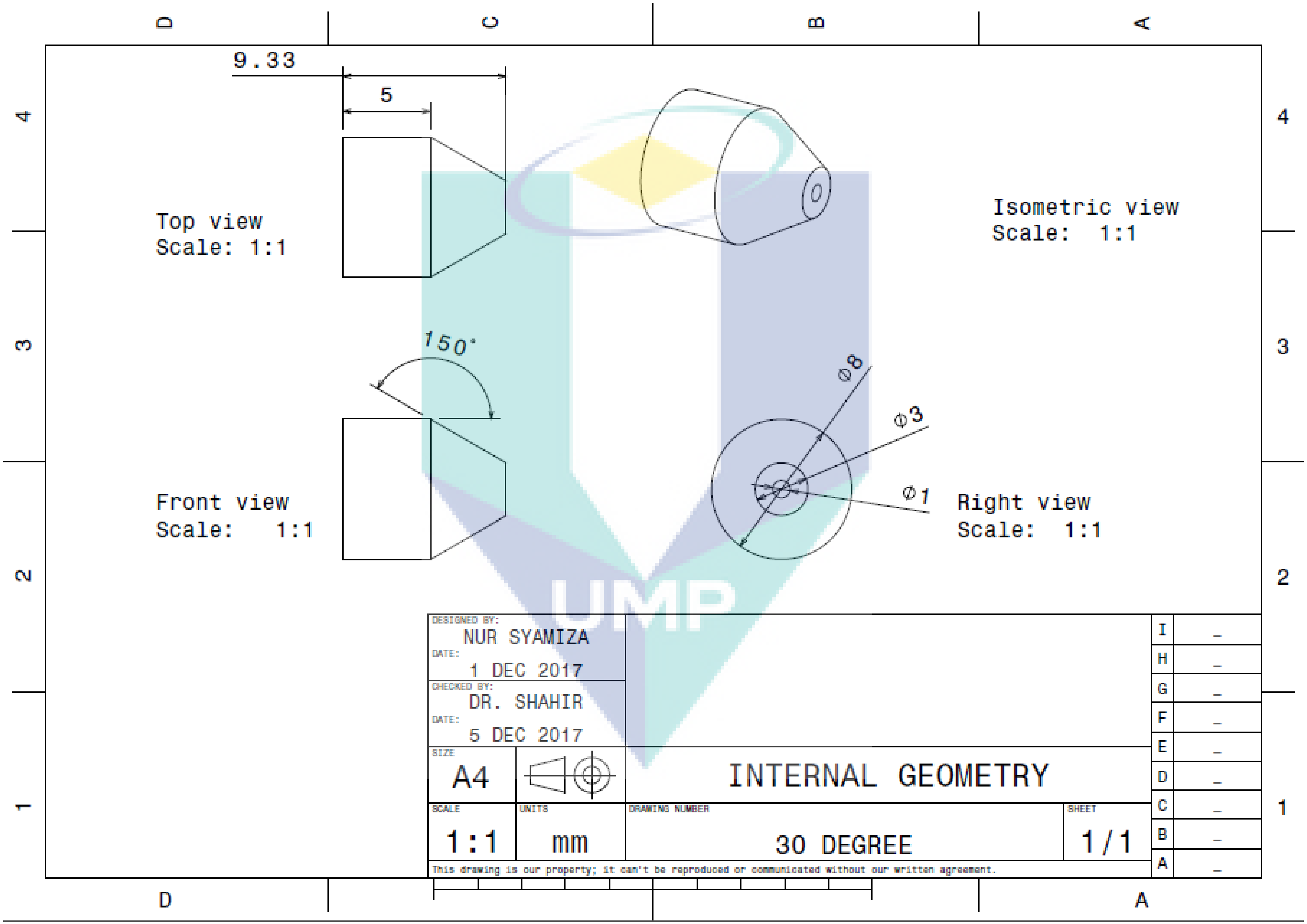
Drawing for Nozzle

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Top view
Scale: 1:1
Isometric view
Scale: 1:1
150°
Ø8
Ø3
Ø1
Front view
Scale: 1:1
Right view
Scale: 1:1
DESIGNED BY:
NUR SYAMIZA
DATE:
1 DEC 2017
CHECKED BY:
DR. SHAHIR
DATE:
5 DEC 2017
SIZE
A4
INTERNAL GEOMETRY
SCALE
1:1
UNITS
mm
DRAWING NUMBER
30 DEGREE
SHEET
1/1
