DEVELOPMENT OF A NEW TYPE OF SPRAYER HEAD OF A WATER MIST SYSTEM

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DEVELOPMENT OF A NEW TYPE OF SPRAYER HEAD OF A WATER MIST SYSTEM

MOHD SYAZWAN BIN ZULKIPLI

A report submitted in partial fulfillment of the requirements for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering

Faculty of Mechanical Engineering
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UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Development of a new type of sprayer head of a water mist system*" is written *by Mohd Syazwan bin Zulkipli*. I have examined the final copy of this project and in my opinion, it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

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Signature : ……………………………………………

Name of Supervisor : EN. ZAIDI BIN SIDEK

Date : 22 JUNE 2012

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I declare that this thesis entitled "Development of a new type of sprayer head of a water mist system” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : …………………………………………….
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Dedicated to my father, Mr. Zulkipli Bin Sulaiman, my beloved mother, Mrs. Norbani Binti Ya, my brothersMuhammad Faisal Bin Zulkipli and Muhammad Nizamuddin Bin Zulkipli, my sisters Nur Syazwani Binti Zulkipli and Nur Farisah Binti Zulkipli, and last but not least to all my fellow friends.

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ABSTRACT

Water mist heads are used in close areas to provide direct and constant mists of water for rapid cooling, watering plant, and fire extinguisher. Majority of the water mist's types in the market has certain problem such as need high pressure and high water volume. Thus, the main aim of this study is to determine the best design of the water mist head. From literature review, the author identifies two parameters as a major concerned, i.e. pressure and flow rate. Three water mist's head prototypes have been produced using RP machine. Then, the experimental works have been conducted with six test configurations, combination of three pressures and three diameters, to determine the mist patterns. For water pressure, the analysis is on 1.4, 1.8 and 2.2 kgforce and for diameter used in range 0.5, 1.0 and 1.5mm. The measured variables are the length of mist spread out from the nozzle. The result show that the optimum design is for the case 7.5mm at pressure 1.8bar and diameter 1.5mm for nozzle with designed internal flow and 20mm at pressure 2.2bar and diameter 1.0mm for nozzle with normal internal flow.

ABSTRAK

Kepala kabus air digunakan di kawasan kecil untuk menyediakan secara langsung dan terus menerus semburan air untuk penyejukan pantas, loji menyiram, dan alat pemadam api. Majoriti jenis kabus air di pasaran mempunyai masalah tertentu seperti perlu tekanan tinggi dan isipadu air yang tinggi. Oleh itu, matlamat utama kajian ini adalah untuk menentukan reka bentuk yang terbaik kepala kabut air. Daripada kajian yang telah dibuat, penulis mengenal pasti dua parameter seperti memerlukan tekanan aliran air yang tinggi dan kadar aliran air. Tiga prototaip kepala kabus air telah dihasilkan menggunakan mesin RP. Kemudian, kerja-kerja eksperimen telah dijalankan dengan enam konfigurasi ujian, gabungan tiga tekanan dan tiga diameter, untuk menentukan corak kabus. Untuk tekanan air, analisis pada 1.4, 1.8 dan 2.2bar dan bagi diameter digunakan dalam julat 0.5, 1.0 dan 1.5mm. Pembolehubah yang diukur adalah kelebaran kabus tersebar keluar dari muncung. Hasilnya menunjukkan bahawa reka bentuk optimum adalah untuk 7.5mm kes di 1.8bar tekanan dan diameter 1.5mm untuk muncung dengan aliran dalaman yang direka dan 20mm pada 2.2bar tekanan dan 1.0mm diameter muncung dengan aliran dalaman yang normal.

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LIST OF SYMBOLS

Re	Reynolds Number
Pr	Nusselt Number
L	Length
f	Friction Factor
ρ	Density
P	Pressure
R	Gas Constant
T	Temperature
K	Coefficient of Compressibility
E	Energy
KE	Kenetic Energy
β	Volume Expension Coefficient
τ	Temperature
σ_s	Shear Stress
U	Internal energy
μ	Coefficient of Viscosity
$\dot{q}_s$	Heat Flux
h	Capillary Effect
Pa	Aero power
H	Heat Transfer Coefficient
M_w	Momentum of Spray
X_{fall}	Maximum Falling Distance

LIST OF ABBREVIATIONS

FEM	Finite Element Method
FEA	Finite Element Analysis
RP	Rapid Prototyping
μm	Micro millimeter
K	Kelvin
m^2	millimeter square
mm	millimeter
kW	kilowatt
Pa	Pascal

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

Advancement of engineering field urged researchers to do more research on some product such as water mist's sprayer head following major trend in modern science and technology which is miniaturization industries. This research is about reverse engineering project is intended to reproduce better type of internal water flow configuration for water mist's sprayer head component. At the end of research, it will come out the data of the results and a finish product.

Water is the most natural of substances, has taken on a new form as a highly efficient ultrafine spray called Water Mist. Water Mist has the unique in ability to deliver water as a fine atomized mist. This mist is quickly converted to steam that smothers the fire and prevents further oxygen from reaching it. At the same time, the evaporation creates a significant cooling effect of combustion gases and blocks the transfer of radiant heat. In this way, Water Mist combines the fire suppression properties of both conventional water-based deluge or sprinkler systems and gaseous fire suppression systems. As a result of extensive research and development, Water Mist has been demonstrated to be a suitable Halon gas 1301 replacement for many commercial and industrial applications. Beside that sprinkler system has been widely used so far in pharmaceutical, chemical, food, and cosmetic industries.

There are several things that can affect water convert to mists. Pressure is one variable that affect in production of fine mist. However, it is not available for large scale production and the spray drying apparatus is cumbersome. To get high speed of water flow in the tube, we need to increase the pressure. If get the high pressure, it easy to convert water to mist. The sizes of mists and dried particles usually become large when high pressure nozzles are used.

The nozzles are not suitable for spraying a suspension because of abrasion. The finest mists will produce.

Second variable is size of hole in the nozzle. From this part we need to decrease the volume of water. So we need to decrease the hole size. Although there are some kinds of nozzles blowing off fine droplets of 10-50 µm in diameter for laboratory scale, there are few of those for industrial scale. The droplet size prepared by an ordinary industrial nozzle is usually ca. 10^2-10^3 µm in diameter. It is much too large, compared to that described above.

On the other hand, the spray dryer particles produced on a laboratory scale are amorphous, while those in the industrial scale are sometimes crystalline. The difference in the crystallinity is due to the difference in the initial droplet size and subsequent drying rate. Development of a nozzle for blowing off fine droplets in the industrial scale has been expected until now. We are now proposing a new type of a spraying nozzle which enables to eject large quantities of liquid but to obtain homogeneous fine mist with a low ratio of air/liquid and without formation of sludge on the nozzle surface. We also propose a new type of a spray-drier which could supply fine plastic by equipping the new nozzle developed in the present study.

1.2 PROBLEM STATEMENT

Currently, majority of the users using the water mist's system that currently sold in the market. Water mist's system that currently sold in the market has certain problem such as need high pressure and high water volume. Thus, we need to reproduce a better type of internal water flow configuration for water mist's sprayer head component. We need to reproduce less pressure and less water volume used. This reduces losses in profits and following the principles of ergonomics. Conventionally, the industrial will produce more type of water mist's sprayer head component. For example, flat spray, hollow cone, solid cone and air atomizing. These types of nozzle just have different shapes. This type also have different in pressure, but still using a high pressure. Further research has to be done in this field to minimize the variable are used to convert water to mist.

1.3 SIGNIFICANCE OF STUDY

After achieving the objectives, the manufacturing industry will have an alternative method in saving the cost of production and increasing the rate of production. By determining the variables of fluids coefficient, the industrial could use the method to control the pressure and volume in water mist's system. Industrial also can reproduce better water mist's system. In currently water mist's sprayer head, they used high pressure of water. It is to get high speed of water through the sprayer head. With high pressure, it gets high velocity than easy to convert water to mist. Secondly, they used high volume of water. It is because they using big hole size of the sprayer head. Thus, a further study is needed in order to accomplish the vision and within given the limitation. Some of the research question that has been proposed through this paper is method to determine the effect of pressure and hole size in water mist's system.

1.4 RESEARCH OBJECTIVE

The main aim of this project is to determine the best water sprayer head design to produce high volume eater mist at optimum setting. To achieve these objectives, several important research activities have been planned as listed below;

i. To design and produce a sprayer nozzle for water mist system.
ii. To produce test rig for sprayer nozzle test.
iii. To run experiment on the sprayer nozzles at the selected test condition.
iv. To establish relation between different process configuration on mist development.

1.5 RESEARCH SCOPES

For the main purpose of this research, the following scopes are developed:

i. To reproduce a better type of sprayer head of a water mist system using with low volume and pressure.
ii. To know what is reverse engineering, finite element analysis and rapid prototyping.
iii. To know the simulation of finite element analysis of the current design and develop the new internal.
iv. Identify all the known factor has important effect on mist development.
v. All of the initial literature reviews and simulation output will be summarized in report.

CHAPTER 2

LITERATURE REVIEWS

2.1 INTRODUCTION

A converging focused literature review within a related field or interest of research is one of the most essential activities in the procedure of completing a research. In order to produce a productive literature review, it is recommended to include the historical perspective, selected heat transfer mechanism with understanding classification of fluid flow which the research paper concerns more on internal forced convection for inserted tape in a tube with turbulent flow. Also, review on previous studies related within the scope as additional guidance for the research paper also its application from engineering perspective. Besides that, discussion of some information on the technology and equipment that used for this study case such as CAD software, FEM software and Turning and Drilling machine are included. By considering the related engineering parameters used in through this research paper, relationships between the parameter are also discussed. Not only elaborate on the parameters, it covers the relationship on the parameters before meets the conclusion for this chapter. Hence, this chapter acts as a platform of reviews to support and define each action performed during the experiment being held.

2.2 CLASSIFICATION OF FLUID FLOW

Fluid flow can be very smooth, calm, and regular, but generally the flow of a fluid is not so disciplined, it becomes a vagabond and starts flowing in random patterns.

While studying the motion of a rigid body we do not have to bother about the relative motion of the particles of the rigid body as they are very firmly fixed to each other and move as a whole. But for the study of the motion of fluids, things are not so simple because the fluid particles are attached with each other with very weak forces. There are various relative motions and a lot of possibilities for relative motion between the fluid particles. Since convection heat transfer have closed bond with fluid mechanics, the science that deals with the behaviour of fluids at rest or in motion, there is a wide variety of fluid problems encountered in our daily practice. As a convenient way, they are classified to certain basis of common characteristics to make it easy to be study.

Some smooth layers of fluid and orderly flows are known as laminar while others flow which is highly disordered flows occurs at high velocities is called turbulent. A flow that contains overlapping laminar and turbulent flows is known as transitional. The required power for pumping the flow does influence by the flow regime. The characteristics that are concern most in this research is internal forced flow with turbulence characteristics.

2.2.1 Laminar Flow

When highly viscous fluids such as oils flow in small diameter tubes or narrow passages, laminar flow is encountered. Although, laminar region is not the case in practice since most pipe flows encountered in practice are turbulent. Under most practical conditions, the flow in a tube is laminar for Re < 2300 where Reynolds number could relate between the average velocity of the flow and the flow¡¦s properties. Deeper discussion regarding Reynolds number could be found in section 2.8.2 from the same chapter.

(Edwards et al., 1997) determined the average Nusselt number in thermal entrance region for a circular tube of length, L subjected to constant surface temperature is stated as follows;

$$Nu = 3.66 + \frac{0.065\left(\frac{D}{L}\right)RePr}{1+0.04\left[\left(\frac{D}{L}\right)RePr\right]^{\frac{2}{3}}} \quad (2.1)$$

The relation assumes that the flow is hydro dynamically developed when the fluid enters the heating section, but it can also be used approximately for flow developing hydro dynamically.

2.2.2 Turbulent Flow

As the flow speed of the otherwise calm layers increases, these smoothly moving layers start moving randomly, and with further increase in flow velocity, the flow of fluid particles becomes completely random and no such laminar layers exist anymore. Shear stresses in the Turbulent Flow are more than those in Laminar Flow. A dimensionless parameter, Reynolds Number, is defined as the ratio of inertial and viscous force to characterize these two types of flow patterns. With increase in flow velocity the initial forces increase so the Reynolds Number.

Since the analysis of turbulent flow conditions is a good deal more involved, greater emphasis is placed on determining empirical correlations. For fully developed turbulent flow in smooth tubes, Dittus-Boelter equation (Dittus and Boelter, 1930) shown in below;

$$Nu = 0.023Re^{0.8}Pr^{n} = \left\{\begin{matrix} Re>10000, n=0.4 heating \\ 0.7\leq Pr\leq 160, n=0.3 cooling \end{matrix}\right\} \quad (2.1)$$

Another equation that improved from Dittus-Boelter equation is Gnielinski equation (Gnielinski, 1976) as follows;

$$Nu = \frac{\left(\frac{f}{2}\right)(Re-1000)Pr}{1+12.7\left(\frac{f}{2}\right)^{0.5}\left(Pr^{\frac{2}{3}}-1\right)} \quad (2.3)$$

Where the friction factor, f can be determine using Fanning friction factor.

$$f = (1.58 ln\ Re - 3.82)^{-2} \quad (2.4)$$

2.3 FLUID PROPERTIES

The mass dependent properties of a system are called *extensive properties* and the others, *intensive properties. Density* is mass per unit's volume, and *specific volume* is volume per unit mass (Cengel Y.A., 2006). The specific gravity is define as the ratio of the density of a substance to the density of water at 4°C,

$$SG = \frac{\rho}{\rho_{H_2O}} \quad (2.5)$$

The ideal gas equation of state is expressed as,

$$P = \rho RT \quad (2.6)$$

Where P is the absolute pressure, T is the thermodynamic temperature, ρ is the density, and R is the gas constant.

At a given temperature, the pressure at which a pure substance changes phase is called the saturation pressure. For phase change processes between the liquid and vapor phases of a pure substance, the saturation pressure is commonly called the vapor pressure, P_v. Vapor bubbles that form in the low pressure regions in a liquid, cavitation collapse as they are swept away from the low pressure regions, generating highly destructive, extremely high pressure waves.

Energy can exist in numerous forms, and their sum constitutes the total energy E of a system. The sum of all microscopic forms of energy is called the internal energy U of a system. The energy that a system possesses as a result of its motion to some reference frame called kinetic energy expressed per unit mass as$KE = V^2/2$, and the energy that a system possesses as a result of its elevation in a gravitational field is called potential energy expressed per unit mass as$PE = gz$.

The compressibility effects in a fluid are represented by the coefficient of compressibility, K defines as:

$$K = -v\left(\frac{\partial P}{\partial v}\right)_T = \rho\left(\frac{\partial P}{\partial \rho}\right)_T \cong -\frac{\Delta P}{\Delta v/v} \quad (2.7)$$

The property that represents the variation of the density of a fluid with temperature at constant is the volume expansion coefficient β, defined as:

$$\beta = \frac{1}{v}\left(\frac{\partial v}{\partial T}\right)_P = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_P \cong -\frac{\Delta\rho/\rho}{\Delta T} \quad (2.8)$$

The viscosity of a fluid is a measure of its resistance to deformation. The tangential force per unit area is called shear stress and is expressed for simple shear flow between plates as:

$$\tau = \mu\frac{du}{dy} \quad (2.9)$$

Where μ is the coefficient of viscosity or the dynamic viscosity of the fluid, u is the velocity component in the flow direction, and y is the direction normal to the flow direction. The fluids that obey this linear relationship are called Newtonian fluids. The ratio of dynamic viscosity to density is called the kinematic viscosity v (Cengel Y.A., 2006).

The pulling effect on the liquid molecules at an interface cause by the attractive force of molecules per unit length is called surface tensionσ_s. The excess pressure ΔP inside a spherical droplet or bubble is given by:

$$\Delta P_{droplet} = P_i - P_o = \frac{2\sigma_S}{R} \quad (2.10)$$

And

$$\Delta P_{bubble} = P_i - P_o = \frac{4\sigma_S}{R} \quad (2.11)$$

Where P_i and P_o are the pressure inside and outside the droplet or bubble. The rise or fall of a liquid in small diameter tube inserted into the liquid due to surface tension is called the capillary effect. The capillary rise or drop is given by:

$$h = \frac{2\sigma_S}{\rho g R} \cos \emptyset \quad (2.12)$$

Where $\emptyset$ is the contact angle. The capillary rise is inversely proportional to the radius of the tube and is negligible for tubes whose diameter is larger than about 1cm.

Density and viscosity are two of the most fundamental properties of fluids.

2.4 PRESSURE

Pressure is defined as a normal force exerted by a fluid per unit area. We speak of pressure only when we deal with a gas or a liquid. The counterpart of pressure in solids is normal stress. Since pressure is defined as force per unit area, it has the unit of newtons per square meter (N/m^2) which is called a Pascal(Pa) (Cengel Y.A., 2006). That is:

$$1Pa = 1\,N/m^2 \quad (2.13)$$

The pressure unit Pascal is too small for pressure encountered in practice. Therefore, its multiples kilopascal ($1kPa = 10^3 Pa$) and megapascal ($1MPa = 10^6 Pa$) are commonly used. Three other pressure units commonly used in practice:

$$1bar = 10^5 Pa = 0.1MPa = 100kPa$$

$$1atm = 101325Pa = 101.325kPa = 1.01325bars$$

$$1\, kgf/cm^2 = 9.807\, N/cm^2 = 9.807 \times 10^4\, N/m^2 = 9.807 \times 10^4 Pa$$

$$= 0.9807bar$$

$$= 0.9679atm$$

The actual pressure at a given position is called the absolute pressure, and it is measured relative to absolute vacuum. Most pressure measuring devices, however, are calibrated to read zero in the atmosphere and so they indicate the difference between the absolute pressure and the local atmospheric pressure. This difference is called gage pressure. Pressures below atmospheric pressure are called vacuum pressures and are measured by vacuum gages that indicate the difference between atmospheric pressure and the absolute pressure (Cengel Y.A., 2006). Absolute, gage, and vacuum pressures are still positive quantities and are related to each other by:

$$P_{gage} = P_{abs} - P_{atm} \quad (2.14)$$

$$P_{vac} = P_{atm} - P_{abs} \quad (2.15)$$

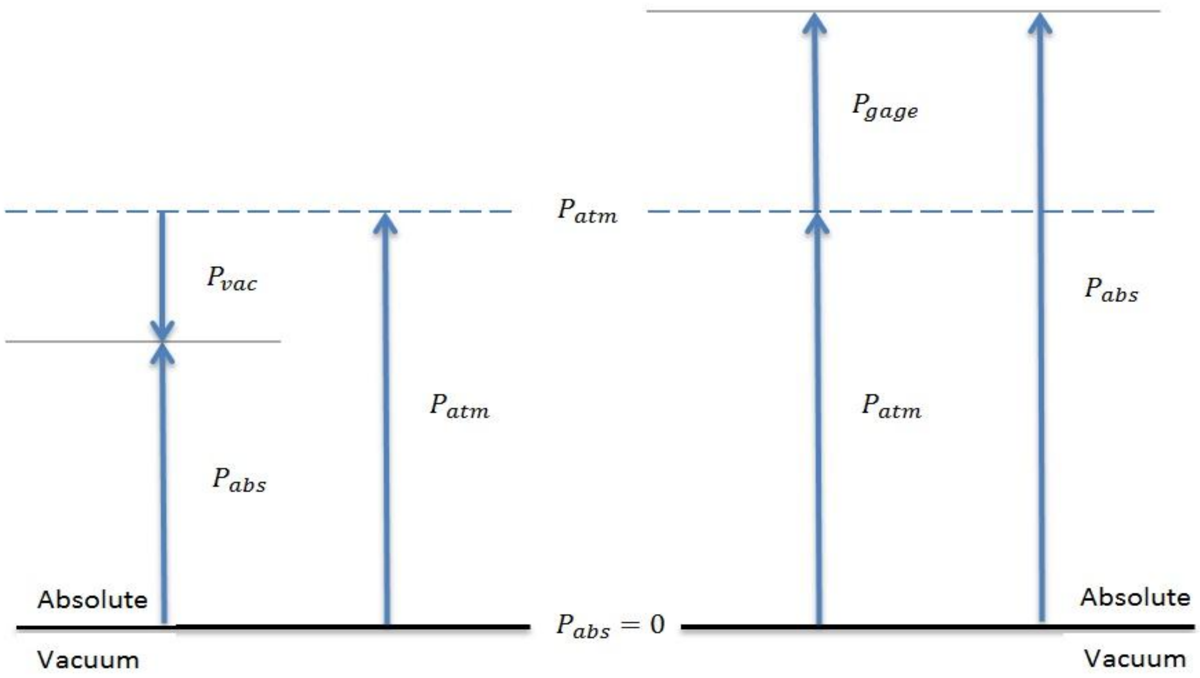


Figure 2.1: Absolute, gage, and vacuum pressures.

Source: (Cengel, 2006)

2.5 EXTINGUISHING MECHANISMS

Water has favorable physical properties for fire suppression. Its high heat capacity (4.2 J/g•K) and high latent heat of vaporization (2442 J/g) can absorb a significant quantity of heat from flames and fuels. Water also expands 1700 times when it evaporates to steam, which results in the dilution of the surrounding oxygen and fuel vapors. With the formation of fine droplets, the effectiveness of water in fire suppression is further increased due to the significant increase in the surface area of water that is available for heat absorption and evaporation (CHEMETRON, 2000). Such an increase in the surface area of water is shown in Table 1 for a given volume of water (0.001 m3).

Table 2.1: The variation of surface area of water with droplet size (volume of water $0.001m^3$)

Droplet Size (mm)	6	1	0.1
Total Number of Droplets	8.8×10^3	1.9×10^6	1.9×10^9
Total Surface Area (m^2)	1	6	60

Source: (Husted B.P, 2009)

Water mist in fire suppression, however, does not behave like a “true” gaseous agent. When water is injected into a compartment, not all the sprays that are formed are directly involved in fire suppression (CHEMETRON, 2000). They are partitioned into a number of fractions as follows:

1) Droplets that are blown away before reaching the fire.
2) Droplets that penetrate the fire plume, or otherwise reach the burning surfaces under the fire plume, to inhibit pyrolysis by cooling, and the resultant steam that dilutes the available oxygen.
3) Droplets that impact on the walls, floor and ceiling of the compartment and cool them, if they are hot, or otherwise run-off to waste.
4) Droplets that vaporize to steam while traversing the compartment and contribute to the cooling of the fire plume, hot gases, compartment and other surfaces.
5) Droplets that pre-wet adjacent combustibles to prevent fire spread.

In their early studies I have identified two mechanisms by which water mist extinguishes fires. That is displacement of oxygen and heat extraction, resulting from the evaporation of water mist in the area surrounding the fire. Research conducted to date has not altered the accuracy of such extinguishing mechanisms. Recent studies, however, suggest that there are additional mechanisms in fire suppression using water mist. For example, that a reduction of fuel evaporation is another extinguishing mechanism, together with cooling and diluting of the fire. Then, that radiant heat attenuation, the kinetic effect of water mist on the flame, and fuel vapor or air dilution by entrained air are additional extinguishing mechanisms. Both of its can be classified the extinguishing mechanisms of water mist in fire suppression as primary and secondary mechanisms, which can be summarized as follows (CHEMETRON, 2000):

Primary mechanisms:

(1) Heat extraction.

- cooling of fire plume
- wetting/cooling of the fuel surface

(2) Displacement.