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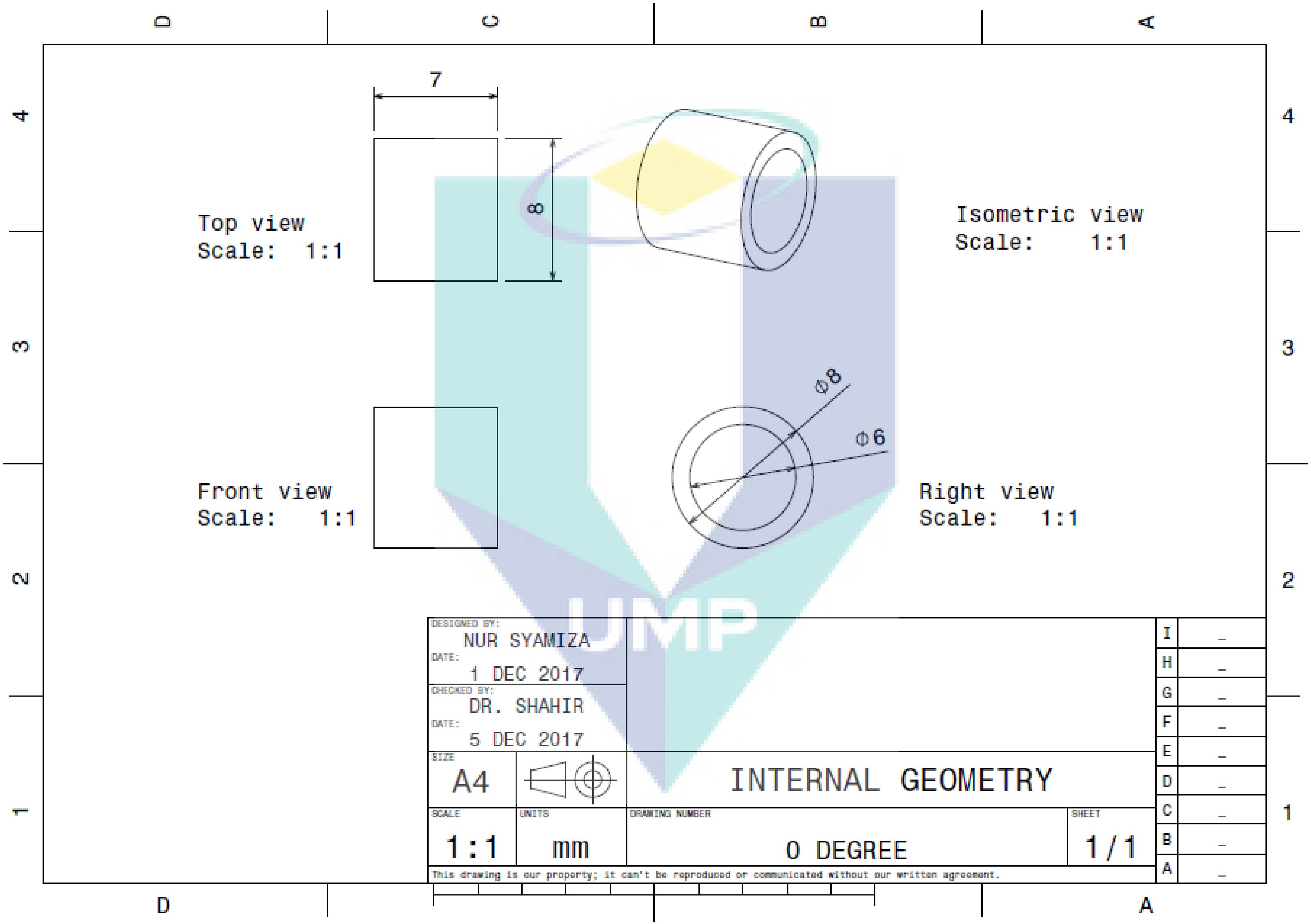
7
8
Top view
Scale: 1:1
Isometric view
Scale: 1:1
Front view
Scale: 1:1
Right view
Scale: 1:1
ϕ8
ϕ6
DESIGNED BY:
NUR SYAMIZA
DATE:
1 DEC 2017
CHECKED BY:
DR. SHAHIR
DATE:
5 DEC 2017
SIZE
A4
INTERNAL GEOMETRY
SCALE
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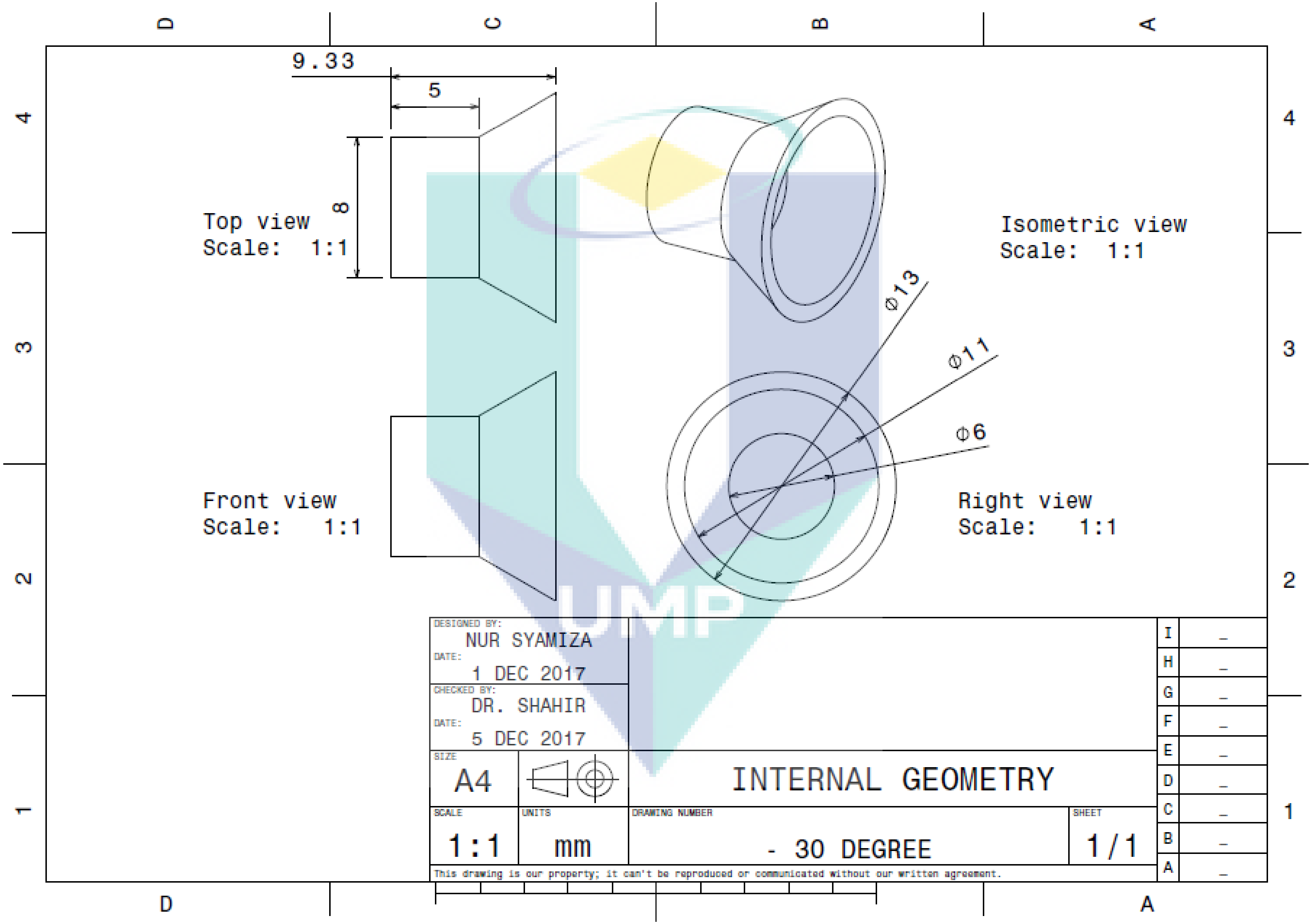
9.33
5
8
Top view
Scale: 1:1
Isometric view
Scale: 1:1
Ø13
Ø11
Ø6
Front view
Scale: 1:1
Right view
Scale: 1:1
DESIGNED BY:
NUR SYAMIZA
DATE:
1 DEC 2017
CHECKED BY:
DR. SHAHIR
DATE:
5 DEC 2017
SIZE
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INTERNAL GEOMETRY
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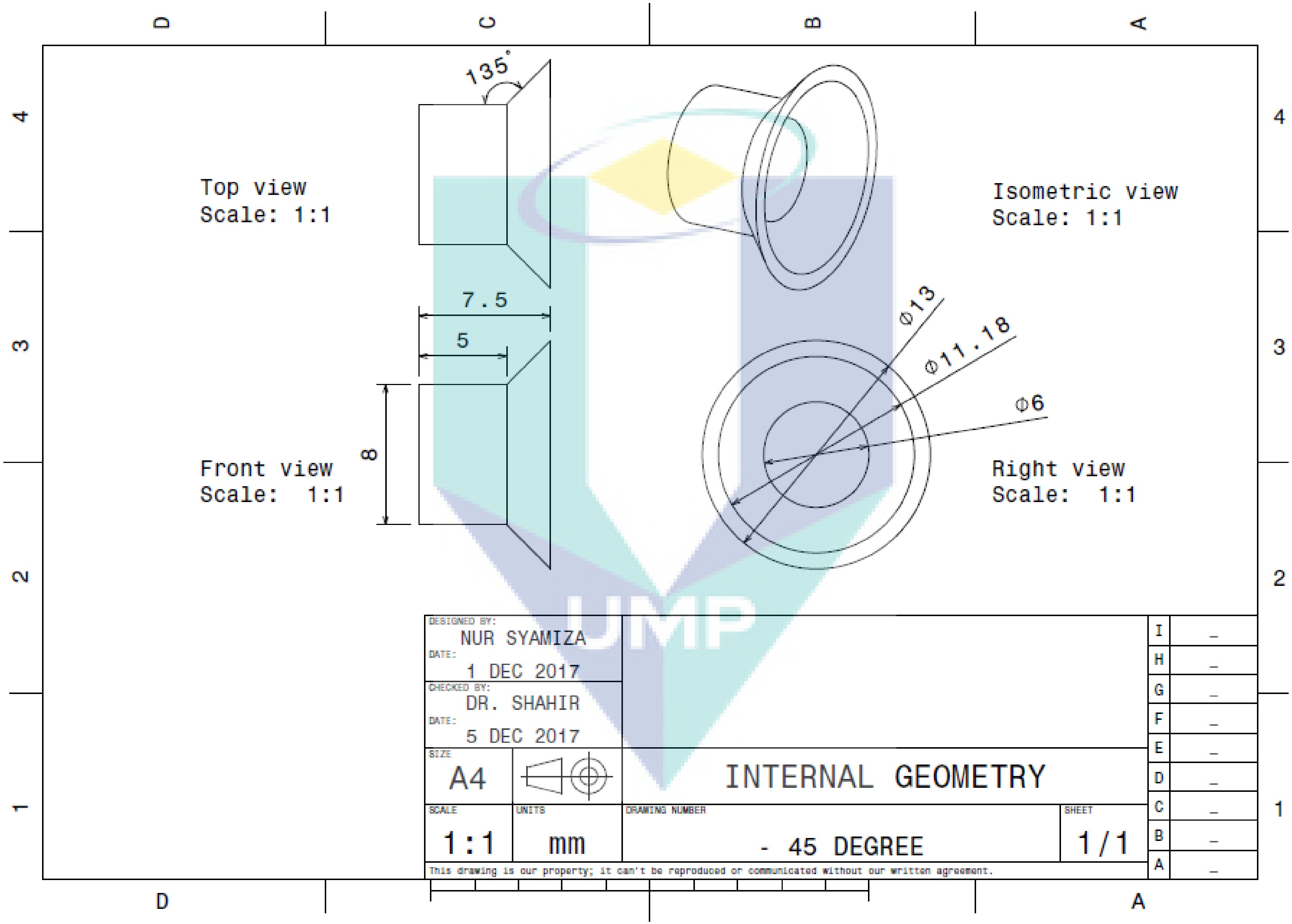