- displacement of oxygen
- dilution of fuel vapor

Secondary mechanisms:

(1) Radiation attenuation.

(2) Kinetic effects.

2.5.1 Heat Extraction (Cooling)

The cooling mechanisms of water mist for fire suppression can be divided broadly into cooling of the fire plume and wetting or cooling of the fuel surface. Flame cooling by water mist is attributed primarily to the conversion of water to steam that occurs when a high percentage of small water droplets enter a fire plume and rapidly evaporate. A fire will be extinguished when the adiabatic flame temperature is reduced to the lower temperature limit, resulting in the termination of the combustion reaction of the fuel-air mixture (Husted B.P., 2009). For most hydrocarbons and organic vapors, this lower temperature limit is approximately 1600 K (1327°C).

The efficiency of water for flame cooling has been calculated. It was found that when all the water is vaporized to steam, the heat absorption required for fire extinction can be halved, in comparison to condensed steam or partly vaporized water. With the formation of fine droplets, the surface area of the water mass and the speed at which the spray extracts heat from the hot gas and flame are significantly increased. The rate of vaporization of a droplet indicated depends on surrounding temperatures, the surface area of the droplet the heat transfer coefficient and the relative velocity of the droplet in relation to the surrounding gas. For droplets of 100 μm < d < 1000 μm, the heat transfer coefficient, H, is directly related to the size of the droplet and can be expressed as:

$$H = \frac{0.6}{d} K Pr^{1.5} Re^{0.5} \qquad (2.16)$$

Where d is the diameter of the droplet, K is the thermal conductivity of air, Pr is the Prandtl number and Re is the Reynolds number.

Various attempts have been made to establish a design relationship between the fire size and the amount of water needed to cool the fire enough for extinguishment. Wighus [33] introduced the concept of the Spray Heat Absorption Ratio (SHAR) in a study of the extinguishment of propane fires by water mist. SHAR was defined as the ratio of the heat absorbed by the spray (Q_{water}) to the heat released by the fire (Q_{fire}):

$$SHAR = \frac{Q_{water}}{Q_{fire}} \qquad (2.17)$$

It was found that the value of SHAR or the heat absorption rate of water needed for fire extinguishment varied substantially with the fire scenarios encountered, because the efficiency of delivery of water mist into flame was almost unpredictable. For an unconfined propane flame, the value of SHAR was as low as 0.3 under optimum conditions while the value was in the range of 0.6 for more ‘realistic’ machinery space conditions due to small fires in shielded areas.

A fire will also be extinguished when the fuel is cooled below its fire point by removing heat from the fuel surface, or when the concentration of the vapour or air mixture above the surface of the fuel falls below the lean flammability limit due to the cooling (Husted B.P., 2009). In order to cool the fuel surface, a spray must penetrate the flame zone to reach the fuel surface and then remove a certain amount of heat from the fuel surface at a higher rate than the flame can supply it. It is recognized that heat is mainly transferred from the flame to the fuel by convection and radiation, while fuel cooling by water mist is primarily due to the conversion of water to steam. Thus, the heat rate per unit area that must be removed by water for fire suppression is given by:

$$S_h = \left(H_f - \lambda_f\right) m_b + R_a - R_s \qquad (2.18)$$

where S_h is heat removed per unit area by water spray, H_f is convective heat transfer from flames per unit mass of fuel entering flames, λ_f is heat required to produce a unit mass of vapour, m_b is burning rate per unit area, R_s is other forms of heat transfer to the fuel surface and R_s is heat lost from the surface not included in λ_f (e.g., radiant heat loss).

Fuel wetting or cooling by water mist also reduces the pyrolysis rate of the fuel and prevents re-ignition when the fuel is cooled down. For fuels whose low flash points are above normal ambient temperature, more water sprays are needed to cool the fuel surface, because less heat is required to produce fuel vapour. Also, more water sprays are needed to prevent re-ignition of a hot, deep-seated fire. The wood crib and slab tests showed that the risk of re-ignition is greater for higher water application rates, if spraying is stopped as soon as the flames go out. This is because higher water flow rates extinguish the fire faster, but the fuel remains hot and continues to pyrolize if the water is switched off immediately after extinction.

Fuel wetting or cooling by water mist may be the predominant extinguishment mechanism for fuels that do not produce combustible mixtures of vapour above the fuel surface. The primary combustion reaction with this type of fuels, such as solid fuels, occurs within the carbon-rich zone that forms on the fuel surface. Hence, cooling of the diffusion flame above an established char zone of solid fuel may not be enough to achieve suppression. Water mist must be applied to cool the fuel surface either before a deep char zone has developed, or water droplets must penetrate the char zone to reach the actual interface between the burned and unburned fuel (Husted B.P., 2009).

2.5.2 Kinetic Effects of Water Mist on Flames

Experimental tests carried out in the journal showed that when "under-designed" water mist systems failed to extinguish a liquid fuel pool fire, the heat release rate of the fire was higher than that of a fire without the suppression by water mist. They indicated that the increase in the heat release rate of the fire may result from kinetic effects of water mist on flames.

A momentary increase in the liquid pool fire size was also observed at the beginning of the water mist discharge in the case of successful fire extinguishment. This increase in fire size, however, is attributed to the enlarged flame surface caused by the impingement of water sprays, as water mist impinged the pool flame and increased the mixing area between the oxidizer and the fuel (Husted B.P., 2009).

Experimental and theoretical studies on the effect of water vapour on the combustion of the fuel-air mixture. Their studies showed that, although the fire extinguishment by water is mainly due to the physical effects, the addition of water vapour to the fuel-air mixture could result in an increase in the flame temperature, CO_2 production rate and O_2 depletion rate as well as a decrease in CO and soot production rate. These effects are due to the water vapour enhancing chemical reactions inside the flames. As the water vapour concentration is increased in the flame, the OH radical concentration increases, resulting in an increase in flame temperature and CO_2 production rate. After the addition of approximately 30% of the water vapour in the fuel-air mixture, however, the chemical enhancement of the flame by water vapour was not observed and the flame temperature began to decrease.

2.6 FACTOR THAT CAN AFFECT WATER MIST PERFORMANCE

It has been recognized that although all the extinguishing mechanisms of water mist are involved to some degree in fire extinguishment, only one or two mechanisms play a predominant role. Which suppression mechanism is dominant, depends on the characteristics of the water mist, fire scenarios, compartment geometry and ventilation conditions. Many other factors, such as the enclosure effect, dynamic mixing created by water mist discharge, types of water mist systems applied total or local application and the use of additives and discharge modes, have important impacts on the effectiveness of water mist in fire suppression (Su L.M., 2003).

2.6.1 Water Mist Characteristics

The effectiveness of a water mist system in suppressing a fire is directly related to the spray characteristics produced by the nozzles. In the journal, it gave a detailed list of the important parameters of water sprays for fire suppression. These are:

1) Mean flow rate per unit area in the fire region.
2) Distribution of flow rate in and about the fire area.
3) Direction of application.
4) Droplet size and distribution.
5) Entrained air velocity.
6) Droplet velocity relative to entrained air, flame velocity, and fuel types.

Although these important spray parameters can be used to describe the characteristics of water mist in fire suppression, they can be further broadly classified as three main parameters which is droplet size distribution, flux density and spray momentum. These three main parameters of water mist not only directly determine the effectiveness of the water mist for fire suppression but also potentially determine the nozzle spacing as well as the ceiling height limitation for a given installation.

2.6.2 Droplet Size Distribution

Droplet size distribution refers to the range of droplet sizes contained in representative samples of a spray or mist cloud measured at specified locations. The droplets produced by a water mist system into three classes to distinguish between "coarser" and "finer" droplet sizes within the 1000 micron window. The classifications are, first is Class 1 mist has 90% of the volume of the spray (Dv0.9) within drop sizes of 200 microns or less. Second is, Class 2 mist has a Dv0.9 of 400 microns or less. Lastly is, Class 3 mist has a Dv0.9 value larger than 400 microns (Su L.M., 2003).

In theory, small droplets are more efficient in fire suppression than large droplets, because of their larger total surface area available for evaporation and heat extraction. They are more effective in radiation attenuation. Also, small droplets have longer residence times, allowing them to be carried by air currents to remote or obstructed parts of an enclosure. They can exhibit more gaseous-like behavior and superior mixing characteristics. However, it is very difficult for small droplets to penetrate into the fire plume and to reach the fuel surface due to the drag and the hydrodynamic effect of the fire plume (Santangelo P.O., 2010). Fine droplets with low momentum are easily carried away from the fire by air currents. In addition, more energy is required to produce fine droplets and transfer them to the fire.

Large droplets can penetrate the fire plume easily to provide direct impingement, and to wet and cool the combustibles. However, large droplets have smaller total surface areas available for heat extraction and evaporation. The capability of water mist in suppressing obstructed/shielded fires is reduced as the size of the droplets is increased. As well, large droplets with high velocities can cause liquid fuels to be splashed, resulting in an increase in fire size (Santangelo P.O., 2010).

A wide range of experimental tests under different fire conditions was carried out to identify the optimum droplet size for fire suppression. Summarization the optimum droplet sizes suggested by various authors, as shown in Table 2. It can be seen that the optimum size of droplets for fire suppression is strongly dependent on many factors, such as the properties of the combustibles, the degree of obstruction in the compartment, and the size of the fire. The droplet size distribution that is most effective in extinguishing one fire scenario will not necessarily be the best for other scenarios. There is no one-size distribution to fit all fire scenarios. Actually, the performance of water mist with a well-mixed distribution of fine and coarse droplets is better than that with a uniform droplet size. Furthermore, any changes in fire size spray velocity (momentum) and enclosure effects will change the optimum droplet size for fire suppression.

Table 2.2: Comparison of optimum droplet size for fire extinguishment

Author	**Date**	**Droplet Size (µm)**	**Notes**
Braidech and Neale	1955	300-350 100-150 150-300	Applied vertically down Applied horizontally Low flash point, immiscible fuel
Herterich	1960	350	
Yao and Kalelkar	1970	<350 4000-5000	For gas layer cooling For plume penetration
Vincent et al	1976	310	Gas explosion suppression
Beyler	1977	>1000	Penetration and prewetting of fires larger than 250 kW
Pietrzak and Patterson	1979	200-300	Flame/gas layer cooling
Rasbash	1985	400	High flash point, immiscible fuels
Kaleta	1986	300-900	Optimum depends on gas layer temperature
Osaka	1988	250-300	Hand-held fog nozzle
Tour and Andersson	1989	300	TA Fogfighter nozzle, hand-held
Marioff	1991	60	Pressure fog nozzle

Source: (Husted B.P, 2009)

2.6.3 Flux Density

Spray flux density refers to the amount of water spray in a unit volume (Lpm/m3) or applied to a unit area (Lpm/m2). On a compartmental scale, the increase in the flux density will reduce the compartment temperature but will have little effect on the oxygen concentrations in the compartment. On a localized scale, however, the fire is extinguished only when water sprays achieve a minimum flux density. Without sufficient flux density of water sprays to remove a certain amount of heat from a fire or to cool the fuel below its fire point, the fire can sustain itself by maintaining high flame temperature and high fuel temperature.

Since water mist does not behave like a true gaseous agent, it is difficult to establish the critical concentration of water droplets required to extinguish a fire example the minimum total mass of water in droplets per unit volume or per unit area for fire suppression (Hino T., 2000). The amount of mist reaching the fire is determined by many factors. These include the spray momentum and angle, shielding of the fuel, fire size, ventilation conditions and compartment geometry.

In addition, current spray technology and corresponding nozzle allocation in the compartment cannot provide a uniform flux density of the spray. The flux density distribution of water mist within a single nozzle spray cone is non-homogeneous. Some types of nozzles for the production of water mist concentrate a high percentage of the water spray into the center of the cone area while other types of nozzles may have less water mist concentration at the center area. When spray cones from a group of nozzles overlap, the flux densities at any point are also different from those observed with a single nozzle due to the dynamics of spray interaction.

Comparison the minimum flow rates required for extinguishing solid fuel fires suggested. It was found that these minimum flow rates varied widely with application conditions and no “critical concentration” of water sprays could fit all applications (Qin X., 2010).

2.6.4 Spray Momentum

Spray momentum refers to the spray mass, spray velocity and its direction relative to the fire plume. The spray momentum determines not only whether the water droplets can penetrate into the flame or reach the fuel surface, it also determines the entrainment rate of surrounding air into the fire plume. The turbulence produced by the spray momentum mixes fine water droplets and water vapour into the combustion zone, which dilutes the oxygen and fuel vapour and increases the extinguishing efficiency of water mist in fire suppression. The spray mass defined in the momentum of the spray, therefore, not only includes the mass of liquid-phase water but also includes the mass of vapour-phase water and air entrained by water mist (Hino T., 2000). The momentum of the spray, M_w, can be expressed as follow:

$$M_w = (m_{wl} + m_{wv} + m_{wa}) \times V_w \quad (2.19)$$

Where m_{wl}, m_{wv} and m_{wa} are mass of liquid-phase water, vapour-phase water and air entrained by mist, respectively, and V_w is associated to the velocity vector of water mist.

Water spray momentum is determined by many factors. These include droplet size and velocity, discharge pressure and cone angle, the spacing of nozzles, ventilation conditions and the compartment geometry. In addition, the spray momentum will gradually decrease, as fine water droplets travel through hot gas and the droplet velocity and size are reduced due to gravitational and drag forces on the droplets with the evaporation. The distance (Xo) from the nozzle which water droplets must travel before falling in the air, is determined by spray momentum and discharge cone angle (Hino T., 2000).

When water droplets fall in the air due to gravitational force, the maximum falling distance of the droplets is mainly controlled by droplet size and surrounding temperature, before they disappear into the hot gas due to the evaporation. Such maximum falling distance, X_{fall}, without considering the upward velocity produced by the fire, is given by:

$$X_{fall} = 2000 \frac{D_O L \rho}{2 K_g \Delta T C_2} \quad (2.20)$$

where D_o is the droplet diameter, L is the Latent heat of vaporization, ρ is the surrounding density, ΔT is the temperature difference between the droplet and surroundings and C_2 is the coefficient.

Table 2.3: Typical falling distance of droplets with droplet sizes at different surrounding temperatures.

$T_g(°C)$	D_o (Droplet Diameter, μm)					
	1	**10**	**50**	**100**	**500**	**1000**
400	1.5pm	15nm	9.1 μm	146 μm	2.5m	9.9m
600	0.88pm	9nm	5.5 μm	87 μm	1.5m	6.0m
800	0.63pm	6nm	3.9 μm	63 μm	1.1m	4.3m
1000	0.49pm	5nm	3.0 μm	49 μm	0.8m	3.3m

Source: (Husted B.P, 2009)

Table 3 lists the typical falling distances for droplets with different sizes at different surrounding temperatures. The falling distances are significantly reduced with the droplet size and with the increase in the surrounding temperature. Hence, with a high ceiling, the momentum of fine water droplets will become very small before they reach the fire. Such fine water sprays with low momentum will not penetrate the strong upward fire plume to reach the region of the fuel surface, resulting in failure to suppress the fire.

To avoid having the mist and the water vapour carried away by the fire plume, the momentum of the mist must be at least equal in magnitude, and opposite in direction, to the momentum of the fire plume (Qin X., 2010). This relationship is given by:

$$M_{wy} \geq M_{fy} \tag{2.21}$$

Where M_{wy} and M_{fy} are the component of water mist and fire plume momentums, respectively.

The fire plume momentum, M_f, can be expressed as follow:

$$M_f = (m_{fp} + m_{fg} + m_{fa}) \times V_f \tag{2.22}$$

where m_{fp}, m_{fg}, and m_{fa} are mass of combustion products, fire gases and air entrained by the fire plume, respectively, and V_f is associated to the velocity vector of the fire plume.

Spray momentum is also particularly important for zoned water mist fire suppression systems and for fires with a high degree of obstruction. For such fire challenges, water mist must be directly discharged onto the fire and extinguish it by flame and fuel cooling. For the protection of electrical equipment by water mist, showed that effective fire suppression was achieved only by exercising rigorous control over spray direction by lying out.

2.6.5 Enclosure Effects

When a fire occurs in an enclosed compartment, the room is heated and the oxygen concentration in the compartment is gradually reduced. In addition, the hot gases from the fire tend to concentrate near the ceiling. With the discharge of water mist downward from ceiling level, a maximum amount of water is converted to vapour and displaces oxygen and fuel vapour around the fire, as fine water droplets quickly absorb heat from their hot surroundings. The capability of the compartment to capture heat and confine combustion products and water vapour has an important impact on the extinguishing performance of water mist, which is described as enclosure effects in fire suppression. With enclosure effects, it is possible to extinguish even shielded fires with low-momentum sprays in heavily obstructed compartments. The flux density required for extinguishment can be as much as 10 times lower than that required for unconfined and well-ventilated fires (Chen L., 2009).

The degree of enclosure effects in fire suppression is mainly dependent on the fire size in relation to the compartment size. Large and small fires are defined loosely in terms of whether the fire will affect the average temperature and oxygen concentrations in the compartment within the activation time of the water mist system. A large fire reduces the ambient oxygen concentration to the point that the combustion efficiency of the fire is reduced, prior to introducing water mist. A 'large' fire also releases more heat in the compartment to evaporate the fine water droplets, and further reduces the oxygen concentration in the compartment. With the enclosure effect, the main extinguishing mechanism of water mist for large fires is oxygen displacement. Test results have shown that, in a compartment with large fires, small fires in a cabinet with a low ventilation rate were also extinguished by water mist due to the depletion of oxygen in the compartment by fires and steam (Qin X., 2010). The extinguishing times were significantly reduced with the increase in the fire size.

For a large fire challenge, the use of a Total Compartment Application (TCA) Water Mist System can quickly extinguish fires with low flux densities. This is because the use of a TCA water mist system maximizes the benefits of oxygen depletion and fuel vapour dilution for fire suppression by combining vitiated combustion products with a large amount of water vapour.

When the fine droplets are discharged into a very hot enclosure due to the existence of large fires, however, the rapid cooling by water mist will result in an overall negative pressure inside the compartment, because the hot air or gases contract faster than the steam can expand. The very high negative pressure produced could cause some damages to the compartment, such as the implosion of double-glazed windows, and lead to fresh air being drawn into the room. The cooling effect of water mist on the room pressure must be carefully assessed when designing a system for a large fire challenge (Qin X., 2010).

With small fires in the compartment, however, less heat and combustion products are released. The reduction in oxygen concentration and the increase in gas temperature in the compartment are small prior to the activation of the water mist system. The enclosure effect no longer has important effect on the extinguishing performance of water mist, because less heat, water vapour and vitiated gases are available for confinement (Chen L., 2009). The extinguishment of a small fire by water mist will depend almost entirely on direct fire plume or fuel cooling. Water mist must be discharged directly on the fire. For small fire challenges, the use of a Local Application (LA) water mist system might extinguish the fire more efficiently.

2.6.6 Heat Flux

(Cengel Y.A., 2006) For constant heat flux, it¡¦s simplify on determine total heat transfer rate,

$$\dot{Q} = \dot{q}_s A_s = \dot{m} C_p (T_e - T_i) \tag{2.23}$$

Note that T_e is the temperature exit and T_i is the temperature inlet. Thus, the mean fluid temperature at the tube exit can be written as,

$$T_e = T_i + \frac{\dot{q}_s A_s}{\dot{m} C_p} \tag{2.24}$$

Where the surface temperature for constant heat flux can be determine from below equation

$$\dot{q}_s = h(T_s - T_m) \rightarrow T_s = T_m + \frac{\dot{q}_s}{h} \tag{2.25}$$

Figure 2.6 shows surface temperature T_s will also increase linearly in the flow direction since both and are constant and thus T_s ¡V Tm will be constant.

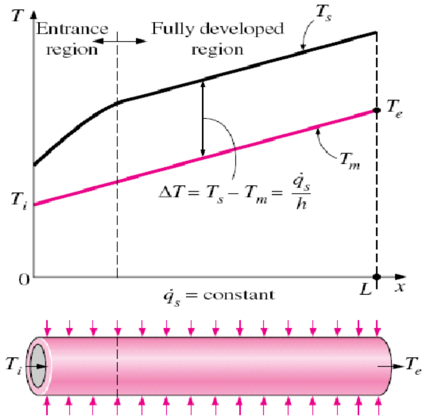


Figure 2.2: Variation of the tube surface and the mean fluid temperature under constant heat flux conditions.

Source: (Cengel, 2006)

2.6.7 Pressure Drop

The power requirements of the fan or pump to maintain flow can be determine based on pressure drop, ΔP and its can denoted as the difference between final and initial of pressure. To emphasize that it is a loss due to viscous effect, pressure drop is called pressure losses indicated byΔP_L.

For fully develop internal flows (laminar and turbulent flows, circular or noncircular pipes, smooth or rough surfaces, horizontal or inclined pipes) (Cengel Y.A., 2006), the pressure drop can be expressed as shown below

$$\Delta P_L = f\,\frac{L}{D}\frac{V^2 avg}{2} \qquad (2.26)$$

With, f is the Darcy friction factor or Darcy-Weisbach friction factor. But, solving for f gives the friction factor only valid for fully developed laminar flow in a circular tube.

The equation as follows:

$$f = \frac{64\mu}{\rho D V_{avg}} = \frac{64}{Re} \quad \textbf{(}2.27\textbf{)}$$

To determine the friction factor for turbulent flow, the Colebrook equation is used so that the pressure drop can be calculated.

$$\frac{1}{\sqrt{f}} = -2.0 \log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right) \quad \textbf{(}2.28\textbf{)}$$

Where, ε is relative roughness of the material and different value with different material. It is present Darcy friction factor for pipe flow as a function of the Reynolds number and ε/Dover a wide range also one of the accepted and used charts in engineering.

Once the pressure loss is known, the required pumping power to overcome the pressure loss can be determine.

2.6.8 Methods of Generating Water Mist

In general, water mist generating systems can be divided into three basic categories based on the atomizing mechanisms used to produce the fine droplets such as, impingement nozzles, pressure jet nozzles and twin fluid nozzles. Any other type of nozzle is a combination of these three basic types.

These three types of nozzles work under different operating pressures and can produce different spray characteristics. In the journal defines three pressure regions for water mist generating technologies: low, intermediate and high pressure systems. Low pressure systems operate at pressures of 12.0 bar (175 psi) or less, intermediate pressure systems operate at pressures greater than 12.0 bar (175 psi) and less than 34.0 bar (500 psi), and high pressure systems operate at pressures greater than 34.0 bar (500 psi) (Lal S., 2010).

The choice of the water mist generating method could influence factors such as spray characteristics, cost-effectiveness and reliability of the system. The method of generating water mist also affects the suppression capability of the system but it is not the only factor. Matching the spray characteristics of drop size distribution, flux density and spray momentum to the fire hazard plays a more important role in fire suppression (Lal S., 2010).

2.7 RAPID-PROTOTYPING

Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data. The company was founded in 1986, and since then, a number of different RP techniques have become available. Rapid Prototyping has also been referred to as solid free-form manufacturing, computer automated manufacturing, and layered manufacturing. RP has obvious use as a vehicle for visualization. In addition, RP models can be used for testing, such as when an airfoil shape is put into a wind tunnel. RP models can be used to create male models for tooling, such as silicone rubber molds and investment casts. In some cases, the RP part can be the final part, but typically the RP material is not strong or accurate enough. When the RP material is suitable, highly convoluted shapes including parts nested within parts can be produced because of the nature of RP (FORTUS User Guide).