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Top view
Scale: 1:1
7.5
5
8
Front view
Scale: 1:1
Isometric view
Scale: 1:1
ϕ13
ϕ11.18
ϕ6
Right view
Scale: 1:1
DESIGNED BY:
NUR SYAMIZA
DATE:
1 DEC 2017
CHECKED BY:
DR. SHAHIR
DATE:
5 DEC 2017
SIZE
A4
INTERNAL GEOMETRY
SCALE
1:1
UNITS
mm
DRAWING NUMBER
- 45 DEGREE
SHEET
1/1
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APPENDICES B

ANSYS ANALYSIS

A) INTERNAL ANGLE 45^{O}

ANSYS

Date

2018/05/08 19:09:01

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1. File Report

Table 1. File Information for FFF

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File Time	01:16:50 AM
File Type	FLUENT
File Version	18.0.0

2. Mesh Report

Table 2. Mesh Information for FFF

Domain	Nodes	Elements
body_nozzle	1424	1185
body_wall	3096	2662
All Domains	4520	3847

3. Physics Report

Table 3. Domain Physics for FFF

Domain - body_nozzle	
Type	cell
Domain - body_wall	
Type	cell

Table 4. Boundary Physics for FFF

Domain	Boundaries	
body_nozzle	**Boundary - contact_region trg**	
	Type	INTERFACE
	Boundary - inlet	
	Type	MASS-FLOW-INLET
	Boundary - wall body_nozzle	
	Type	WALL
body_wall	**Boundary - body_wall.1**	
	Type	WALL
	Boundary - contact_region src	
	Type	INTERFACE
	Boundary - outlet	
	Type	OUTFLOW

4. User Data

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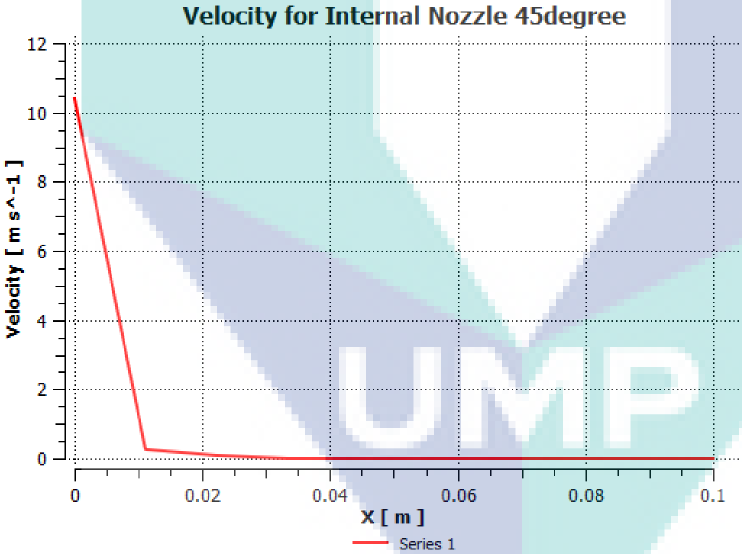

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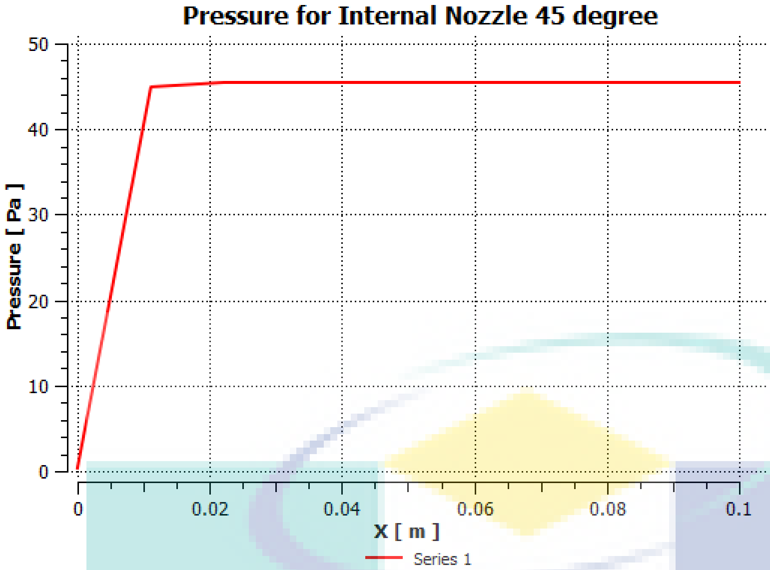
Pressure for Internal Nozzle 45 degree
Pressure [Pa]
50
40
30
20
10
0
0
0.02
0.04
0.06
0.08
0.1
X [m]
Series 1

B) INTERNAL ANGLE 30^O

Date

2018/05/08 22:29:24

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File Time	10:16:14 PM
File Type	FLUENT
File Version	18.0.0

2. Mesh Report

Table 2. Mesh Information for FFF

Domain	Nodes	Elements
body_nozzle	1710	1440
body_wall	3108	2695
All Domains	4818	4135

3. Physics Report

Table 3. Domain Physics for FFF

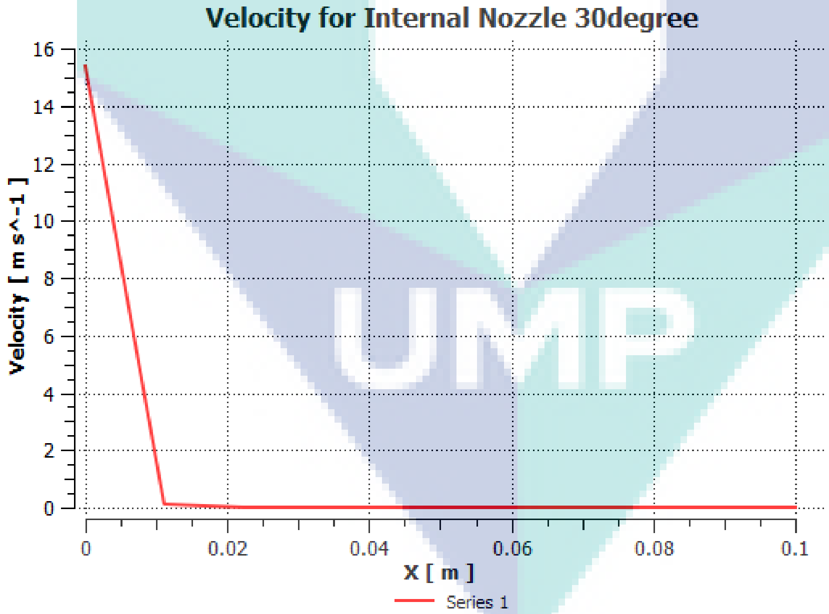
Domain - body_nozzle	
Type	cell
Domain - body_wall	
Type	cell