Source: (Stratasys Inc., 2012)

Figure 2.3: Rapid prototyping machine type FORTUS 360mc/400mc

The Fortus 360mc was designed for users with demanding applications for high accuracy prototyping and direct digital manufacturing. The system is equipped with an extrusion head and gantry that maintains tight positional accuracy and can produces parts with high tolerance. With FDM (Fused Deposition Modeling) technology, the Fortus 360mc manufactures Real Parts in production-grade thermoplastics.

The standard build envelope is 14x10x10 inches (355x254x254mm), which can be upgraded to 16x14x14 inches (406x356x406 mm). with the upgrade comes two more material canister bays, for a total of four bays (two build material and two support material) the larger build envelope and the additional material canisters enable users to run larger build runs. When the first material canister is empty, an auto-changeover function loads the second canister and continues the build process uninterrupted allowing users to leave the machine unattended for long periods of time (FORTUS User Guide).

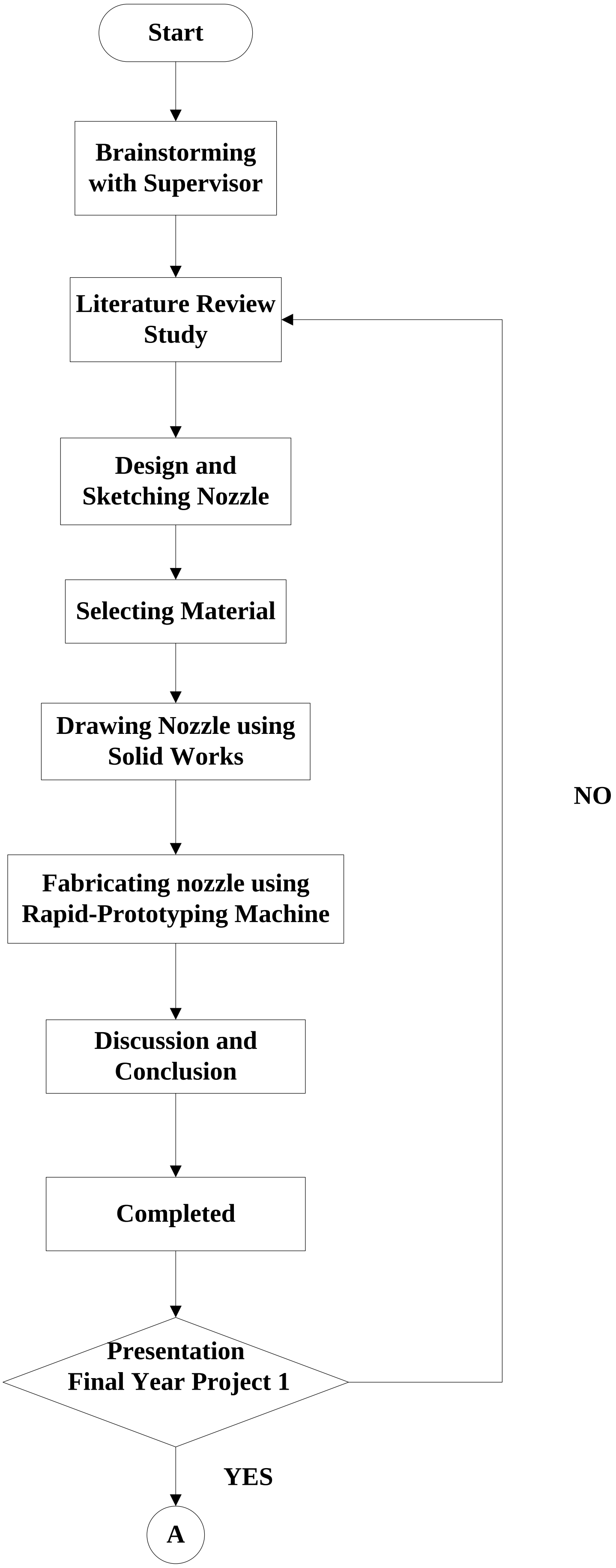
CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The objective of the project can be achieved by setting the methodology in well. This will make the project is cable of complete on time. This chapter will explain the detailed about the methodology progress during Final Year Project 1 and 2. The title was given by the supervisor in the beginning of this semester with the title "Development of a New Type of Sprayer Head of a Water Mist System". Besides that, this chapter includes the flow of the research paper, information on preparation of water mist system development solution proposed by the researcher, the flow of experiment done using the suitable apparatus, and method of interpreting the result. The detailed related literature review was informed acquired the important things in the Chapter 2.

The project is suggested to vary in development of a new type of sprayer head of water mist system by difference in diameter and pressure flow in the system. First of all, the nozzle was fabricating using rapid-prototyping machine. Then the nozzle was test by doing experiment. On the nozzle experiment, it will be able to analyzed and study the pattern of a mist flow out from the nozzle. To solve all the problem, first thing to do is to determine all the flow works with the duration of time, the Gantt chart is a recommended method to use. So that all the flow work with the description of works were carried out to meet the date line.


Start
Brainstorming with Supervisor
Literature Review Study
Design and Sketching Nozzle
Selecting Material
Drawing Nozzle using Solid Works
Fabricating nozzle using Rapid-Prototyping Machine
Discussion and Conclusion
Completed
Presentation Final Year Project 1
NO
YES
A

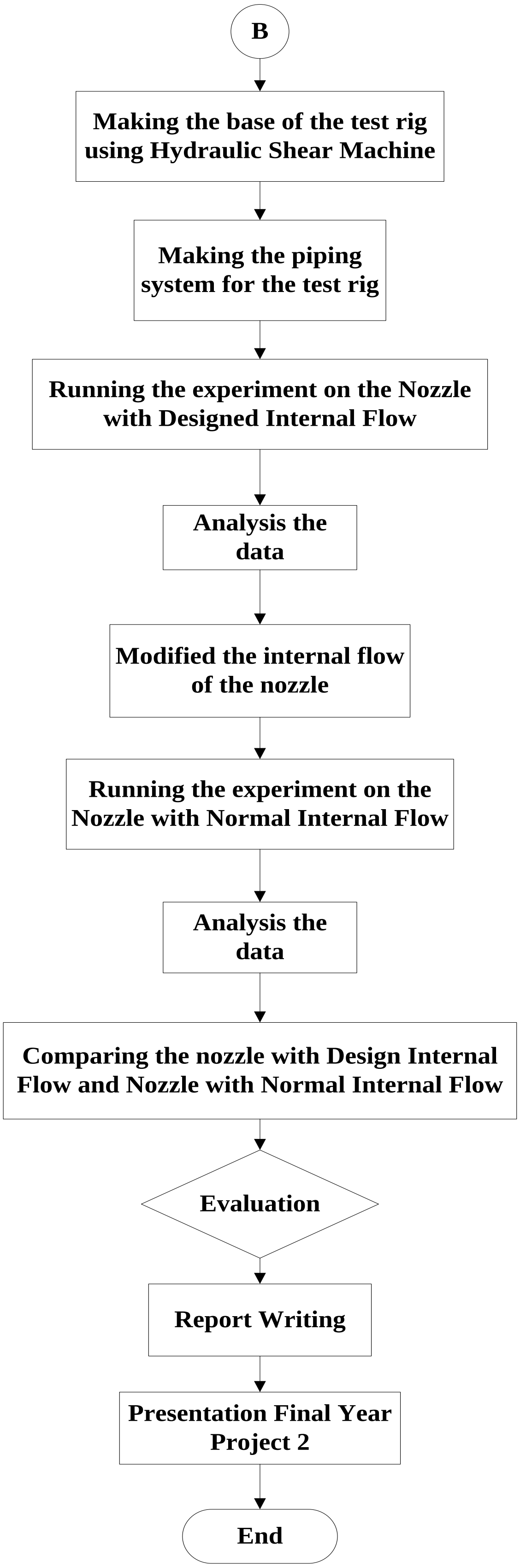


Figure 3.1: Methodology flow chart

3.2 PROBLEM SOLVING

By referring to this project, the main problem solving is by running the experiment on the nozzle to analyze and identify the pattern of mist spread out from the nozzle by using different pressure and nozzle diameter. To complete that there must be a problem solving method or flow to complete that. So, the works are regarding to this solving problem must be more organize. With referring to the methodology flow chart, the detail for each activity can be referring to next sub topics.

3.2.1 Literature Study

This project is start with the literature review and research from the internet, company websites, market survey, books and journal about the title. This stage is very important to make a literature study about basic of the development a new type of nozzle for water mist sprayer such as characteristic of the nozzle, internal flow of nozzle, diameter of the internal flow, water pressure, material used in making nozzle and others fluid dynamics requirement. In this part, the detail about the design of the nozzle and all the effect about the pattern mist flow out from the nozzle will be explained. The literature study was continued from the beginning of this project so that all the latest information will be updated from the time to time. This part also can give the individual to understand what the important things needed before proceed to the next stage.

3.2.2 Identify Project Objectives

Objective is the most important part in this project. By the determination of the objective, the project will clearly see what will be doing from the beginning. The problem that will occur at the fabricating the nozzle and mist flow pattern with the nozzle must be analyzed. This is very important so that the target objective from the starting can be achieved. The scopes of this project can be done after determine the objective the objective. This will help the project to progress smoothly and can be success.

3.3 DIMENSION OF THE NOZZLE

Before the analysis of this project, the nozzle model is requiring to get the dimension. From the literature study, the nozzle was made in small dimension and it has a lot of type. For the study, I choose the nozzle from Solid Cone Spray type BC. This dimension was only to know the nozzle dimension. After that the nozzle will modified with the designed internal flow and different diameter. Figure 3.2 below are the dimension of the solid Cone Spray type nozzle.

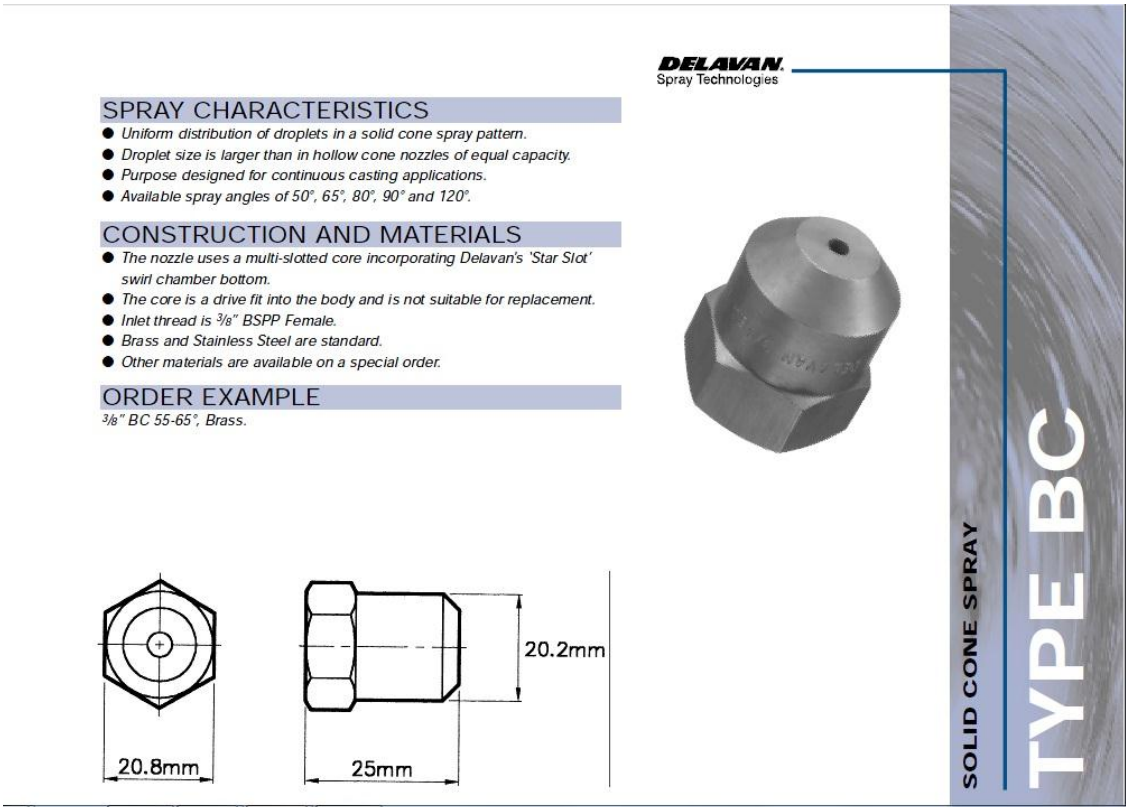


Figure 3.2: Solid cone spray $DELAVAN_{®}$ spray technologies brochure

All solid cone catalogs were added in Appendix B1.

3.3.1 Design Nozzle with Exact Dimension

The nozzle was modeling and transferred into a 3-D modeling using the Solid Work (2010). The model is modeling by referring the true dimension from the brochure. After that the model was modified into some characteristic that want to study and to get match size with the test-rig. The model dimension and actual nozzle from brochure dimension is not quite match. It because of the characteristic that want to study is designed internal flow of the nozzle and the diameter of the internal flow of the nozzle. From that characteristic, I need to find which one is the most suitable to produce mist. All the part that has been mention at above, the part is modeled together with the test-rig because the project is focusing on the mist flow pattern only.

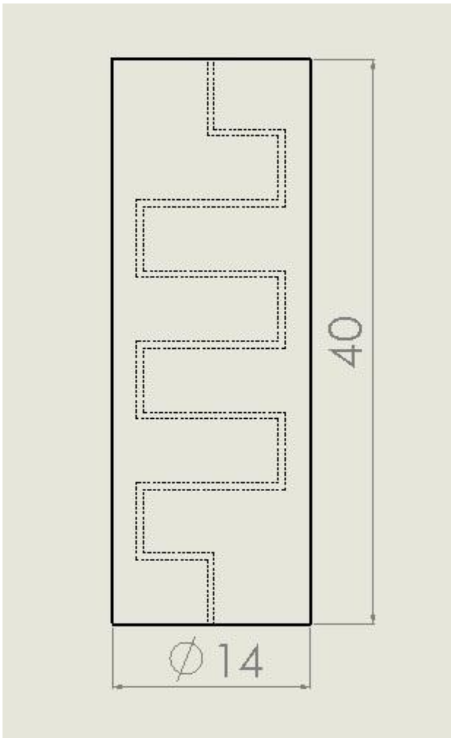


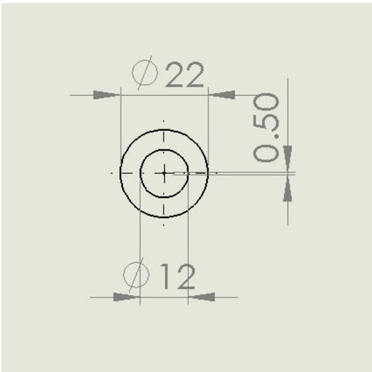
Figure 3.3: Actual dimension of nozzle from the brochure

3.4 SKETCHING APPLYING FOR NOZZLE IMPROVEMENT

The dimension of the nozzle model was modified to full fill the analysis and test-rig by using Solid Work software. Figure below is the Nozzle model with the characteristic that want to study which is nozzle with designed internal flow and nozzle with normal internal flow in diameter 0.5mm. For diameter 1.0mm and 1.5mm is in Appendix B2.

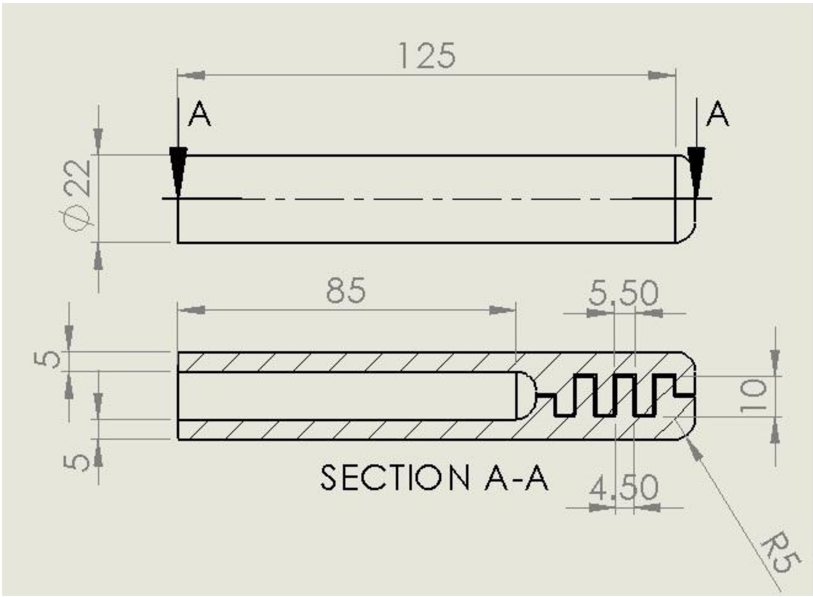
3.4.1 Nozzle with Designed Internal Flow

1) Diameter 0.5mm



(a) Front view

(b) Dimetric view

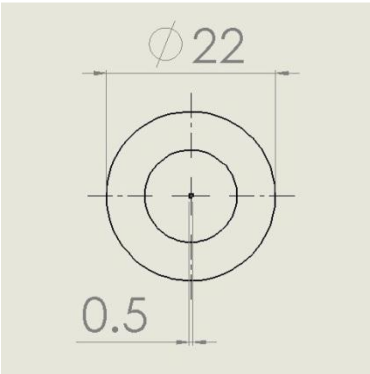


(c) Horizontal view

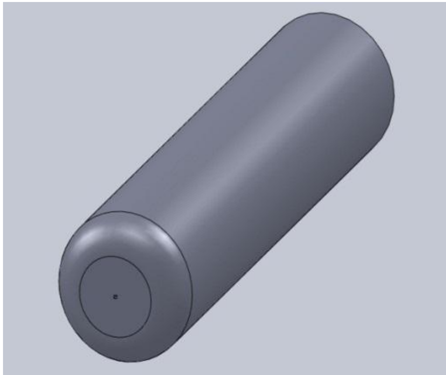
Figure 3.4: Dimension of the nozzle with designed internal flow, diameter 0.5mm from different side of view

3.4.2 Nozzle with Normal Internal Flow

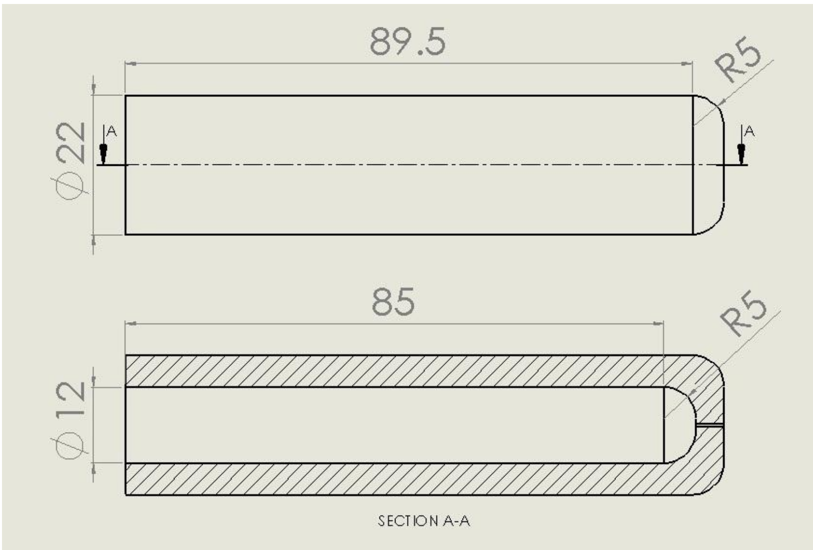
1) Diameter 0.5mm



(a) Front view



(b) Dimetric view



(c) Horizontal view

Figure 3.5: Dimension of the nozzle with normal internal flow, diameter 0.5mm from different side of view.

3.5 NOZZLE FABRICATING USING RAPID-PROTOTYPING

3.5.1 Insight Software

After the Nozzle modeling on Solid Work, the model will be save in STL (*.stl) file format. Then the model will be transfer into a Insight^{TM}Software to fabricate. The software will make an analysis about the structure of the nozzle and to set the base of the nozzle to fabricate it. Then, go to the control center to create packs and send part build commands to the Rapid-Prototyping machine. Figure below show the commands in the software for nozzle with diameter 0.5mm. Nozzle with diameter 1.0mm and 1.5mm is in Appendix B2.

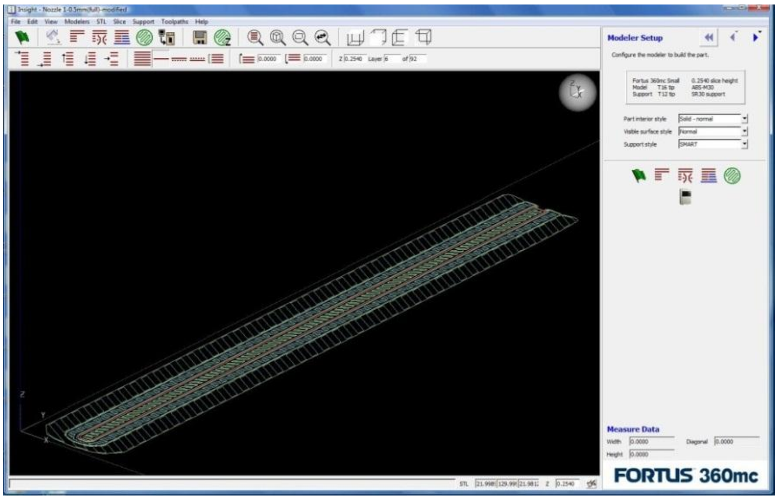


Figure 3.6: Base for 0.5mm nozzle by using insight^{TM} software.

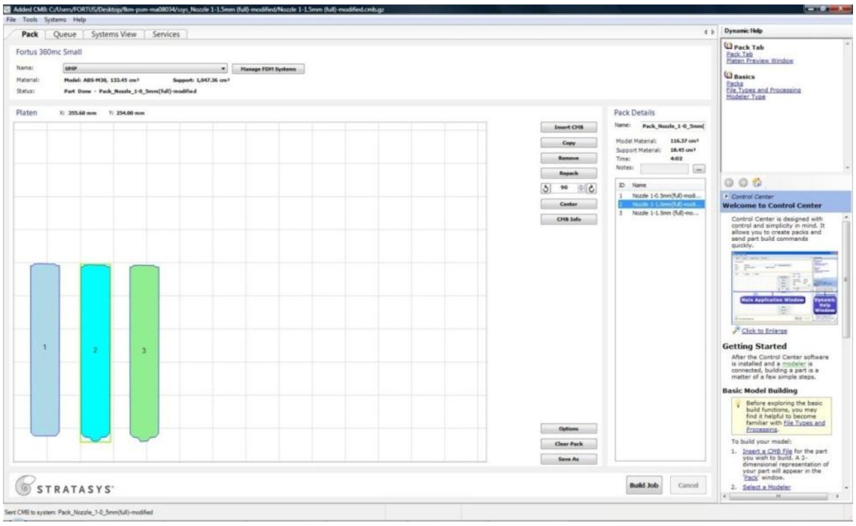
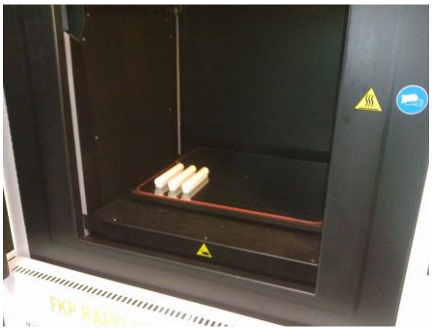


Figure 3.7: Control centre of the insight^{TM} software

3.5.2 Rapid-Prototyping Machine

After setting the nozzle in the Insight software, the commands will transfer to the rapid-prototyping machine. The machine used in fabricate nozzle is type FORTUS 360mc/400mc. This machine system was incorporating the latest in innovative technologies to provide with precise prototypes from a CAD design. Stratasys' Fused Deposition Modeling (FDM) technology provides prototype part, including internal feature, that can be used to field-test form, fit, and function. The FORTUS 360mc/400mc system feature a servo/belt driven XY gantry with multiple high temperatures modeling material capability. The machine takes about 4hour to fully fabricate the nozzle.