Table 4. Boundary Physics for FFF

Domain	Boundaries	
body_nozzle	**Boundary - contact_region trg**	
	Type	INTERFACE
	Boundary - inlet	
	Type	MASS-FLOW-INLET
	Boundary - wall body_nozzle	
	Type	WALL
body_wall	**Boundary - body_wall.1**	
	Type	WALL
	Boundary - contact_region src	
	Type	INTERFACE
	Boundary - outlet	
	Type	OUTFLOW

4. User Data

Chart 1.



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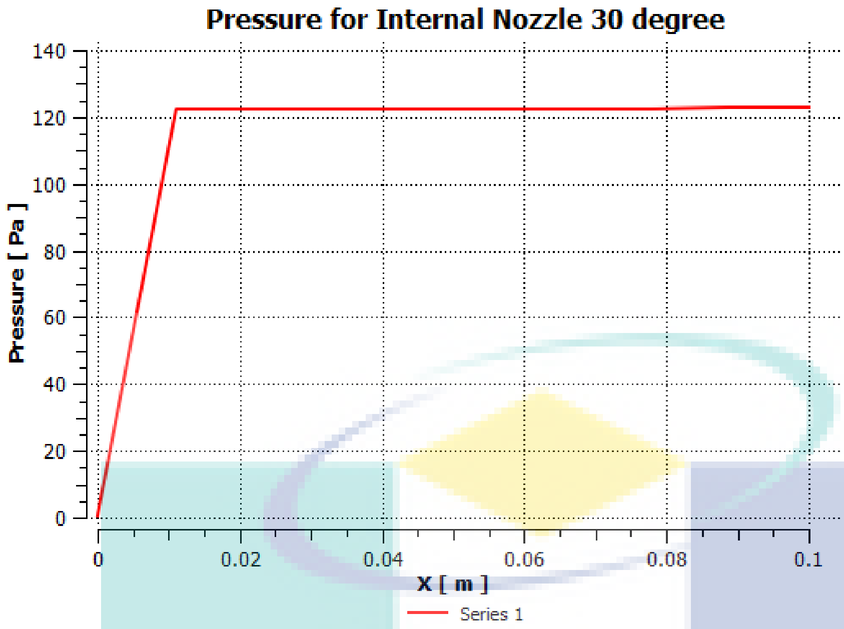
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Pressure [Pa]
140
120
100
80
60
40
20
0
0
0.02
0.04
0.06
0.08
0.1
X [m]
Series 1

C) INTERNAL ANGLE 0^O

ANSYS

Date

2018/05/08 18:11:37

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File Time	05:59:45 PM
File Type	FLUENT
File Version	18.0.0

2. Mesh Report

Table 2. Mesh Information for FFF

Domain	Nodes	Elements
body_nozzle	680	525
body_wall	3096	2662
All Domains	3776	3187

3. Physics Report

Table 3. Domain Physics for FFF

Domain - body_nozzle	
Type	cell
Domain - body_wall	
Type	cell

Table 4. Boundary Physics for FFF

Domain	Boundaries	
body_nozzle	**Boundary - contact_region trg**	
	Type	INTERFACE
	Boundary - inlet	
	Type	MASS-FLOW-INLET
	Boundary - wall body_nozzle	
	Type	WALL
body_wall	**Boundary - body_wall.1**	
	Type	WALL
	Boundary - contact_region src	
	Type	INTERFACE
	Boundary - outlet	
	Type	OUTFLOW

4. User Data

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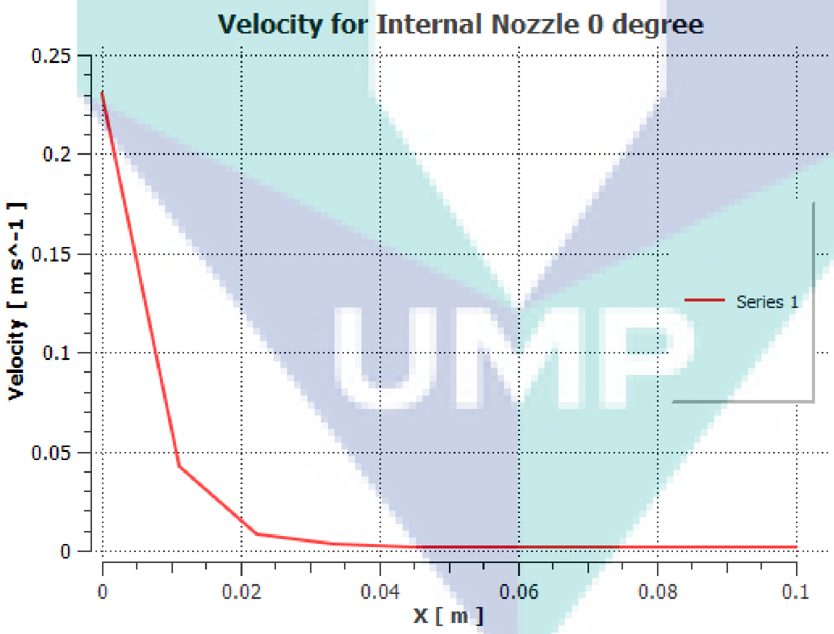