(b) User interface



(a) FORTUS 360mc/400mc

(c) Oven

Figure 3.8: Parts of FORTUS 360mc/400mc, (a) FORTUS 360mc/400mc, (b) User interface, (c) Oven

Material that used by FORTUS 360mc/400mc is ABS-M30. ABS-M30 is up to 25-70 percent stronger than standard Stratasys ABS and is an ideal material for conceptual modeling, functional prototyping, manufacturing tools, and end-use-parts. ABS-M30 has greater tensile, impact, and flexural strength than standard ABS. Layer bonding is significantly stronger than that of standard ABS, for a more durable part. This results in more realistic functional tests and higher quality parts for end use. ABS-M30 gives the product or part that are stronger, smoother, and with better feature detail. The machine takes about 4 hour duration to fully fabricate the nozzle. Table and figure below show the nozzle after fabricating and support material and properties for ABS-M30.

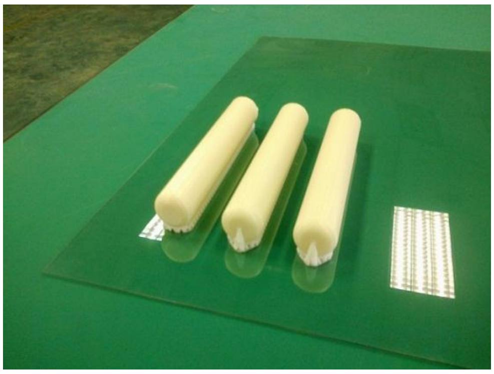
Table 3.1: Mechanical properties for material ABS-M30

Mechanical Properties[1]	Test Method	English	Metric
Tensile Strength (Type 1, 0.125", 0.2"/min)	ASTM D638	5,200 psi	36 MPa
Tensile Modulus (Type 1, 0.125", 0.2"/min)	ASTM D638	350,000 psi	2,400 MPa
Tensile Elongation (Type 1, 0.125", 0.2"/min)	ASTM D638	4%	4%
Flexural Strength (Method 1, 0.05"/min)	ASTM D790	8,800 psi	61 MPa
Flexural Modulus (Method 1, 0.05"/min)	ASTM D790	336,000 psi	2,300 MPa
IZOD Impact, notched (Method A, 23°C)	ASTM D256	2.6 ft-lb/in	139 J/m
IZOD Impact, un-notched (Method A, 23°C)	ASTM D256	5.3 ft-lb/in	283 J/m

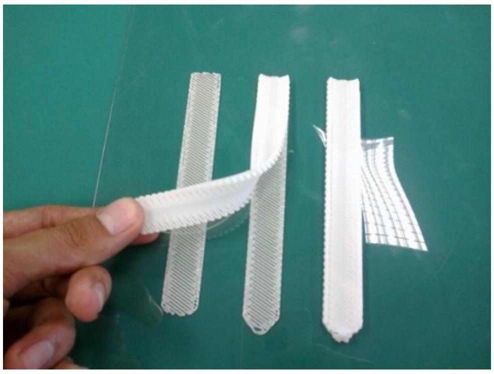
Table 3.2: Thermal properties for material ABS-M30

Thermal Properties[2]	Test Method	English	Metric
Heat Deflection (HDT) @ 66 psi, 0.125" unannealed	ASTM D648	204°F	96°C
Heat Deflection (HDT) @ 264 psi, 0.125" unannealed	ASTM D648	180°F	82°C
Vicat Softening Temperature (Rate B/50)	ASTM D1525	210°F	99°C
Glass Transition (Tg)	DSC (SSYS)	226°F	108°C
Coefficient of Thermal Expansion (flow)	ASTM E831	4.9E-05 in/in/°F	8.82E-05 mm/mm/°C
Coefficient of Thermal Expansion (xflow)	ASTM E831	4.7E-05 in/in/°F	8.46E-05 mm/mm/°C
Melt Point	- - - - - - - - -	Not Applicable[2]	Not Applicable[2]

Source: (DELAVAN, 2000)



(a) Nozzle after fabricating



(b) Support material

Figure 3.9: The nozzle after finish fabricating using FORTUS 360mc/400mc, (a) Nozzle after fabricating, (b) Support material

3.5.3 Ultra-Sonic Machine

After finish fabricating the nozzle, it must immerse in the Ultra-Sonic machine. This machine work using the Water Work liquid. Ultra-Sonic machine is to remove all support material that used in fabricating the nozzle. It used the Ultra-Sonic sound and adds up with heat about 75°C. Process to remove all the support material in the fabricating nozzle takes duration about 6 hour.

(a) Ultra-Sonic Tank side view

(b) Ultra-Sonic Tank top view

(c) Ultra-Sonic crest

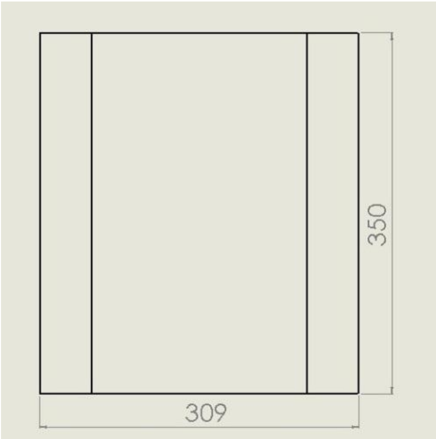
(d) Water Work liquid

Figure 3.10(a-d): Component used in the support material remove process, (a) Ultra-Sonic Tank side view, (b) Ultra-Sonic Tank top view, (c) Ultra-Sonic crest, (d) Water Work liquid

3.6 PIPING SYSTEM DEVELOPMENT

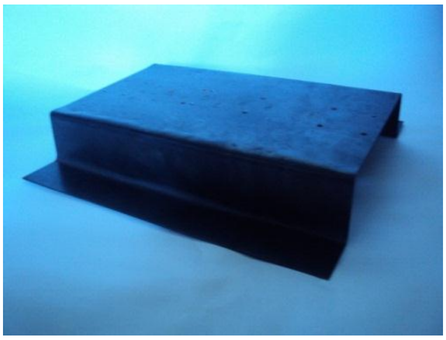
3.6.1 Making Base

For the piping system development, first is making a base for the test-rig. Material for the base was Mild Steel plate. It thickness was 1.5mm.



(a) Dimension of base

(b) Mild steel plate



(c) Base of the test-rig

Figure 3.11: Base for the test-rig, (a) Dimension of base, (b) Mild steel plate, (c) Base of the test-rig

From the large mild steel plate, hydraulic shear machine was used to cut it to get the size that need. Hydraulic Shear machine is use to cut plate and shaping sheet plate. It is basic form is that of horizontal cutter which shear about the cutter and moveable cutter at horizontal. Hydraulic shear using the concept shear with the horizontal cutter moveable by hydraulic system. First, switch on the machine. Then, it needs to put estimated length. For this estimated length must long than exact length that we need, because the machine will adjust the length between the holder and the cutting blade. After that, put value length that need to cut in x direction. Figure 3.12(a-c) below shows the part of the hydraulic shear machine.

(a) Hydraulic shear machine

(b) Control switch box

(c) Plate holder and cutting blade

Figure 3.12: Hydraulic Shear Machine Component, (a) Hydraulic shear machine, (b) Control switch box, (c) Plate holder and cutting blade

3.6.2 Test-Rig

For the test-rig, I used GI pipe type for the piping system. Reason that I used GI pipe, because in testing the nozzle, large pressure is used. Diameter of the pipe is 1 inch. There is some other part in piping system used in this pipe. Such as, Clip, Tee Socket, Elbow Socket, Valve and Pressure Gauge. Figure 3.13 below show the continuation of piping system for the test-rig.

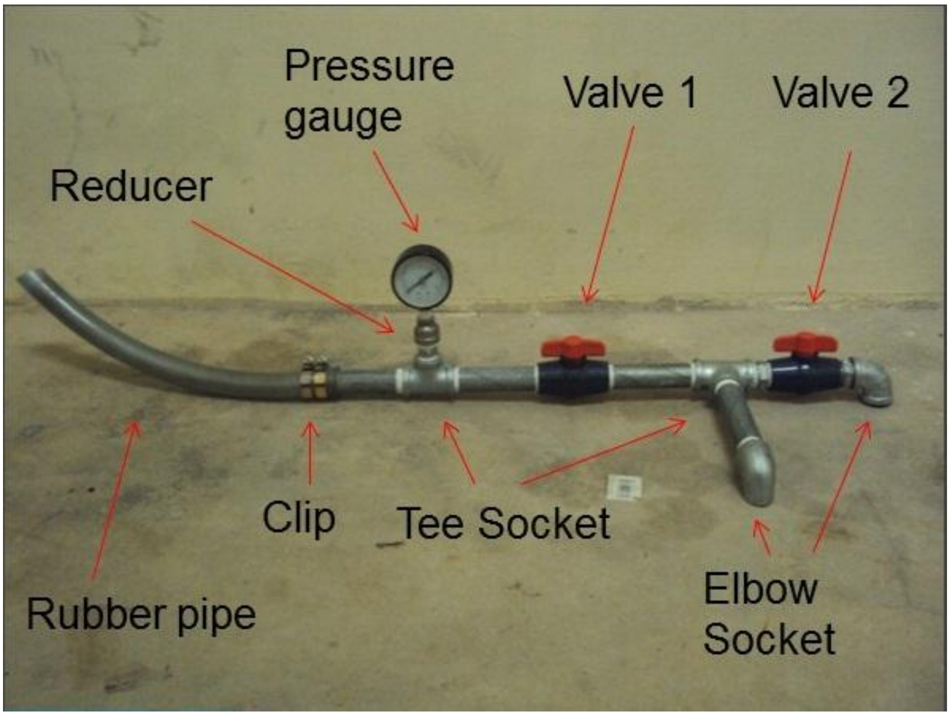


Figure 3.13: Piping system for the test-rig

1)	Clip:	For tight the rubber pipe with the GI pipe.
2)	Pressure Gauge:	For measure the pressure of water in the pipe.
3)	Tee-Socket:	To make junction of GI pipe.
4)	Elbow-Socket:	To connect the nozzle with pipe and to make water flow downward.
5)	Valve 1:	To control water flow in the system.
6)	Valve 2:	To control water pressure in the system.

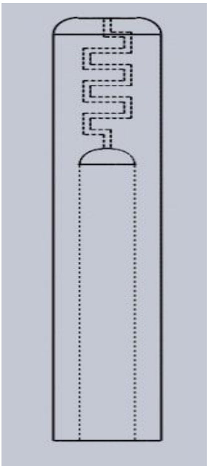
3.7 EXPERIMENT

The main aim of this project is to determine the best water sprayer head design to produce high volume eater mist at optimum setting. To start the project, we need to design and produce a sprayer nozzle for water mist system. After finish fabricating the nozzle, we must produce or make a test rig for test the nozzle. Then, the nozzle need to be test or run experiment at the selected test condition. After finish the experiment, it needs to establish relation between different process configurations on mist development.

3.7.1 Nozzle Preparation

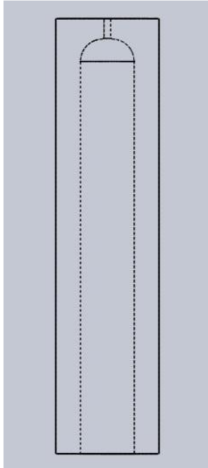
Before run the experiment, the nozzle must be prepared. The nozzle must wrap with the white tape and put it some silicon glue. It is because, for the first test on the nozzle, water still came out on surround of the nozzle. These problems happen because of the fabricating nozzle using rapid-prototyping machine. Rapid-prototyping machine fabricate a product using layer by layer making. Maybe, the material is not melted enough before do another layer. If the material not melted enough, it will make a very small hole at the nozzle. The nozzle needs to be test using high water pressure. That why, water still came out on surround of the nozzle and need to be wrapping using white tape and silicon glue.

(a) Nozzle preparation



(b) Illustrate nozzle in 3D

Figure 3.14: Nozzle with design internal flow, (a) Nozzle preparation, (b) Illustrate nozzle in 3D



(a) Nozzle preparation (b) Illustrate nozzle in 3D

Figure 3.15: Nozzle with normal internal flow, (a) Nozzle preparation, (b) Illustrate nozzle in 3D

3.7.2 Test Setup

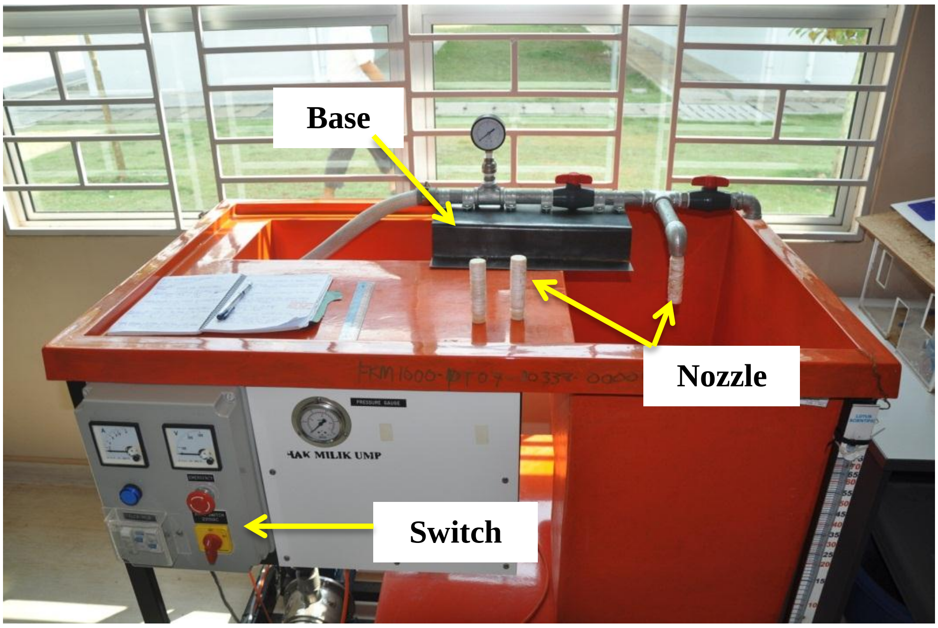


Figure 3.16: Water mist system

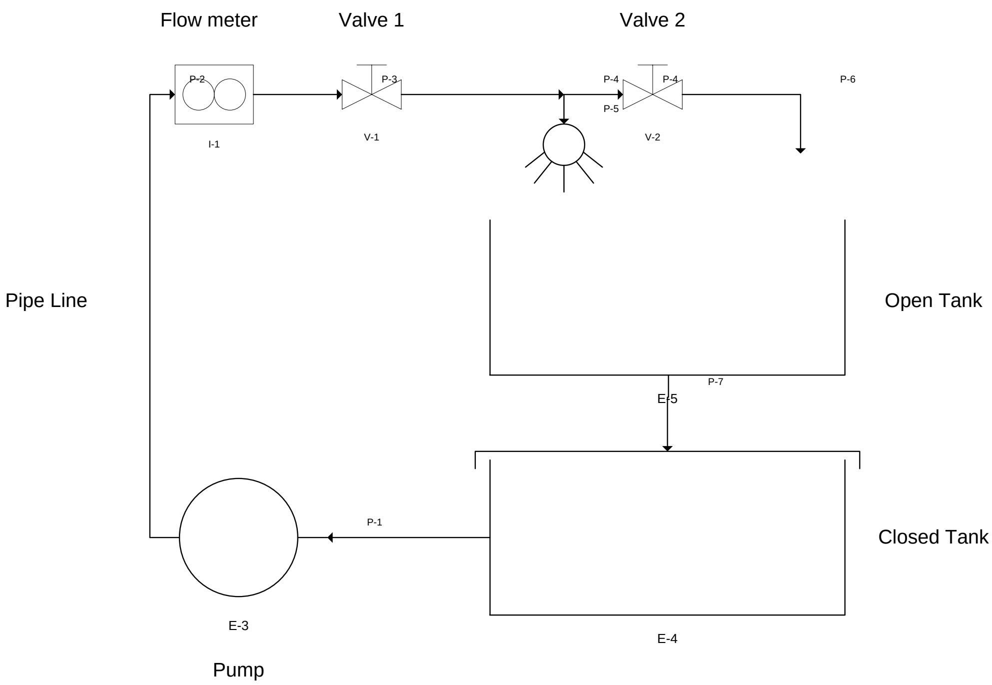


Figure 3.17: Illustrate water mist system using microsoft visio

3.7.3 Test Procedure

For test 1:

1) Connect the test rig and the pipe on the tank.
2) Put the nozzle with designed internal flow with diameter 0.5mm at the end of the pipe line like on Figure 3.17.
3) Open all valve.
4) Switch on the pump.
5) Wait for whole pipe full with water than closed the valve 2.
6) Look at the pressure gauge while adjust the valve 1 to get pressure 1.4bar.
7) Take a picture of mist pattern flow out from the nozzle.
8) Repeat step 2 to step 7 with pressure 1.8bar and 2.2bar.
9) Repeat step 2 to step 8 with nozzle diameter 1.0mm and 1.5mm
10) Change the nozzle with normal internal flow.
11) Repeat step 2 to step 9.

For test 2:

1) Connect the test rig and the pipe on the tank.
2) Put the nozzle with designed internal flow with diameter 0.5mm at the end of the pipe line like on Figure 3.17.
3) Open all valve.
4) Switch on the pump.
5) Wait for whole pipe full with water than closed the valve 2.
6) Look at the pressure gauge while adjust the valve 1 to get pressure 2.4bar.
7) Take a picture of mist pattern flow out from the nozzle.
8) Repeat step 2 to step 7 with nozzle diameter 1.0mm and 1.5mm.
9) Change the nozzle with normal internal flow but using pressure 2.3bar.
10) Repeat step 2 to step 8.

3.7.4 Test Planning

For test 1, the nozzle was test on different pressure for each diameter. Example, for the nozzle with diameter 0.5mm was test on pressure 1.4bar, 1.8bar and 2.2bar. For second test is on same pressure but with different diameter. Pressure 2.4bar for nozzle with designed internal flow and pressure 2.3bar for nozzle with normal internal flow. Table 3.3 and 3.4 below show the parameters that want to test the nozzle.

Table 3.3: Test 1 planning

Test 1:

PRESSURE	P1 = 1.4bar	P2 = 1.8bar	P3 = 2.2
Nozzle 0.5mm	Picture 1	Picture 2	Picture 3
Nozzle 1.0mm	↓	↓	↓
Nozzle 1.5mm			

Table 3.4: Test 2 planning

Test 2:

NOZZLE DIAMETER	D = 0.5mm	D = 1.0mm	D = 1.5mm
P = 2.4bar	Picture 1	Picture 2	Picture 3

For taking the value of length of the mist spread out, I was using a ruler. Put the ruler at the back of the nozzle then take the length value with same distance and same angle. Then the data value was recorded. Figure 3.18 below show how to take the value length of the mist spread out.

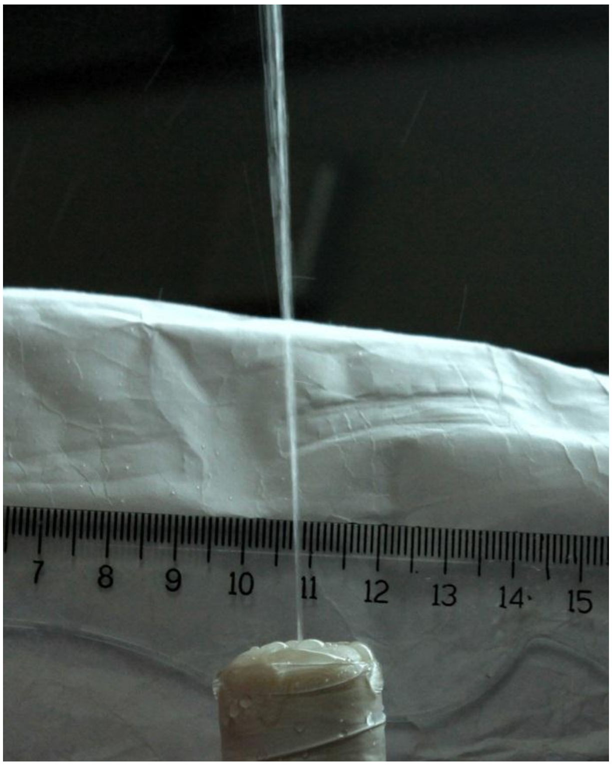


Figure 3.18: How to take value of mist spread out from the nozzle

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

The main objective of this project is about to study the nozzle producing mist from the water on water pressure and diameter of the internal flow. The study also apply rapid-prototyping machine in fabricating the nozzle. The development of mist will be studies between different pressure and different diameter of the internal flow. As an engineer, we should have thought of creating something new or modify existing items that can be quickly and easily in human life. This nozzle device will used in fire extinguisher, rapid cooling, plant watering device, device to cool the area, and others.

Nowadays, there are many new product have develop. This project has been developing a new type of nozzle by using rapid-prototyping machine to fabricate the nozzle. In this project, analysis will show the result when a nozzle with designed internal flow and normal internal flow will be compare with different pressure and different diameter of the internal flow. By using different pressure and different internal diameter, it can be studies on the mist flow out pattern. By mean, this is also one of the ways how the developers create or make a new product. This experiment on the nozzle, will determine there is any changing and improvement on the mist flow pattern with the different pressure and different internal diameter.