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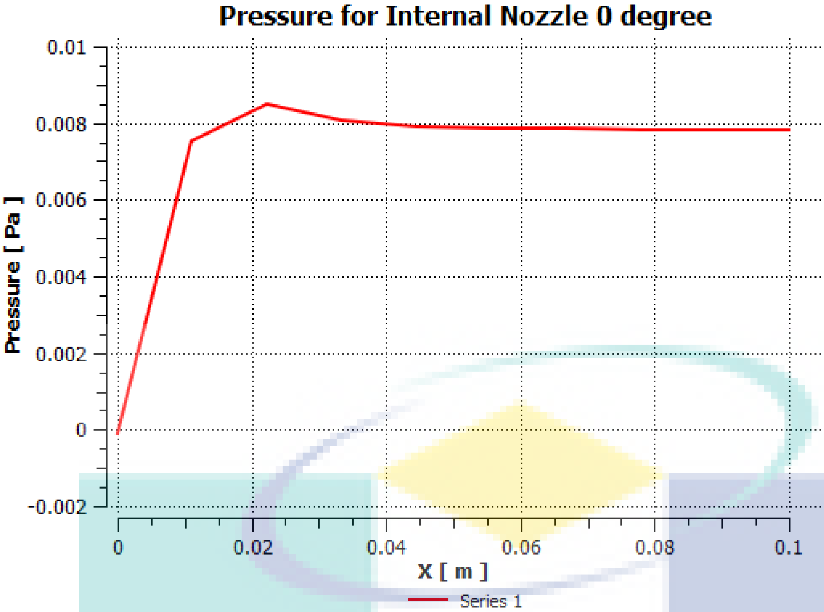
Pressure for Internal Nozzle 0 degree
Pressure [Pa]
0.01
0.008
0.006
0.004
0.002
0
-0.002
0
0.02
0.04
0.06
0.08
0.1
X [m]
Series 1

D) INTERNAL ANGLE -30^O

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2018/05/08 18:00:17

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File Version	18.0.0

2. Mesh Report

Table 2. Mesh Information for FFF

Domain	Nodes	Elements
body_nozzle	830	675
body_wall	3108	2695
All Domains	3938	3370

3. Physics Report

Table 3. Domain Physics for FFF

Domain - body_nozzle	
Type	cell
Domain - body_wall	
Type	cell

Table 4. Boundary Physics for FFF

Domain	**Boundaries**	
body_nozzle	**Boundary - contact_region trg**	
	Type	INTERFACE
	Boundary - inlet	
	Type	MASS-FLOW-INLET
	Boundary - wall body_nozzle	
	Type	WALL
body_wall	**Boundary - body_wall.1**	
	Type	WALL
	Boundary - contact_region src	
	Type	INTERFACE
	Boundary - outlet	
	Type	OUTFLOW

4. User Data

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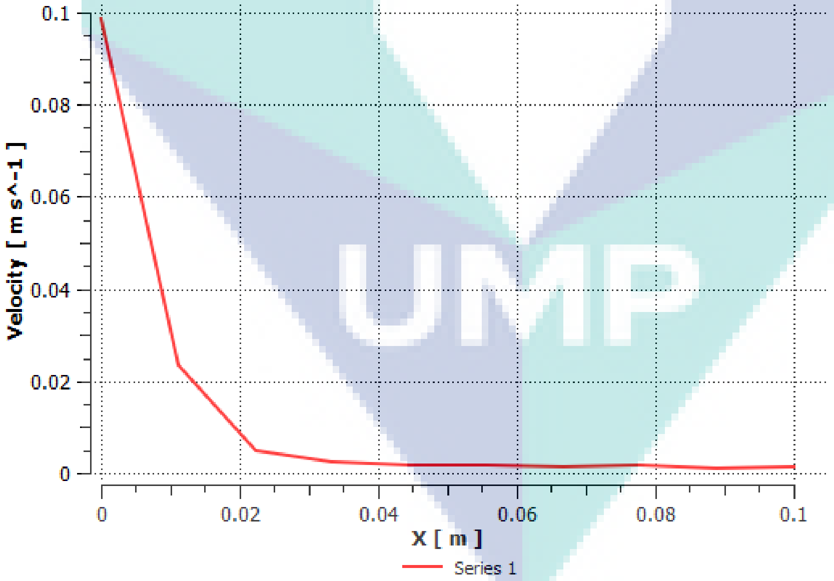
Velocity for Internal Nozzle Negative 30degree



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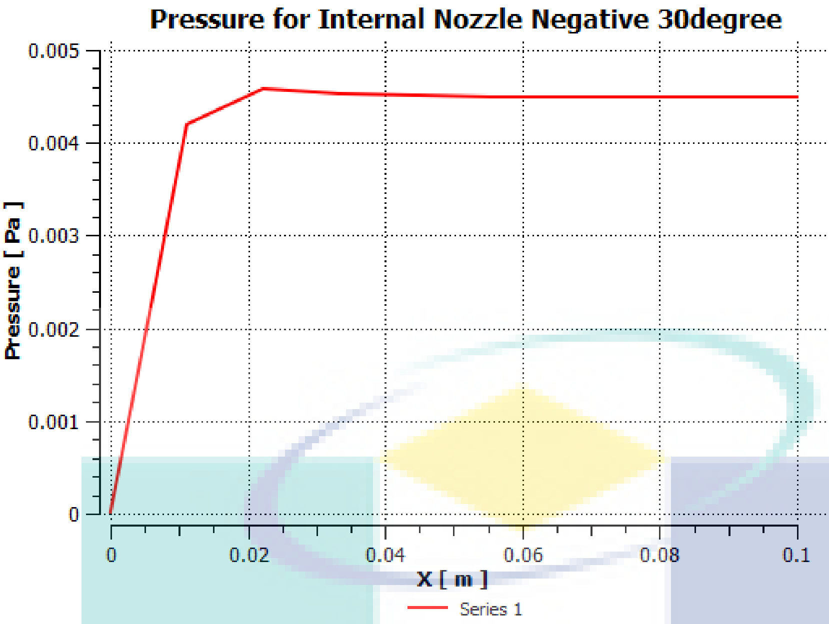
Pressure for Internal Nozzle Negative 30degree
Pressure [Pa]
0.005
0.004
0.003
0.002
0.001
0
0
0.02
0.04
0.06
0.08
0.1
X [m]
Series 1

E) INTERNAL ANGLE -45^{O}

Date

2018/05/08 15:51:18

Contents

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2. Mesh Report

Table 2. Mesh Information for FFF

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body_wall	3096	2662
All Domains	4140	3494

3. Physics Report

Table 3. Domain Physics for FFF

Domain - body_nozzle	
Type	cell
Domain - body_wall	
Type	cell

Table 4. Boundary Physics for FFF

Domain	Boundaries	
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	Type	INTERFACE
	Boundary - inlet	
	Type	MASS-FLOW-INLET
	Boundary - wall body_nozzle	
	Type	WALL
body_wall	**Boundary - body_wall.1**	
	Type	WALL
	Boundary - contact_region src	
	Type	INTERFACE
	Boundary - outlet	
	Type	OUTFLOW

4. User Data

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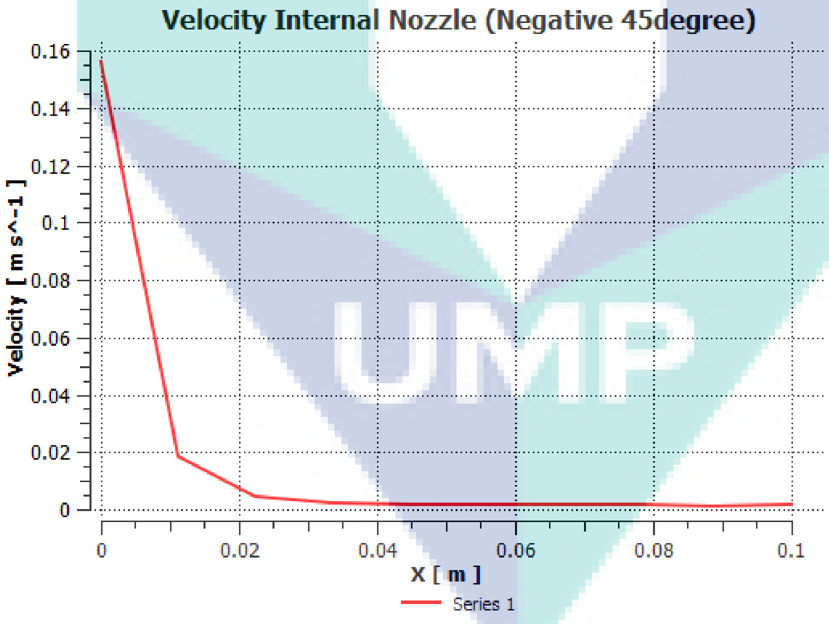
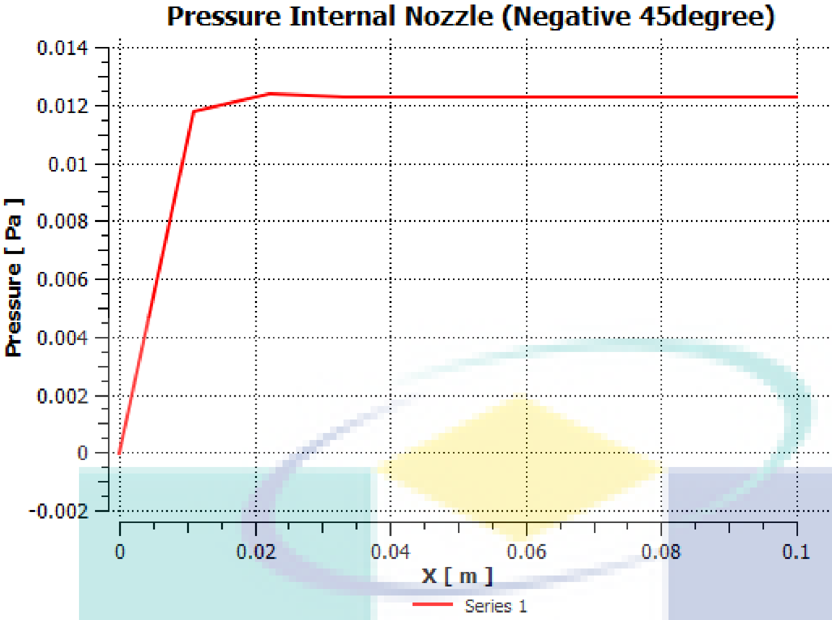


Chart 2.


Pressure Internal Nozzle (Negative 45degree)
Pressure [Pa]
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0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
0
0.02
0.04
0.06
0.08
0.1
X [m]
Series 1

Study on the effectiveness of Extreme Cold Mist MQL system on turning process of stainless steel AISI 316

A S Jamaludin[1],*, A Hosokawa[2], T Furumoto[2], T Koyano[2], Y Hashimoto[2]

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[2] Institute of Science and Technology, Kanazawa University, Kakuma-machi, Kanazawa, 920-1192, Ishikawa, Japan

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Abstract. Cutting process of difficult-to-cut material such as stainless steel, generates immensely excessive heat, which is one of the major causes related to shortening tool life and lower quality of surface finish. It is proven that application of cutting fluid during the cutting process of difficult-to-cut material is able to improve the cutting performance, but excessive application of cutting fluid leads to another problem such as increasing processing cost and environmental hazardous pollution of workplace. In the study, Extreme Cold Mist system is designed and tested along with various Minimum Quantity Lubrication (MQL) systems on turning process of stainless steel AISI 316. In the study, it is obtained that, Extreme Cold Mist system is able to reduce cutting force up to 60N and improve the surface roughness of the machined surface significantly.