4.2 EXPERIMENT RESULT

In this experiment, there is 2 different nozzle which is nozzle with designed internal flow and nozzle with normal internal flow. Firstly, both of the nozzles were testing with 3 different diameters and with 3 different pressures. Second test is with same pressure but with 3 different diameter of internal flow. Flow rate of water in the pipe are calculated for 10L:-

$$\textbf{Average Time} = \frac{9.90s+11.00s+10.84s}{3} = \frac{31.74s}{3} = 10.58s$$

$$\textbf{Flow Rate} = \frac{V}{T} = \frac{10L}{10.58s} = 0.94518\,{}^{L}/_{s}$$

4.2.1 Nozzle with Designed Internal Flow

Diameter = 0.5mm, Pressure = 1.4bar

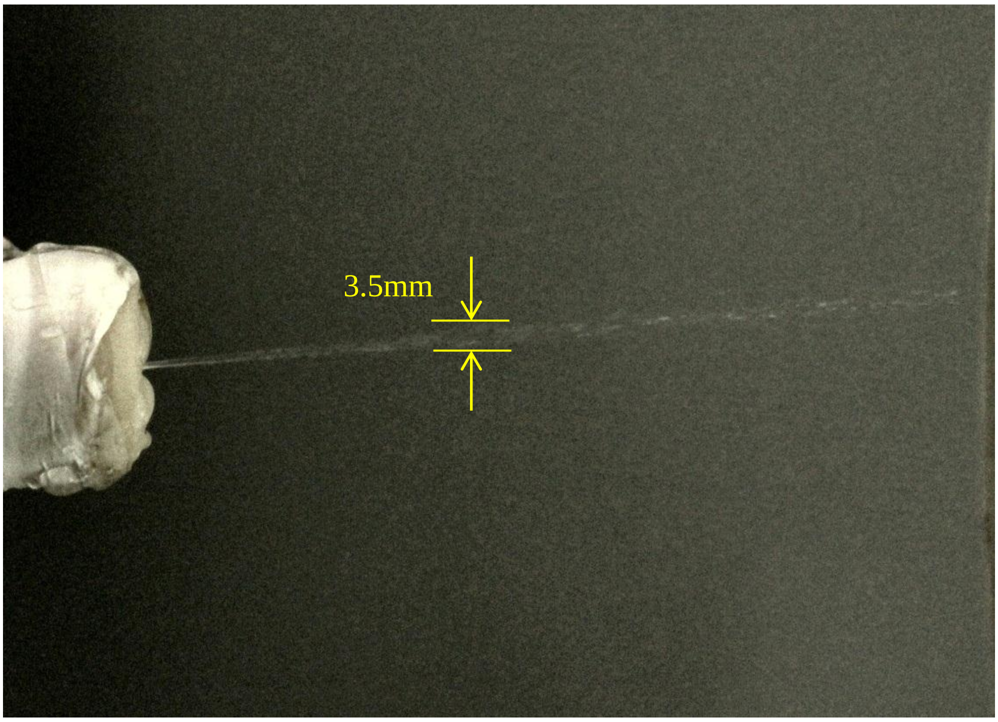


Figure 4.1: Nozzle with designed internal flow D1=0.5mm, P1=1.4bar

Diameter = 0.5mm, Pressure = 1.8bar

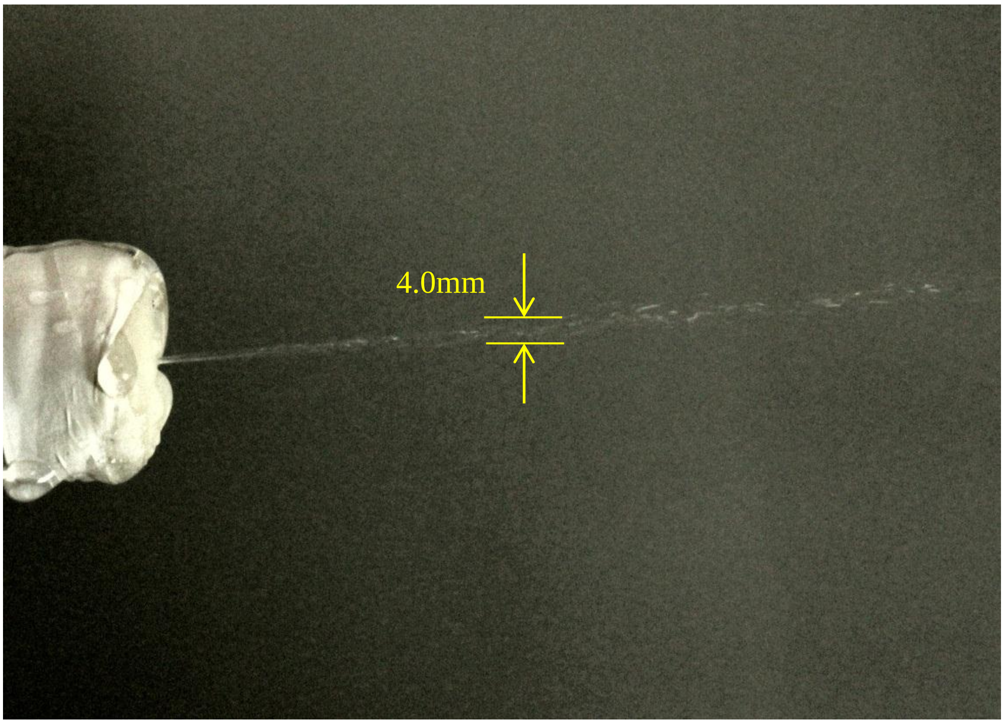


Figure 4.2: Nozzle with designed internal flow D1=0.5mm, P2=1.8bar

Diameter = 0.5mm, Pressure = 2.2bar

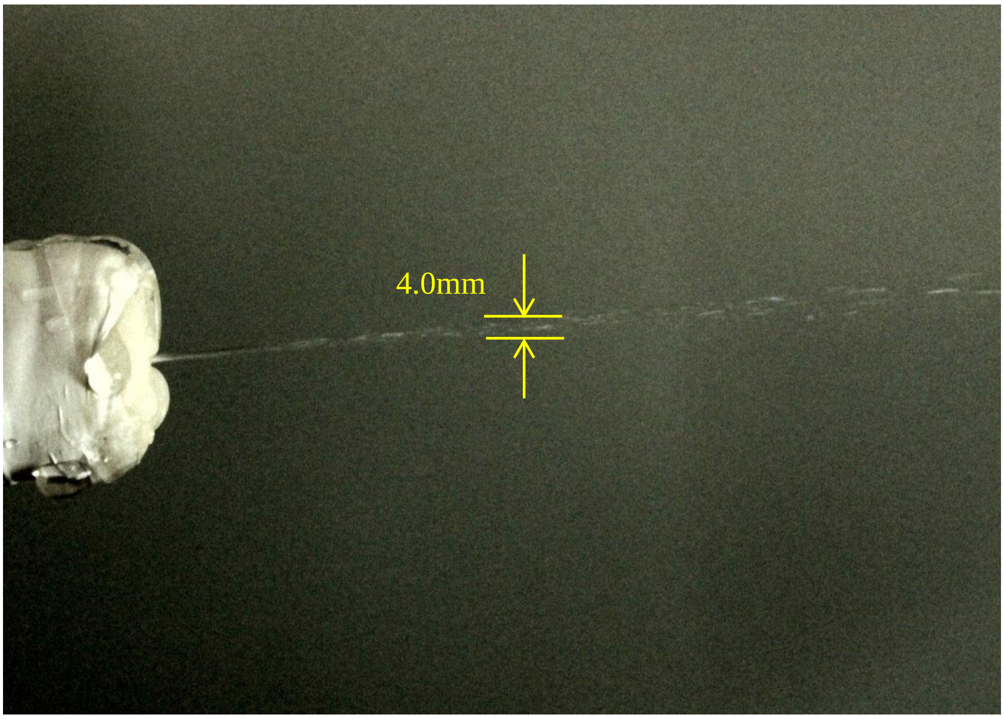


Figure 4.3: Nozzle with designed internal flow D1=0.5mm, P3=2.2bar

Diameter = 1.0mm, Pressure = 1.4bar

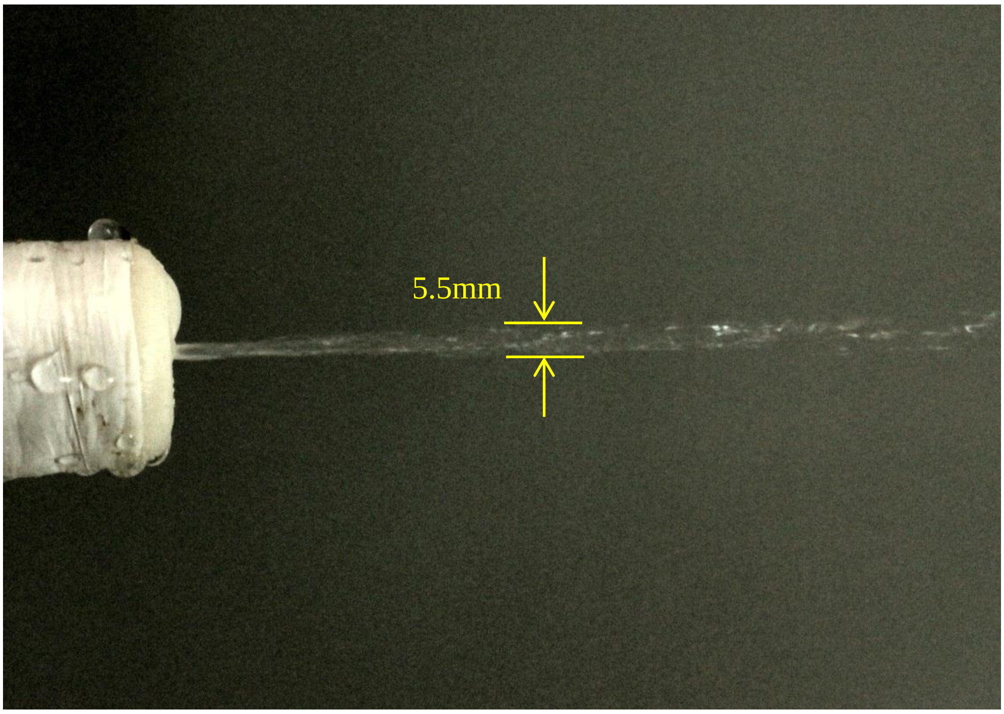


Figure 4.4: Nozzle with designed internal flow D2=1.0mm, P1=1.4bar

Diameter = 1.0mm, Pressure = 1.8bar

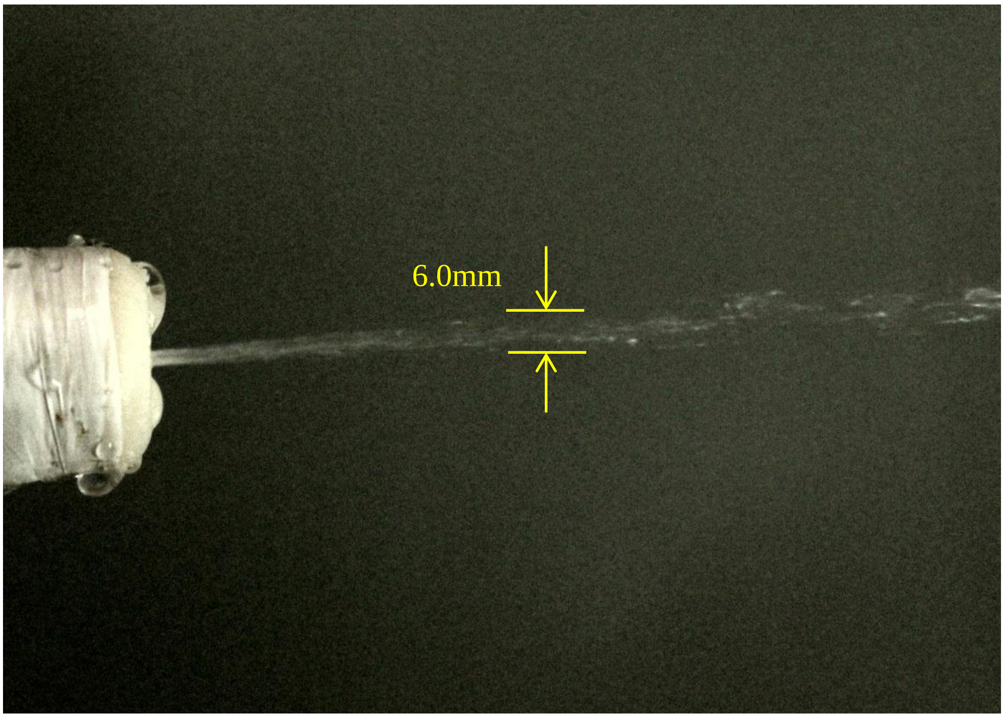


Figure 4.5: Nozzle with designed internal flow D2=1.0mm, P2=1.8bar

Diameter = 1.0mm, Pressure = 2.2bar

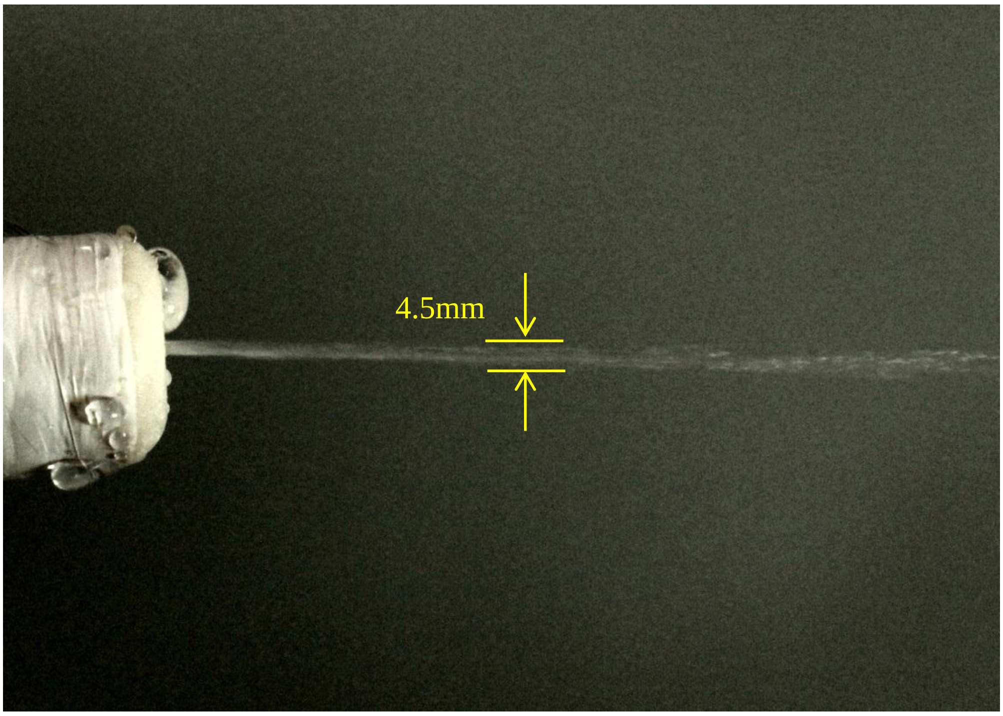


Figure 4.6: Nozzle with designed internal flow D2=1.0mm, P3=2.2bar

Diameter = 1.5mm, Pressure = 1.4bar

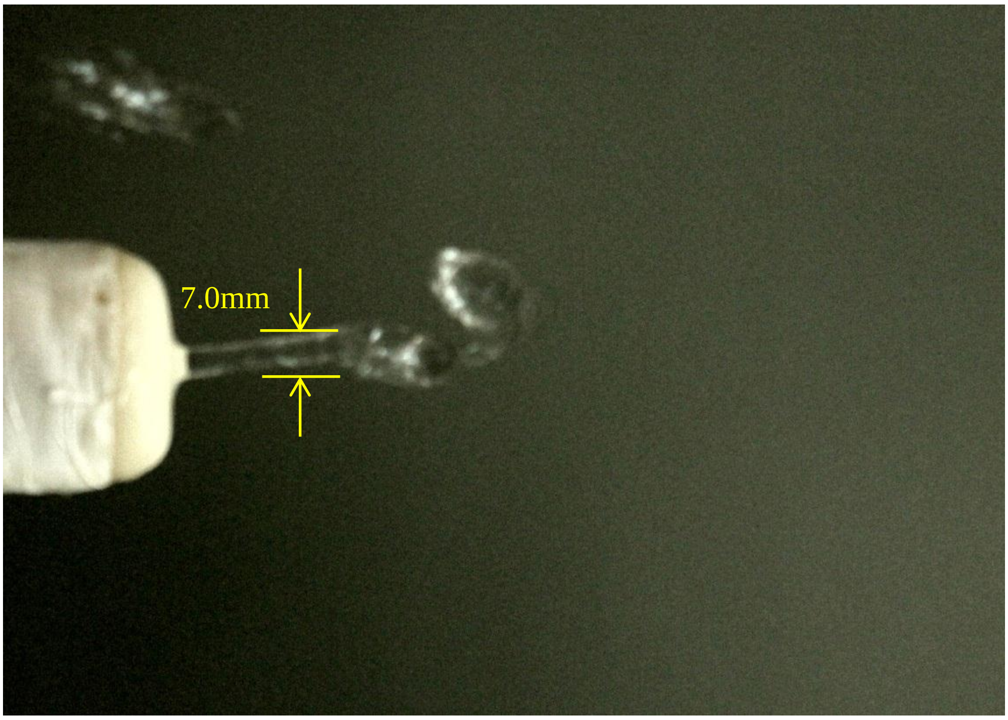


Figure 4.7: Nozzle with designed internal flow D3=1.5mm, P1=1.4bar

Diameter = 1.5mm, Pressure = 1.8bar

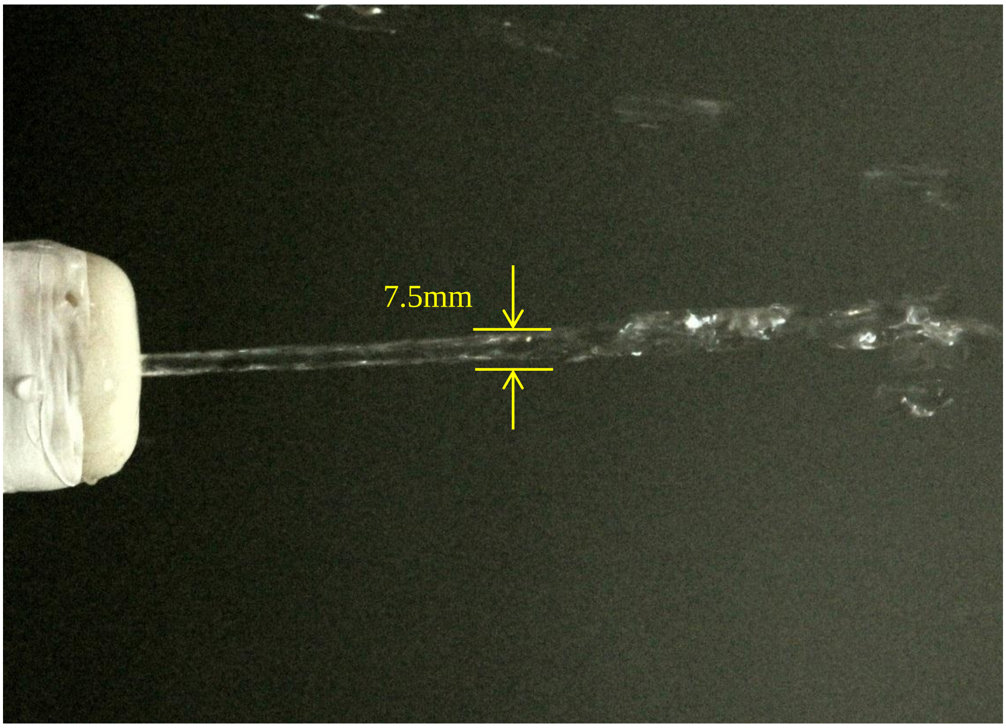


Figure 4.8: Nozzle with designed internal flow D3=1.5mm, P2=1.8bar

Diameter = 1.5mm, Pressure = 2.2bar

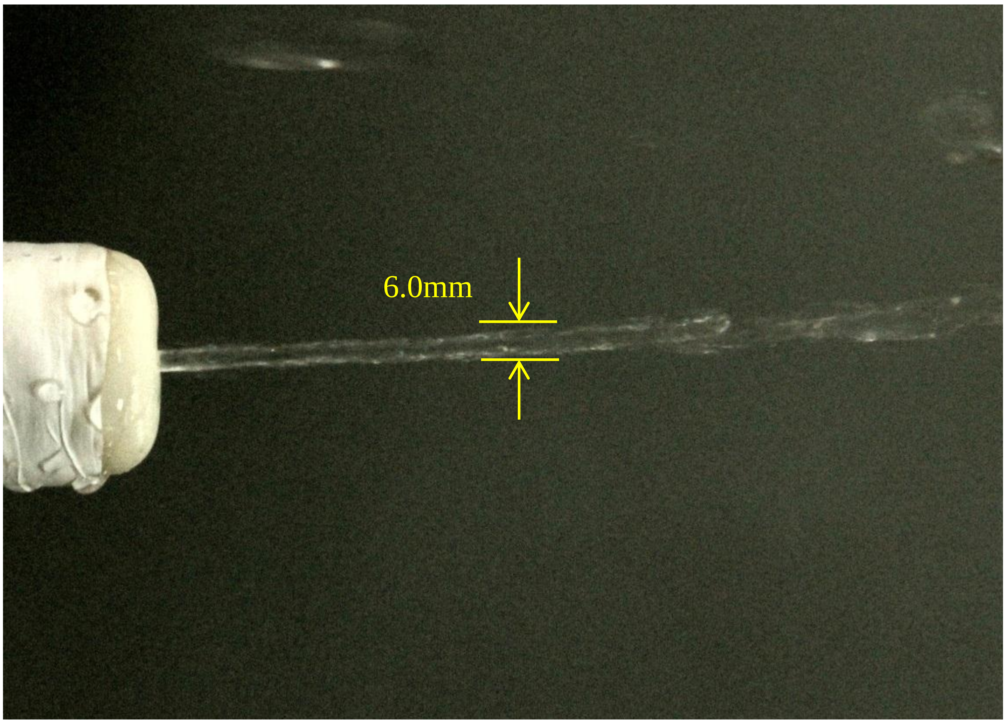


Figure 4.9: Nozzle with designed internal flow D3=1.5mm, P3=2.2bar

Diameter = 0.5mm, Pressure = 2.4bar (same)

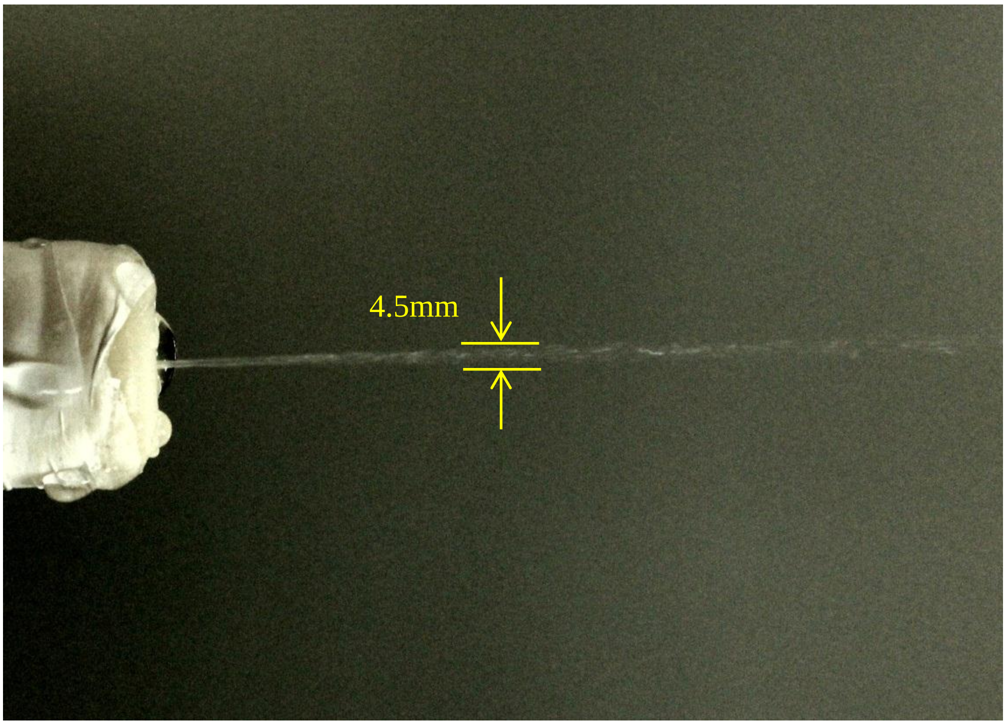


Figure 4.10: Nozzle with designed internal flow D1=0.5mm, P=2.4bar

Diameter = 1.0mm, Pressure = 2.4bar (same)

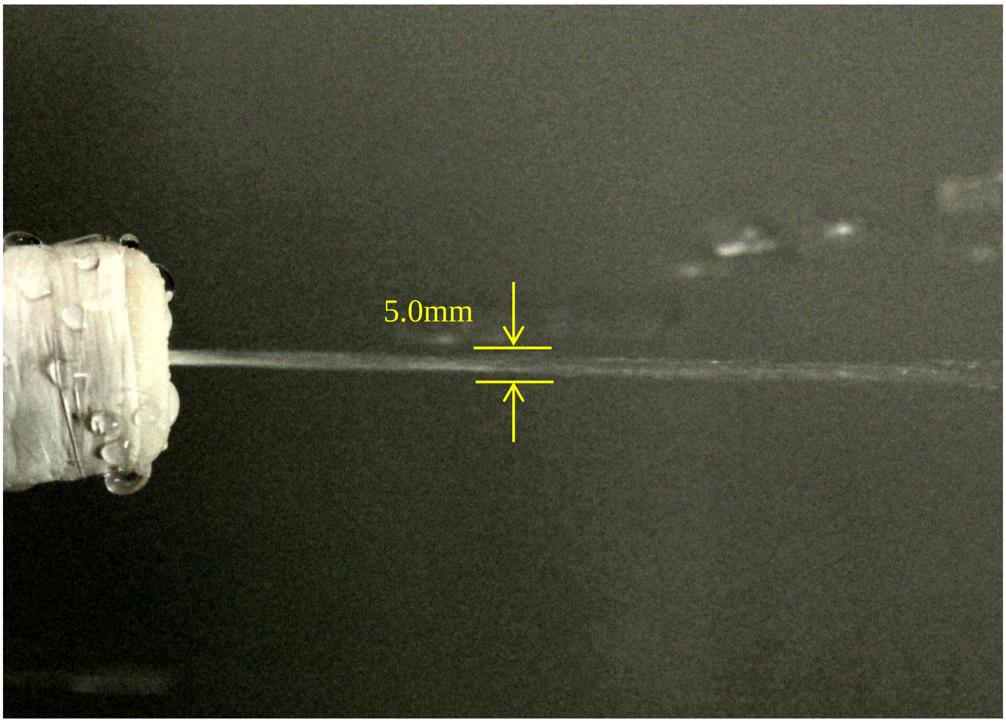


Figure 4.11: Nozzle with designed internal flow D2=1.0.mm, P=2.4bar

Diameter = 1.5mm, Pressure = 2.4bar (same)

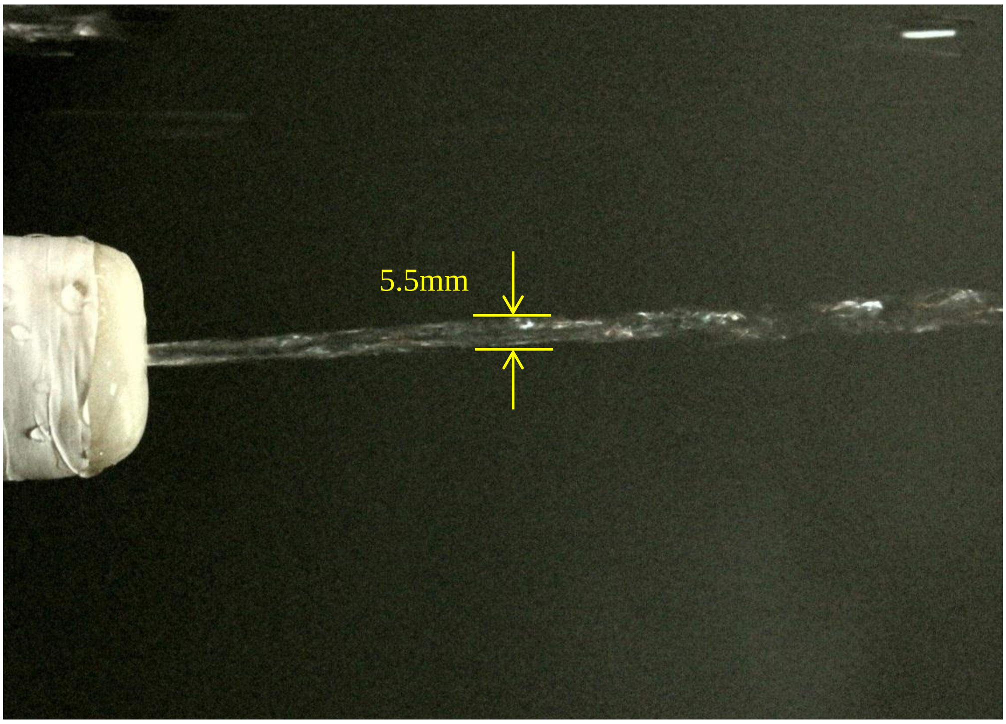


Figure 4.12: Nozzle with designed internal flow D3=1.5mm, P=2.4bar

Table 4.1: Length of mist spread out from the nozzle with designed internal flow with different diameter and different pressure.

PRESSURE	$P_1 = 1.4bar$	$P_2 = 1.8bar$	$P_3 = 2.2bar$
Nozzle 0.5mm	3.5mm	4.0mm	4.0mm
Nozzle 1.0mm	5.5mm	6.0mm	4.5mm
Nozzle 1.5mm	7.0mm	7.5mm	6.0mm

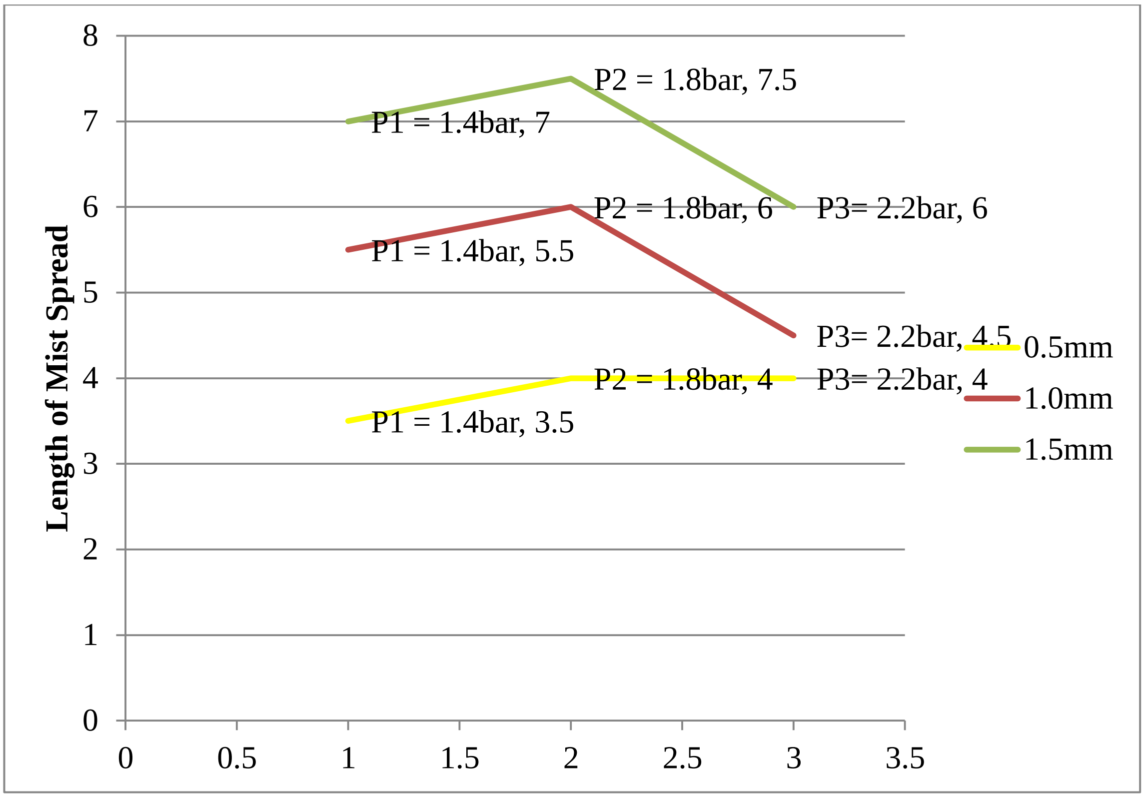


Figure 4.13: Length of mist spread vs. pressure for designed nozzle

The Figure 4.13 show the length of water spread related with the pressure and diameter of the internal flow. The different color lines of length of water mist spread out from the nozzle with different diameter are plotted. When the changing of the pressure, the higher length is obtained and the flow contour also changes. Above graph also shows the different diameter of internal flow, gives different length of water spread out. By this analysis, increasing value of pressure from 1.4bar to 1.8bar will increase length of mist spread out. But increasing pressure from 1.8bar to 2.2bar will decrease the length of mist spread out. From the graph, if the diameter of the internal flow increases, the length of mist spread out increase too. By using different diameter, it will give different length of mist spread out. From the pressure observation, length of mist spread out increase from pressure 1.4bar to 1.8bar and it decrease from 1.8bar to 2.2bar. This is because maybe 1.8bar is the most suitable pressure for nozzle to produce mist from water. For 1.4bar, maybe it to small and water cannot fully spread out. For pressure 2.2bar, it is too big because, maybe it needs to use more high pressure to give mist more spread out from the nozzle. Second observation is from the diameter of internal flow in the nozzle. From the graph, larger diameter will produce the large length of mist spread out. This is because mist flow follows the diameter of the nozzle. If the diameter large, more mist can came out from the nozzle. But from the mist flow pattern, 1.0mm is the most suitable. It is because, mist flow out the nozzle can spread out. Compare with diameter 1.5mm, mist flow pattern cannot spread out. It looks more just list water, not a mist. From the graph, the minimum length of mist spread out is from nozzle diameter 0.5mm at pressure 1.4bar is 3.5mm and the maximum length of water mist spread out is from the nozzle diameter 1.5mm at pressure 1.8bar which is 7.5mm.

Table 4.2: Length of mist spread out from the nozzle with designed internal flow with same pressure and different diameter.

NOZZLE DIAMETER	$D_1 = 0.5mm$	$D_2 = 1.0mm$	$D_3 = 1.5mm$
P = 2.4bar	4.5mm	5.0mm	5.5mm

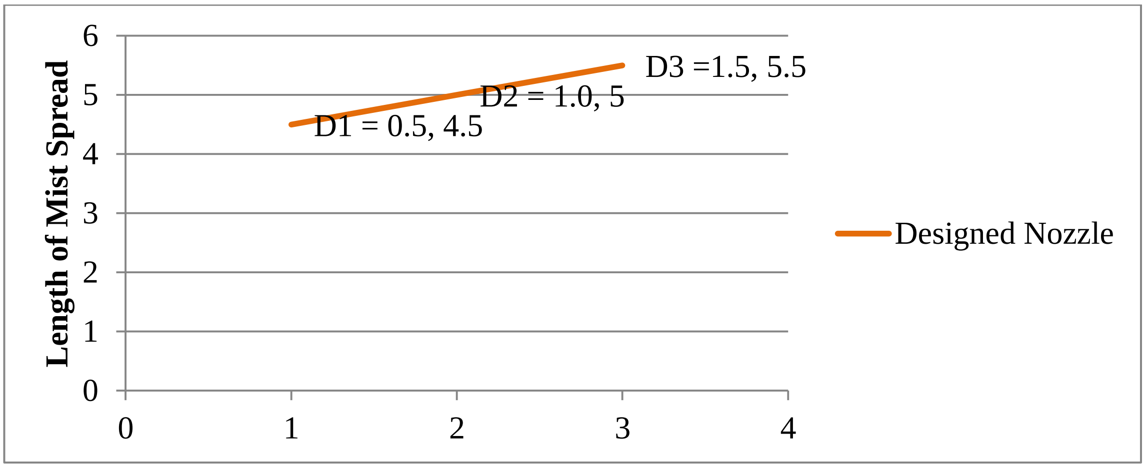


Figure 4.14: Length of mist spread vs. diameter for designed nozzle

Second testing is on same pressure with different diameter of internal flow. The Figure 4.14show the length of mist spread out related with the diameter of the internal flow. The graph of the length with same pressure, 2.4bar and different diameter of internal flow are plotted. When the changing the diameter, the higher length value is obtained. By this analysis, increasing value of diameter will make length of mist spreading out from nozzle increase too. By using same pressure, we can know which diameters are more suitable to use in the nozzle to produce a mist. The minimum length of mist spreading is obtained at diameter 0.5mm and the maximum length is obtained at diameter 1.5mm. From what has been discussion above, the pattern of mist spreading is more important thing. So that, from Figure 4.12 pattern of mist flow from the nozzle diameter 1.5mm is not good compare with pattern on nozzle 1.0mm. The mist from diameter 1.5 is not completely fully spread out.

4.2.2 Nozzle with Normal Internal Flow

After finish on the nozzle with designed internal flow, the nozzle was modifying. The designed internal flow was removed, so that it became normal internal flow. By do the modification, we can see the pattern of mist spread out from the nozzle with same characteristic that want to study.