1. Introduction

Several approaches are proposed to improve the cutting process difficult-to-cut materials, especially in improving the tool life and higher surface finish. It is necessary to understand about the mechanic of heat generation and temperature increment during the machining process. Basically, lubricating process can be considered as successful when the cutting fluid penetrated the sticking-sliding zone of tool-chip contact. It is proven that, cutting process assisted by cutting fluid is able to improve the tribological properties at the interfaces through alteration of normal, shear stresses, and their distribution, and/or by removing the excessive heat, thus improving the machined surface roughness and tool wear etc. [1-8].

Previous studies had shown that dry machining is the optimum solution in most of material removal processes for soft material, but less effective in machining difficult-to-cut material. Thus, a near-dry cutting system is proposed by implementing the Minimum Quantity Lubrication (MQL) method. This MQL system utilizes only a tiny amount of cutting fluid, with flowrate unit of ml/h compared to conventional cutting fluid supplying method. The cutting fluid is turn into microscale droplet and supplied to the cutting [4, 7].

There are various types of cutting fluids available nowadays that can be utilized for MQL system, which are lubrication purpose oil-based cutting fluid, cooling purpose of emulsion-based cutting fluid (made of soluble oil in water and hopefully to be able to reduce oxidation on the surface of material), water or cold air that are mostly for cooling application [4,7]. Various studies had shown

High Precision Estimation on Physical Behavior for Cutting with Various Tool Rake Angle by Finite Element Method

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Abstract. In metal cutting process, cutting force holds significant information of the cutting tool performance and material machinability. However, it still remains unclear regarding to the relationship between cutting forces and other cutting parameters, such as cutting speed and contact friction coefficient. The main objective of this paper is to design a feasible Finite Element model to estimate cutting behavior with high accuracy. Several FEM models are designed reflecting the process of orthogonal cutting. In the meantime, actual orthogonal cutting tests of mild steel AISI1045 with TiCN-coated cermet tool are executed in order to observe the real life behavior. There are two significant phenomena can be observed from the simulation: chip thickness and contact length. It is proven that, combination of chip thickness and contact length plays major role in estimating cutting behavior with high accuracy.

Keywords: Orthogonal Cutting, Finite Element Method, Chip Thickness, Contact Length

1 Introduction

Conventional wet cutting method has tended to shift to dry or semi-dry cutting as large amount of cutting fluid not only leads to the increment of power consumption and processing cost, but also environmental pollution[1]. Recently, the development of higher efficiency Minimum Quantity Lubrication (MQL) system for machining has been emphasized to solve or control these matters [1-3].

In MQL system, a very small amount of cutting fluid is turned into fine oil mist and supplied onto tool-chip contact zone and tool-machined workpiece surface contact zone. The system leads to cleaner working environment and reduction of waste liquid, which leads to lesser processing cost. It is believed that, MQL is capable to decrease the frictional contact between cutting chip and tool surface and lowering the cutting tool temperature [1-3]. However, due to the complex tribological behavior, the mechanism of MQL application is difficult to be explained. In addition, friction can

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Bold Approach in Finite Element Simulation on Minimum Quantity Lubrication Effect during Machining

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ABSTRACT

Application of Minimum Quantity Lubrication (MQL) in cutting process is becoming widespread, whereas manufacturers had gradually turns to the utilization of dry and semi dry cutting during the machining process. Compared to the conventional wet cutting method, utilization of MQL can be considered as parameter sensitive, whereas only a very small amount of cutting fluid is utilized during the process to cater similar or better performance as conventional wet cutting. Thus, it is necessary to understand precisely the characteristic of MQL applied cutting process, where behavior of tool-work/chip interface need to be observed sufficiently, due to its relationship with the cutting performance such as cutting force, cutting temperature, chip morphology, and surface finish. In this paper, bold approach of Finite Element Method (FEM) modelling is proposed in simulating the characteristic of the MQL in machining process. Two interrelated FEM analytical models are designed and executed using the application package software DEFORM™-3D. As a validation, orthogonal cutting tests of medium steel JIS S45C is executed with the TiCN-coated cermet tool in order to evaluate the involved parameter during the application of Minimum Quantity Lubrication in parallel. During the application of MQL in the orthogonal cutting process, three significant variables are observable, which are cutting force, chip thickness and contact length. In this paper, comparison of appearance friction and FEM input friction is done, where it is found that both parameter is related but not similar. Additionally, it is proven that FEM is capable in assessing MQL characteristic with a good degree of accuracy through FEM input friction and chip morphology modelling, thus it is easier to distinguish between contact condition and environmental condition through the proposed FEM validation process.

INTRODUCTION

In recent manufacturing trend, conventional wet cutting method has tended to shift to dry or semi-dry cutting processes in optimizing the power consumption and processing cost. In addition, the chemical by-product from conventional wet cutting process increases the pollution rate of working environment, possibility to affect the health quality of the machine operators. Therefore, application of Minimum Quantity Lubrication (MQL) is proposed during machining process to solve and contain the conventional wet cutting problem [1-3]. In MQL assisted cutting, a very small amount of cutting fluid is turned into fine oil mist and supplied onto cutting point, expecting to increase the cutting performance of tools, product quality finish and machining power consumption. Approximately only 1/10000 fluid volume of that in the