Diameter = 0.5mm, Pressure = 1.4bar

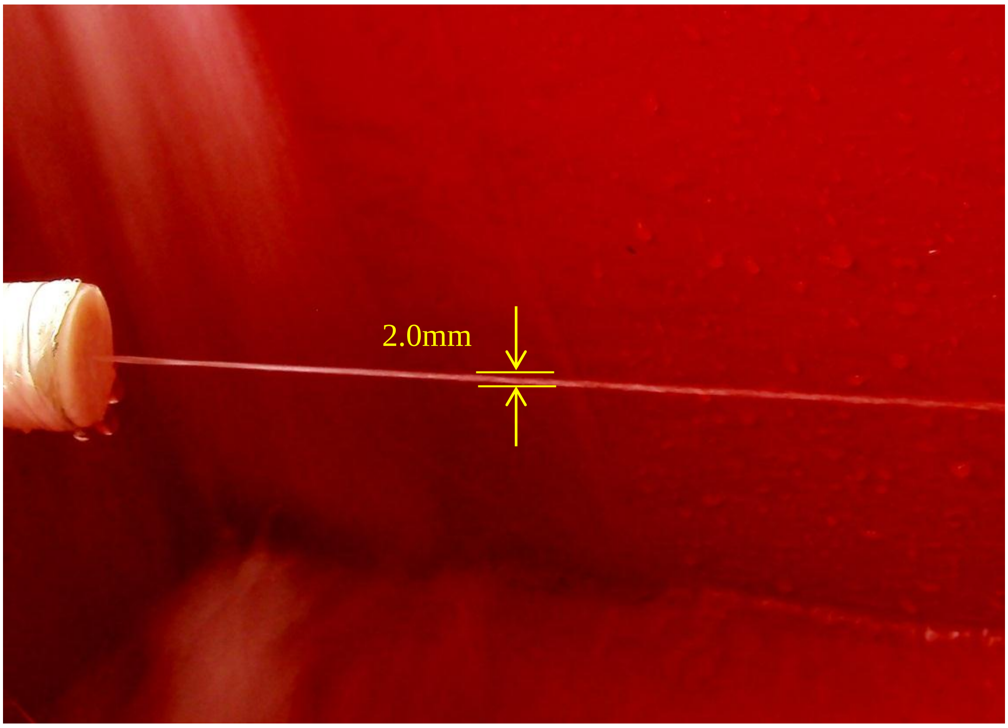


Figure 4.15: Nozzle with normal internal flow D=0.5mm, P1=1.4bar

Diameter = 0.5mm, Pressure = 1.8bar

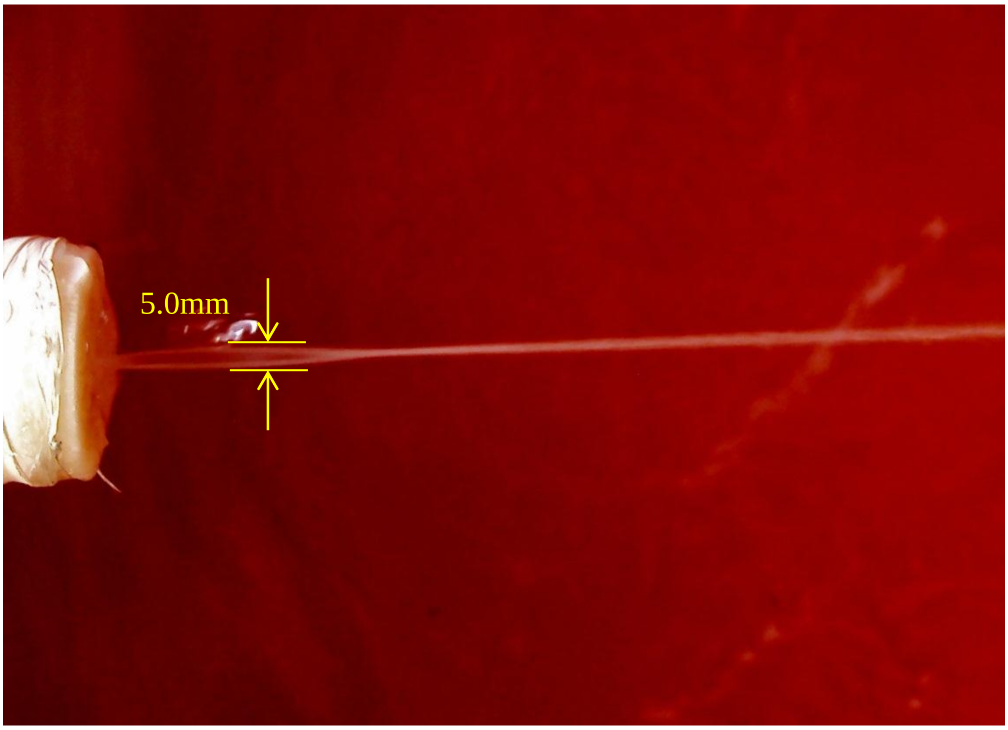


Figure 4.16: Nozzle with normal internal flow D=0.5mm, P2=1.8bar

Diameter = 0.5mm, Pressure = 2.2bar

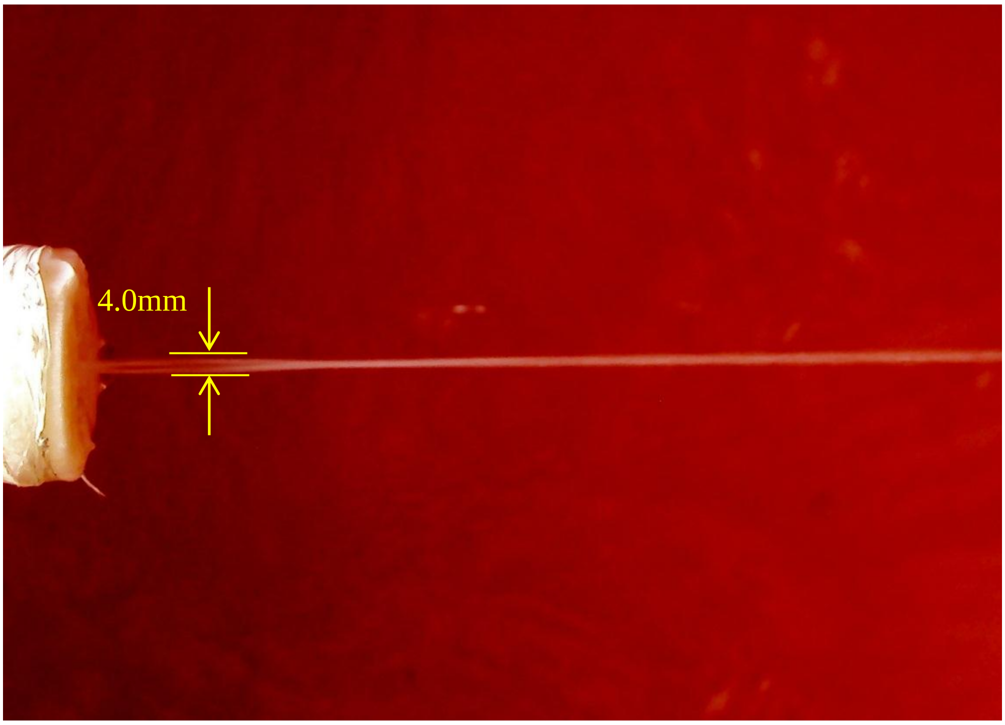


Figure 4.17: Nozzle with normal internal flow D=0.5mm, P3=2.2bar

Diameter = 1.0mm, Pressure = 1.4bar

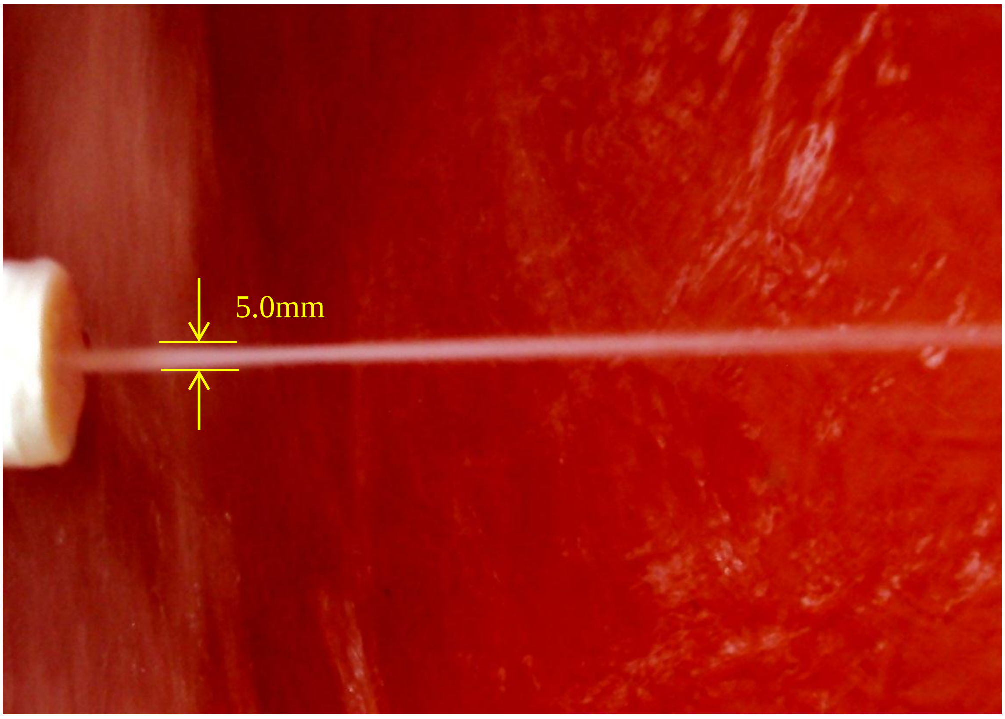


Figure 4.18: Nozzle with normal internal flow D=1.0mm, P1=1.4bar

Diameter = 1.0mm, Pressure = 1.8bar

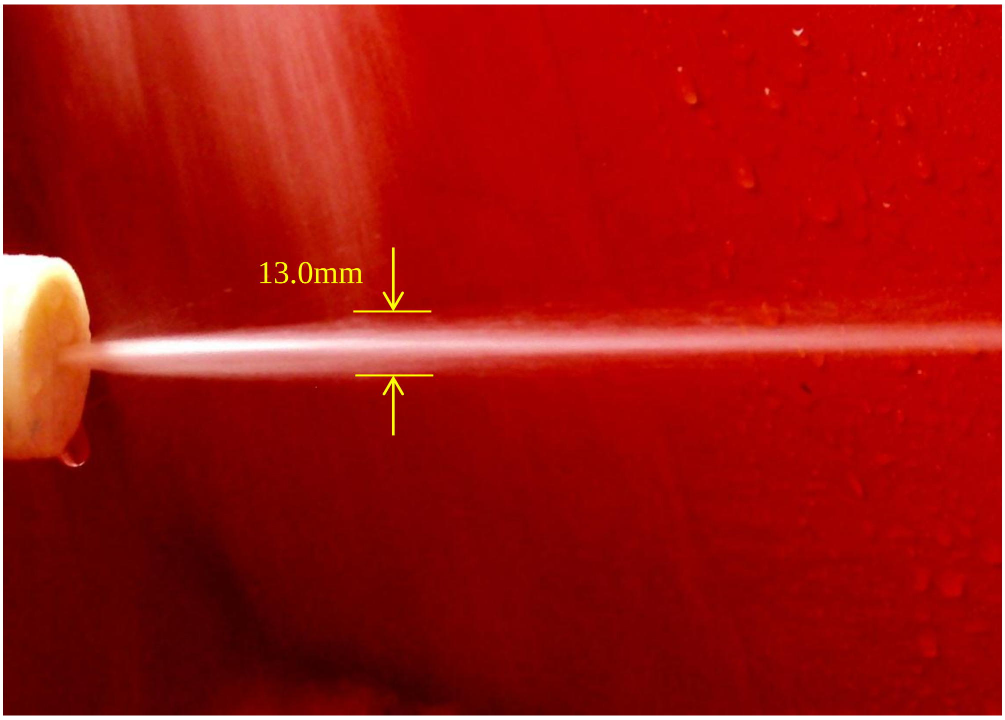


Figure 4.19: Nozzle with normal internal flow D=1.0mm, P2=1.8bar

Diameter = 1.0mm, Pressure = 2.2bar

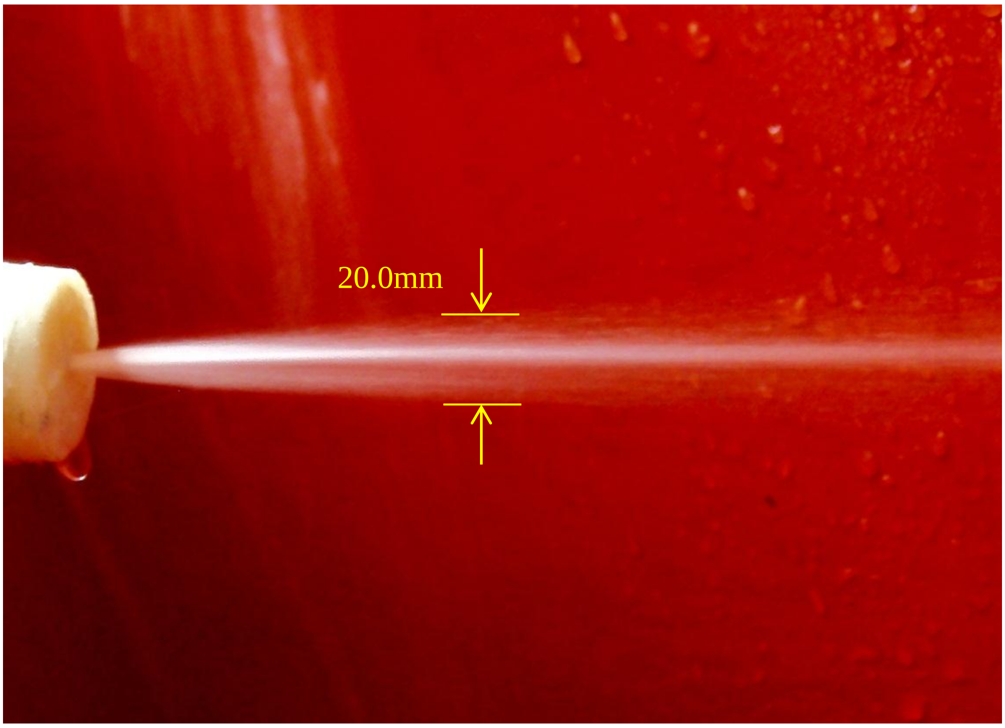


Figure 4.20: Nozzle with normal internal flow D=1.0mm, P3=2.2bar

Diameter = 1.5mm, Pressure = 1.4bar

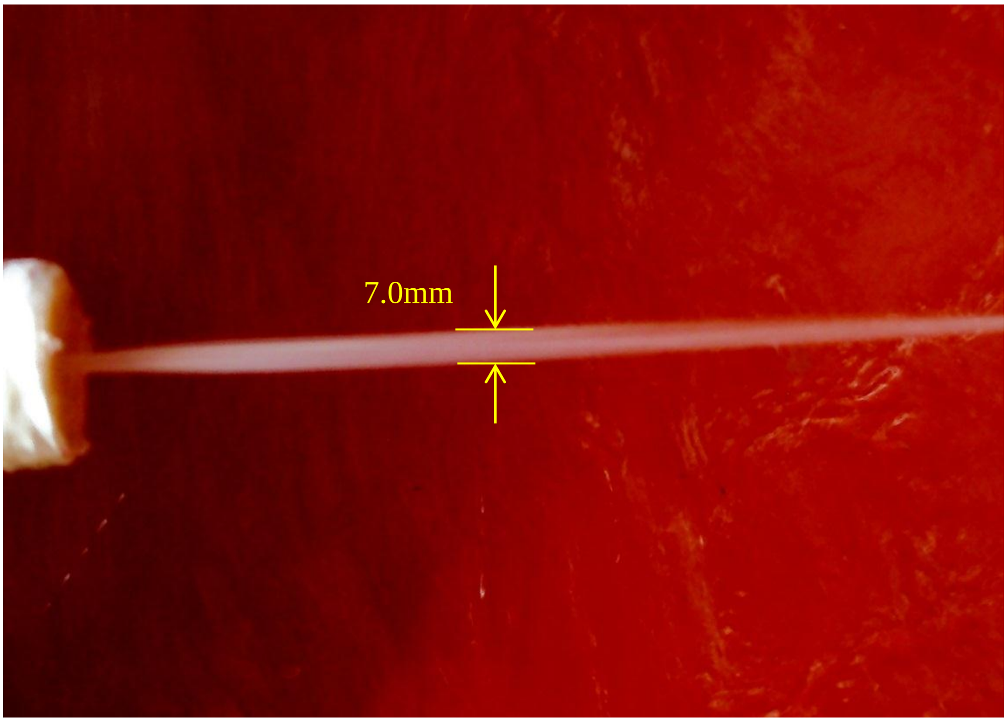


Figure 4.21: Nozzle with normal internal flow D=1.5mm, P1=1.4bar

Diameter = 1.5mm, Pressure = 1.8bar

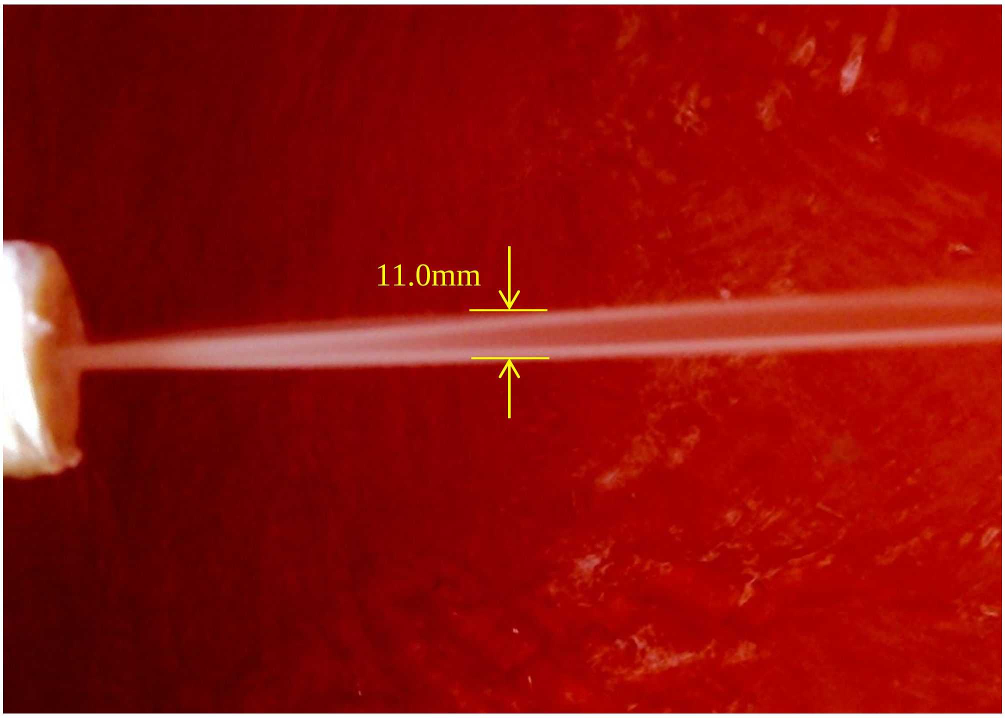


Figure 4.22: Nozzle with normal internal flow D=1.5mm, P2=1.8bar

Diameter = 1.5mm, Pressure = 2.2bar

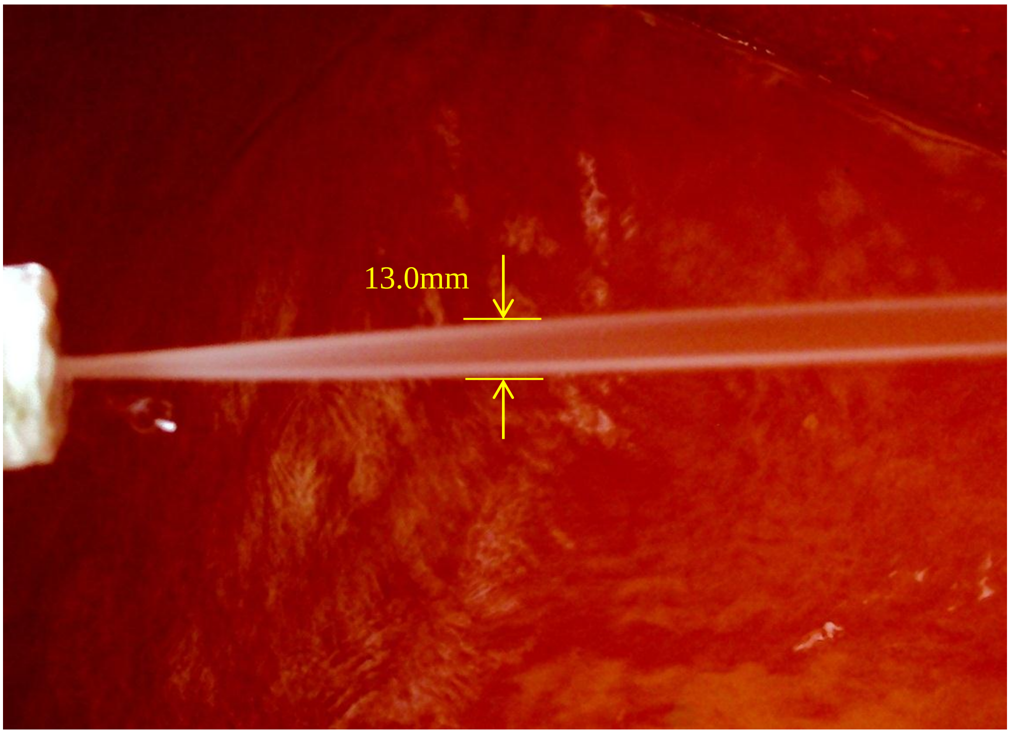


Figure 4.23: Nozzle with normal internal flow D=1.5mm, P3=2.2bar

Diameter = 0.5mm, Pressure = 2.3bar (same)

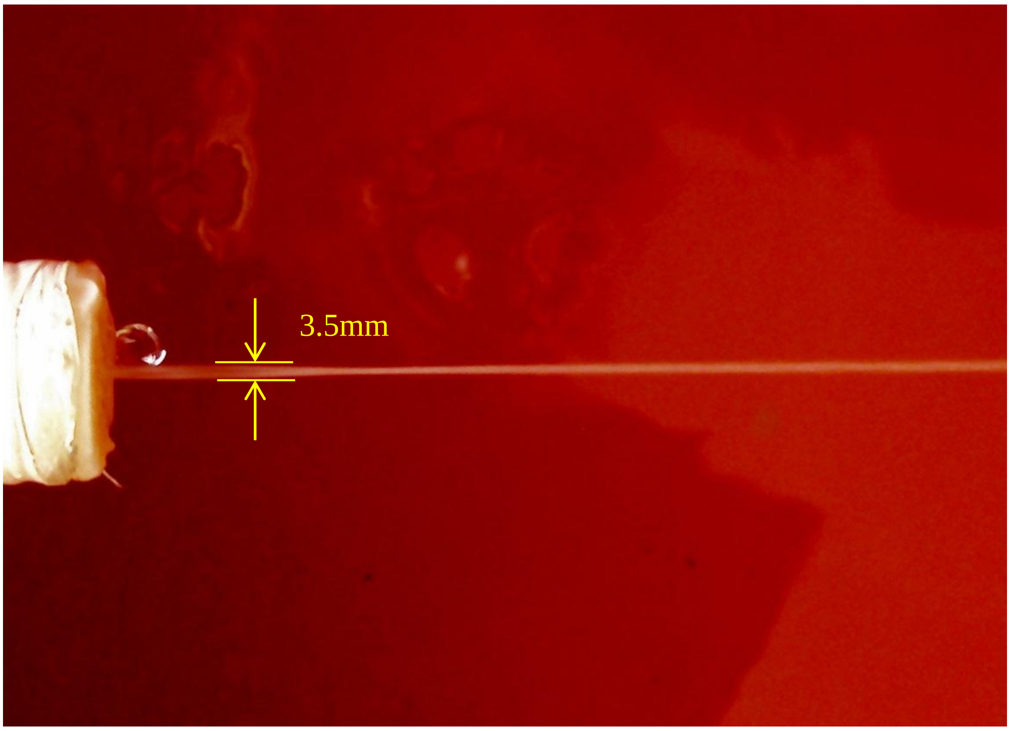


Figure 4.24: Nozzle with normal internal flow D1=0.5mm, P=2.3bar

Diameter = 1.0mm, Pressure = 2.3bar (same)

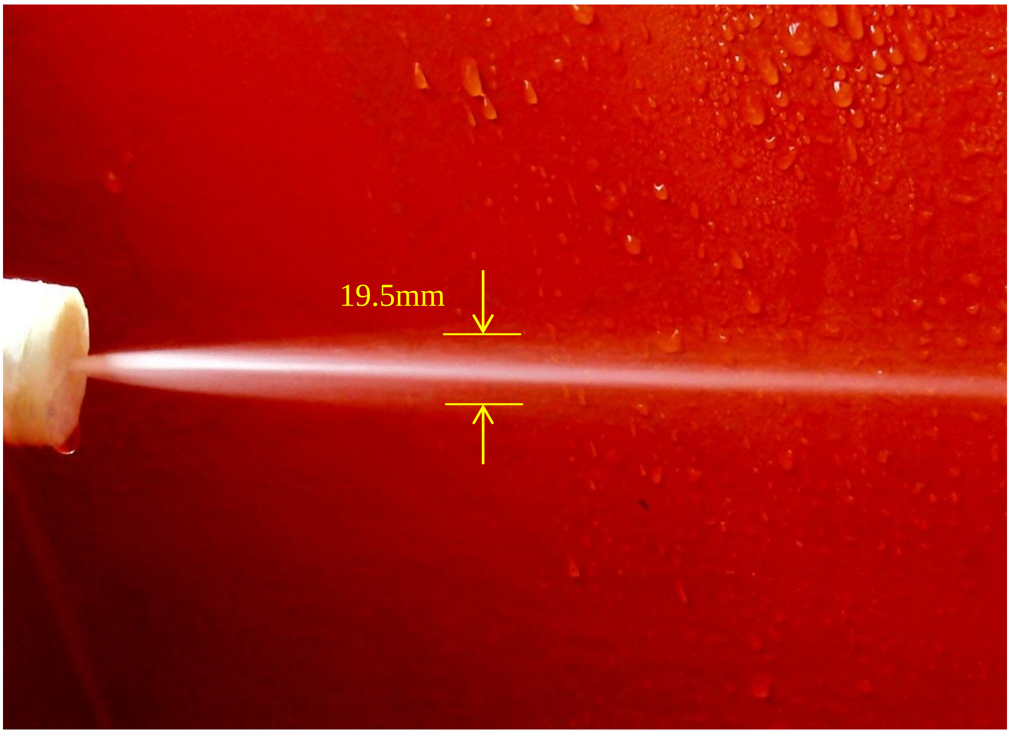


Figure 4.25: Nozzle with normal internal flow D2=1.0mm, P=2.3bar

Diameter = 1.5mm, Pressure = 2.3bar (same)

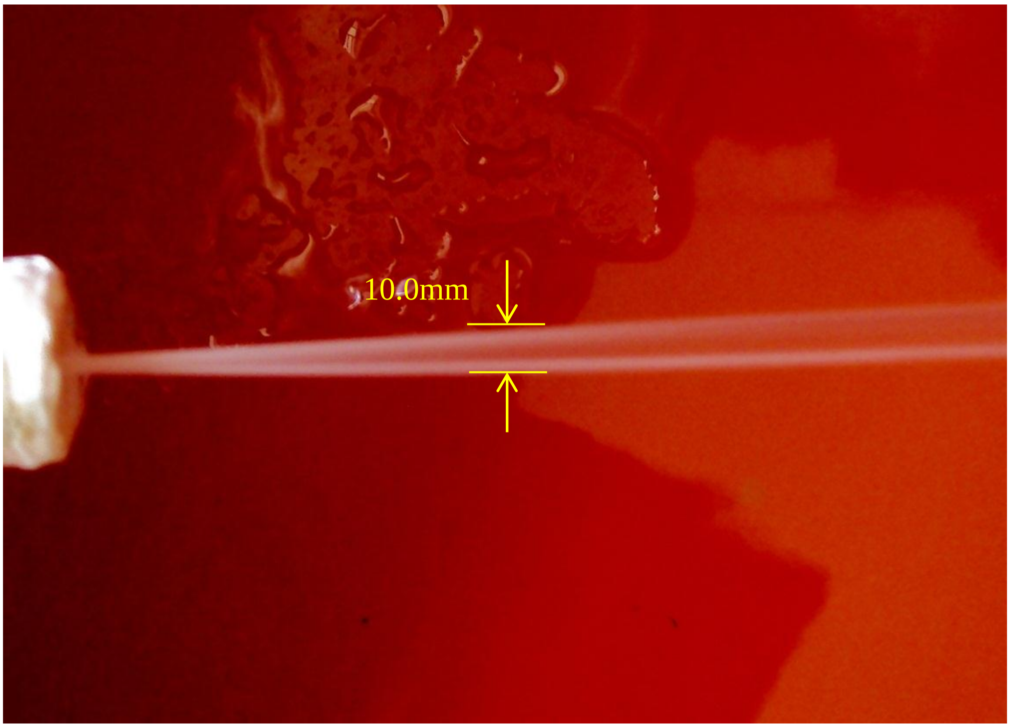


Figure 4.26: Nozzle with normal internal flow D3=1.5mm, P=2.3bar

Table 4.3: Length of mist spread out from the nozzle with normal internal flow with different diameter and different pressure.

PRESSURE	$P_1 = 1.4bar$	$P_2 = 1.8bar$	$P_3 = 2.2bar$
Nozzle 0.5mm	2.0mm	5.0mm	4.0mm
Nozzle 1.0mm	5.0mm	13.0mm	20.0mm
Nozzle 1.5mm	7.0mm	11mm	13.0mm

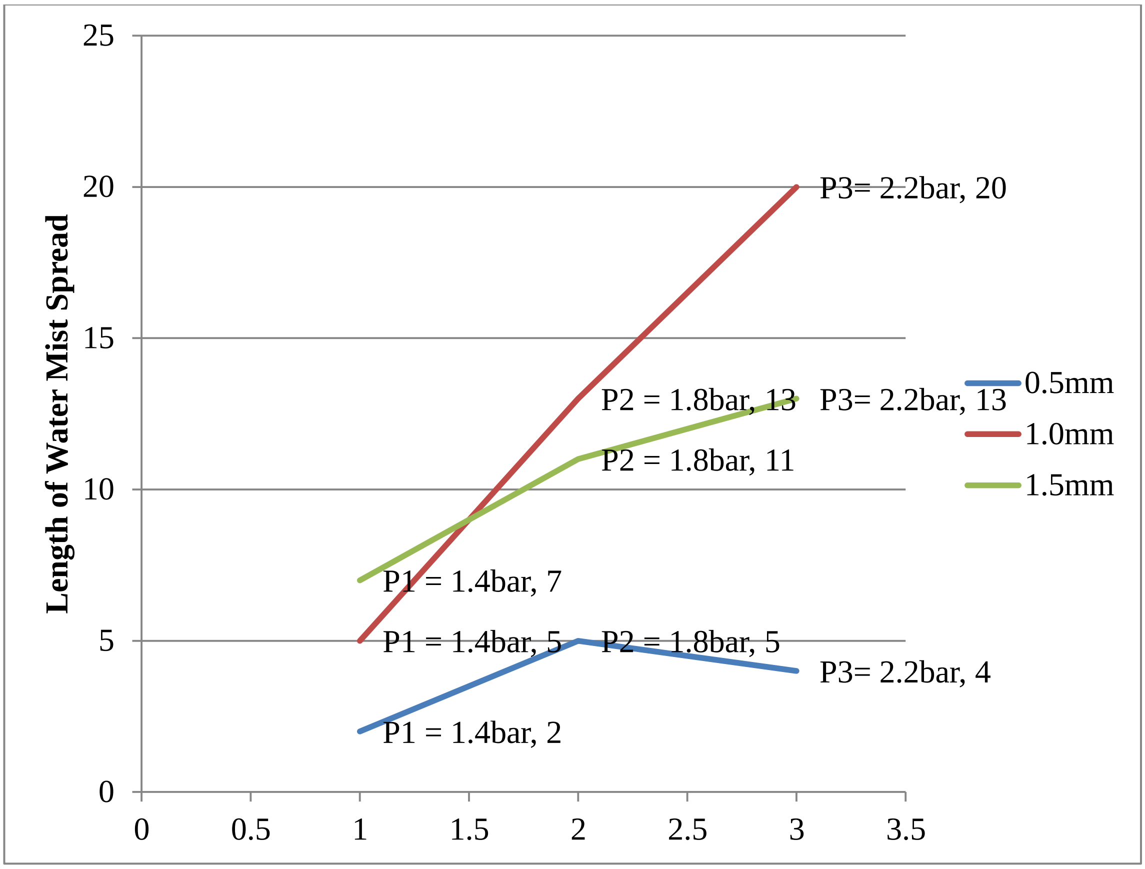


Figure 4.27: Length of mist spread vs. pressure for normal nozzle

The Figure 4.27 show the length of water spread related with the pressure and diameter of the internal flow for the nozzle with normal internal flow. The different color lines of length of water mist spread out from the nozzle with different diameter are plotted. When the changing of the pressure, the higher length is obtained and the flow contour also changes. Above graph also shows the different diameter of internal flow, gives different length of water spread out. By this analysis, increasing value of pressure from 1.4bar to 1.8bar will increase length of mist spread out. But increasing pressure from 1.8bar to 2.2bar will decrease the length of mist spread out. That for nozzle with diameter 0.5mm, for nozzle diameter 1.0mm and 1.5mm it is increase from 1.4bar to 2.2bar. From the graph, if the diameter of the internal flow increases, the length of mist spread out increase too. By using different diameter, it will give different length of mist spread out. From the observation, at pressure 1.4bar diameter 0.5mm is the minimum value for length of mist spread and maximum value of length at diameter 1.5mm. For pressure 1.8bar, minimum still at diameter 0.5mm but the maximum value of length at diameter 1.0mm and it remain to pressure 2.2 bars. This is because, 0.5mm is so small and it cannot fully develop a mist. For diameter 1.5mm, at the low pressure it becomes maximum value length of spread because it actually not fully develops a mist. It became large length because of the diameter is big from the other. We can see from the flow pattern of mist spread out from the nozzle. For overall observation, the minimum length of mist spreading at pressure 1.4bar, diameter 0.5mm is 2mm and the maximum value of length at pressure 2.2bar, diameter 1.0mm which is 20mm.

Table 4.4: Length of mist spread out from the nozzle with normal internal flow with same pressure and different diameter.

NOZZLE DIAMETER	$D_1 = 0.5mm$	$D_2 = 1.0mm$	$D_3 = 1.5mm$
P = 2.3bar	3.5mm	19.5mm	10.0mm

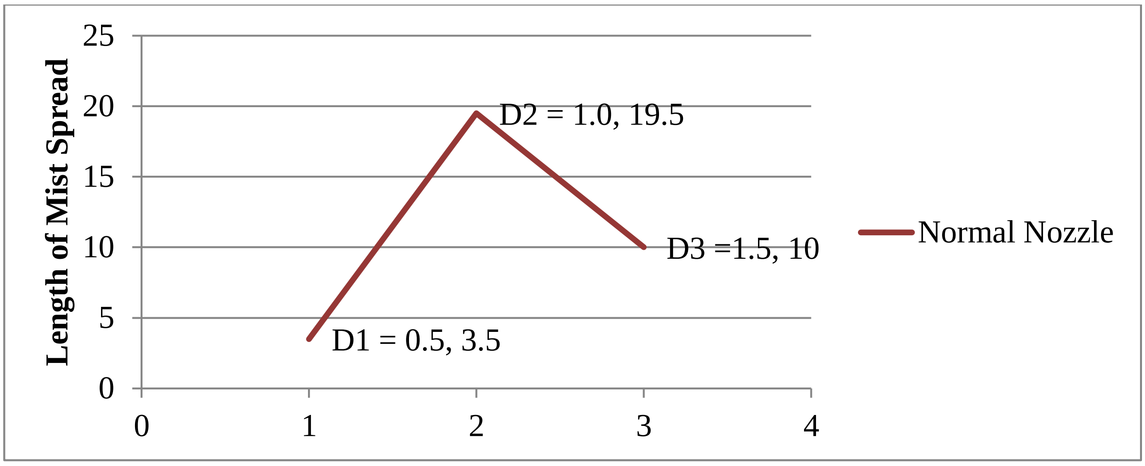


Figure 4.28: Length of mist spread vs. diameter for normal nozzle

Second testing is on same pressure with different diameter of internal flow. The Figure 4.28 show the length of mist spread out related with the diameter of the internal flow. The graph of the length with same pressure, 2.3bar and different diameter of internal flow are plotted. When the changing the diameter, the higher length value is obtained. By this analysis, increasing value of diameter from 0.5mm to 1.0mm will make length of mist spreading out from nozzle increase too. From diameter 1.0mm to 1.5mm, the value length of mist spread out is decrease. By using same pressure, we can know which diameters are more suitable to use in the nozzle to produce a mist. The minimum length of mist spreading is obtained at diameter 0.5mm and the maximum length is obtained at diameter 1.0mm. From what has been discussion above, the pattern of mist spreading is more important thing. So that, from Figure 4.25 pattern of mist flow from the nozzle diameter 1.0mm is a good compare with pattern on nozzle diameter

0.5mm and diameter 1.5mm. The mist from diameter 0.5mm and 1.5mm is not completely fully spread out.

4.3 DISCUSSION

As the pressure of water and diameter of the nozzle internal flow contribution at nozzle, development a new type of nozzle will make a difference in production a mist from water. In producing a mist from water, there is some factor need to be considered. First is the pressure of water. From the analysis that has been done, using a low pressure and high pressure cannot completely can produce a mist from water. From Figure 4.13, pressure of 1.4bar and 2.2bar cannot produce a large value of mist spread out from the nozzle, compare with pressure 1.8bar. All three diameter of the internal flow are same. For pressure 1.4bar to 1.8 bar, value length of mist spread out is increase, then from 1.8bar to 2.2bar the value length decrease. That why, by using a low pressure or high pressure cannot completely produce a mist from water. 1.8bar is more effective pressure for a nozzle in producing a mist from water. Second factor is the diameter of the nozzle internal flow. From the analysis, diameter that has been used is 0.5mm, 1.0mm and 1.5mm. 0.5mm and 1.5mm is not suitable to use in development a nozzle. It is because, from figure normal and designed of mist spread out, 0.5mm and 1.5mm not completely show a good pattern of mist spread out from the nozzle. It because 0.5mm is too small and need very high pressure to push water flow out through that internal flow. For the 1.5mm it is too big, because also need a high pressure to. From the result table, sometimes the value of length is high from the other. It because width of the water, not a spread out mist from the nozzle. For the first test, by using three different pressures and three different diameters, maximum value of length for nozzle with designed internal flow is 7.5mm at pressure 1.8bar, diameter 1.5mm. Maximum value of length for nozzle with normal internal flow is 20mm at pressure 2.2bar, diameter 1.0mm. Second test, is on different diameter but same pressure. For the nozzle with designed internal flow, maximum value of length mist spread out is 5.5mm at diameter 1.5mm. For the nozzle with normal internal flow, maximum value of length is 19.5mm at diameter 1.0mm.

From this experiment, there are several things can be carried out:-

- In development a new product, we have to study all factor that effect the product functioning.

- Different pressure will give different result to the experiment because of the changing mist distribution.

- Different diameter of the internal flow also give different result in the producing a mist.

- The nozzles need to be developing with a right pressure and diameter, so that it can produce a good pattern of mist spread out.

- Development a nozzle using rapid-prototyping machine is not good, because of layer by layer making a product give a very small hole to the product.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In this project, I can learn and get a new experience and skills. For the first one is on fabrication the nozzle. In fabricated the nozzle, I have to explore solid work software to designed the nozzle. After designed the nozzle, I able to used rapid prototyping machine, that is FORTUS 360mc/400mc. I can know how the machine runs in producing a product. Before this, thought that after fabricating product using rapid prototyping machine, we used the product right away. What have I learn, this machine have two bay material which are support and product material. For the nozzle, I make a very small hole in the middle. So, to build it needs the support material. And the support material needs to remove from the nozzle before I used the nozzle. To remove the support material, we need to put the nozzle in ultra-sonic machine. The nozzle must immersion with the liquid work. By using the ultra-sonic machine, all support material will remove from the nozzle. Then the nozzle is ready to test. Second, I also learn how to use hydraulic shear machine. This machine needs to put some command like length that want to cut, what kind of material and the thickness. By doing this project, I also can learn certain instrument that used to test the nozzle.

Develop a new product can give better in human life. All products that have been produce, full fill the human need. With create or make a new item can save time and reduce the burden of human. From what we can see, bottle to keep water, plastic bags, card holders, and many more. To develop a new thing, all research has been doing the important of the product. This project title is development of new type of nozzle of a water mist system. There is some purpose of the nozzle such as, for rapid cooling system, fire extinguisher, for plant watering device, device to cool areas such as room and many more. Firstly is to produce test-rig for the piping system. To run the experiment on the nozzle, there must have the piping system to make water flow. There also have wasted pipe in the system so that can avoid loses in the pipe.

By using different water pressure and different diameter of the nozzle internal flow, the result will show with condition is the best to get a good pattern of spread out mist. From the result, it is shown an improvement by using exact pressure and exact diameter to the pattern of spread out mist.

This project was started by fabricate the nozzle using rapid-prototyping machine. The model of nozzle was designed using solid work. Then fabricate it using FORTUS 360mc/400mc. The material is ABS-M30. The purpose was to study whether rapid-prototyping machine can or cannot produce a product that need to used high pressure of water. After run the experiment, there is one problem at the nozzle, which is water has been come out around the nozzle with high pressure. This is because, the rapid-prototyping machine was fabricating a product layer by layer. Maybe it not melts enough to do the next layer so it leaves small space. Using a high pressure can make water flow out through that space.

5.1 FUTURE RESEARCH RECOMMENDATION

As for future researches, the pressures of water need to focus at 1.8bar only. Also for the diameter of the nozzle internal flow, just do the research on 0.8mm to 1.2mm only. For design of the internal flow also need to be determined because it also can influent the characteristic of the mist flow pattern. Some other recommendation can be carried out:-

- Cannot use the rapid-prototyping machine to fabricate the nozzle, in spite of that should use solid plastic or solid metal.

- For the piping system also need to be change to small diameter pipe. It is because, to avoid big loss in the pipe where the water need to flow nozzle which just a small diameter.

- Determined the design of nozzle also influent the characteristic of mist flow pattern.

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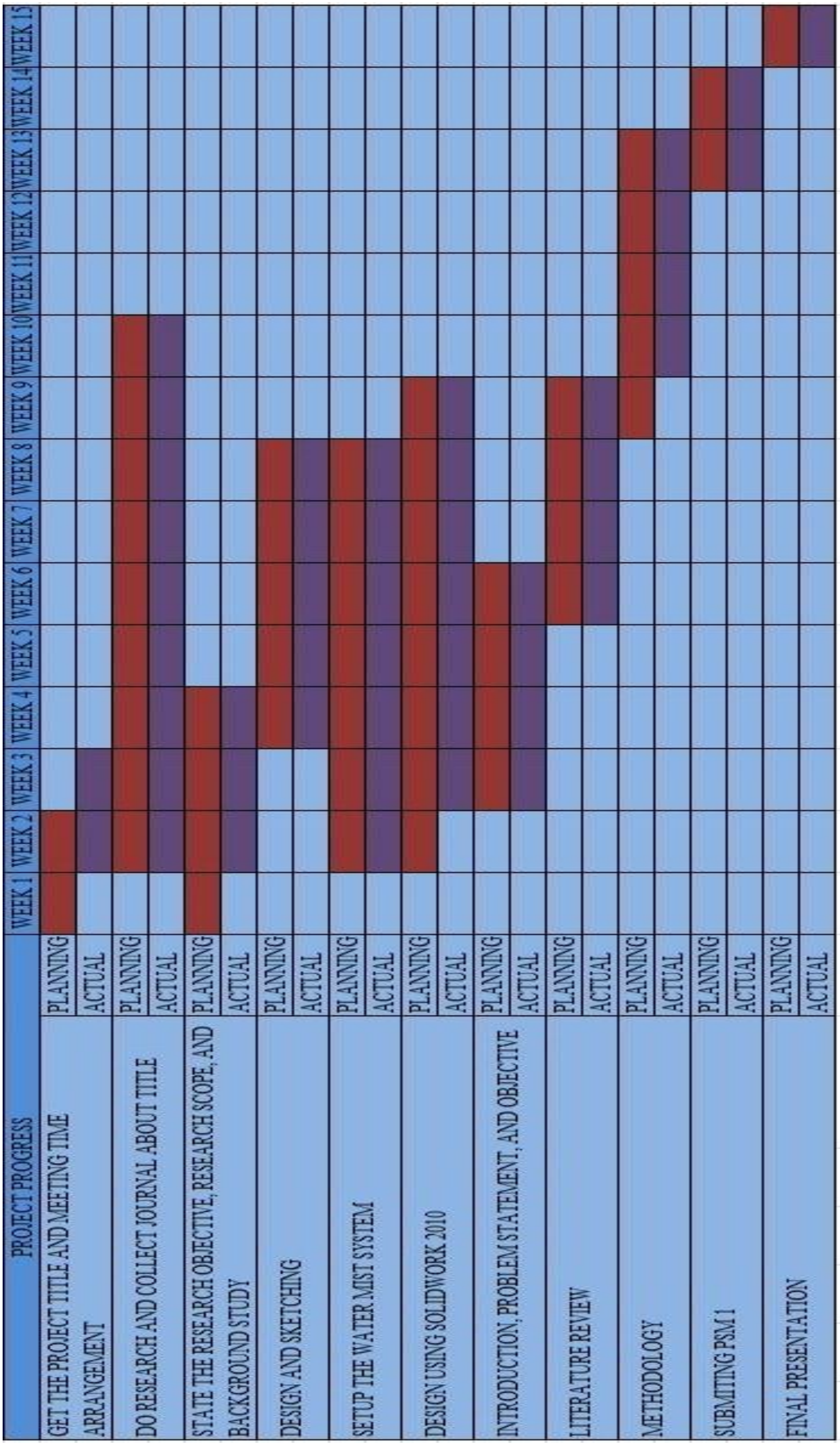
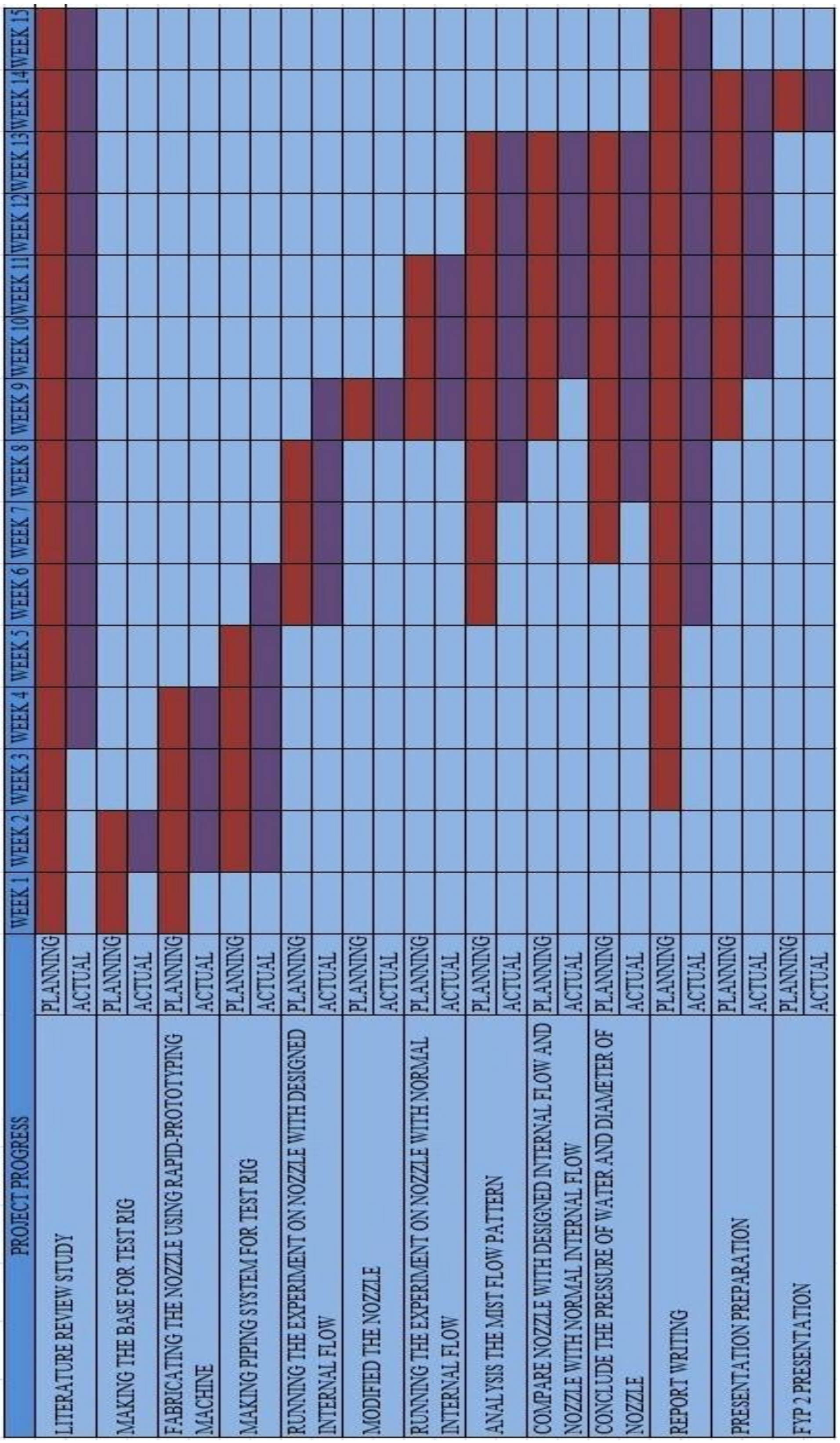
APPENDIX A1

GANTT CHART FOR FINAL YEAR PROJECT 1



APPENDIX A2

GANTT CHART FOR FINAL YEAR PROJECT 2



APPENDIX B1

SPRAY NOZZLE BROCHURE (SOLID CONE TYPE)

NOZZLE TECHNOLOGY

INTRODUCTION

This page gives a basic introduction to nozzle technology. To help you make the best use of Delavan products and services we have produced a full 16 page guide to spray nozzle technology. This is available on our web site or on CD-rom and is designed to take you through the fundamentals of spray technology step by step.

TYPES OF NOZZLE

In addition there are variations on these sprays for specific applications. Please refer to the Application Guide section on our web site or CD-rom. These are:-

- **a) Flat sprays**
- **b) Hollow cone sprays**
- **c) Solid cone sprays**
- **d) Air atomising sprays**

In addition there are variations on these sprays for specific applications. Refer to the Application Guide section.

Delavan produces a vast range of spray nozzles with many variations on each basic type. Your choice of nozzle will depend on several key factors. These are:

1. *Flow rate (capacity)*
2. *Operating pressure*
3. *Spray pattern*
4. *Spray angle*
5. *Liquid to be sprayed*
6. *Quality of atomisation*
7. *Material of manufacture*

To help you with your choice of spray nozzle, each of the above key factors is discussed in detail on our website.

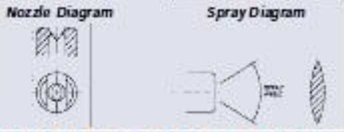
www.delavan.com

A SELECTION OF TYPICAL SPRAY PATTERNS

FLAT SPRAY

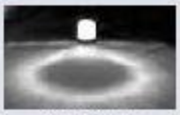
An elliptical orifice formed by the intersection of a 'V' groove with a hemispherical cavity.

Nozzle Diagram **Spray Diagram**



HOLLOW CONE

A circular exit orifice which is preceded by a swirl chamber with a tangential inlet.

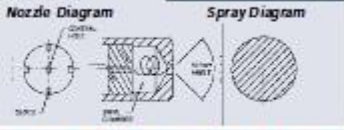


Nozzle Diagram **Spray Diagram**

SOLID CONE

A circular exit orifice which is preceded by a swirl chamber with a multi-slotted in-line distributor and central line.

Nozzle Diagram **Spray Diagram**



AIR ATOMISING

These are produced by using air as the atomising agent and sprays are generally of the external (siphon or pressure) and internal (pressure) mix design.

Spray Diagram

NOZZLE RANGE & INDEX

The following two pages give a brief overview of all the Delavan Industrial spray nozzles and accessories The products highlighted in blue are illustrated further in the brochure on the pages indicated.

Information on all our products can be found on our website at **www.delavan.com** , or alternatively you can request a copy of our CD-rom. Don't forget WE ARE HERE TO HELP – If you need more detailed information or advice then Delavan personnel are always available to answer your questions.

FLAT SPRAY NOZZLES

	Nozzle Type	Spray Angles	Basic Description
FLAT SPRAY	AC/WF	0° – 90°	1/8"- 1" Male BSPT thread. 1/4" and 3/8" Female BSPP thread
	CAC	0° – 90°	1/16" NPT 1/8" to 3/4" BSPP Male thread. More compact than AC type.
	ACS	0° – 90°	1/8" and 1/4" Male BSPT thread. Supplied with optional strainer
	LF	0° – 110°	Flanged tip design for use with standard threaded bodies and caps.
	LA	0° – 90°	Large flanged tip design for use with threaded/welded bodies and cap
	LC	0° – 110°	Robust flanged tip design for use with standard threaded bodies and caps.
	LE	80°	Flanged tip design for use with standard threaded bodies and caps.
	LX	70° offset	Flanged tip design for use with standard threaded bodies and caps.
	WJ	70° offset	1/8"- 1" Male BSPT thread.
	LK	15° – 90°	Flanged tip design for use with standard threaded bodies and caps. ceramic orifice insert.
	LD	0° – 90°	Flanged tip design with dovetail connection. Uses special bodies for positive alignment
	AD	0° – 90°	Flanged tip design with dovetail connection. Uses special bodies for positive alignment
	ED	45° – 90°	Flat disc with 1/8" UNF thread for direct fitting into pipe walls.
	EF	45° – 90°	Flat disc as ED. but for use with standard bodies and caps.
	D	90° – 140°	Flanged tip design for use with standard threaded bodies and caps.
	AN/F	90° – 140°	1/8"- 1" Male BSPT thread.
	TJ/SJ	25° – 50°	1/4"- 1/2" Male BSPT thread.
SPECIAL PURPOSE	Blow-off	55° – 100°	Flanged tip design for use with standard threaded bodies and caps.
	SL	80° – 115°	Flanged tip design for use with standard threaded bodies and caps.
	DJ	80° – 115°	1/4"- 1/2" Male BSPT thread.

	Nozzle Type	Spray Angles	Basic Description
HIGH PRESSURE	AZ	0° – 50°	1/8"-1/4" Male BSPT thread.
	BZ	30°	1/8"-1/2" Male BSPT thread.
	343	25° and 32°	3/8" Male NPT thread.
	344	25° and 32°	3/8" Male NPT thread.
	DD	25° and 32°	3/4" and 1" Male NPT thread and welding bodies Dovetail connection for positive alignment of orifice.
	AQ	25° – 95°	1/4" Male BSPT thread. Tungston Carbide orifice insert
	LQ	25° – 95°	Flanged tip design with dovetail connection. Uses special bodies for positive alignment.
	DQ	25° and 32°	3/4" and 1" Male NPT thread and welding bodies. Dovetail connection for positive alignment of orifice. Tungston Carbide orifice insert
	DE	25° and 32°	3/4" and 1" Male NPT thread. Unique connection for positive alignment of orifice. Tungston Carbide orifice insert.

HOLLOW CONE NOZZLES

	Nozzle Type	Spray Angles	Basic Description
HOLLOW CONE	WM	40°,60°,80°	1/4" BSPT Male thread.
	WG	60°,80°	Flanged tip design for use with standard bodies and caps.
	WA	60°,80°	7/16" UNEF thread for use with special Male and Female BSP threaded adaptors.
	WDA	30°,45°,60°,70°,80°,90°	7/16" UNEF thread for use with special Male and Female BSP threaded adaptors.
	HB/HC	70°	Flanged tip design for use with standard bodies and caps.
	BJ	44° – 98°	1/8"-1" BSPT Male and BSPP Female threads.
	DC	20° – 110°	Two piece nozzle design for use with standard bodies and caps.
	AG	65° – 75°	1/8"-3/4" BSPT Male thread.
	AH	100° – 115°	3/8"-3/4" BSPT Male thread.
	WS	75°	1/8"-3/4" NPT Male and Female threads.
	CBJ	44° – 98°	1/8"-1" BSPP Male threads. More compact than BJ type.
	PJ	90°,120°,150°,180°,210°	1/4"-3/4" BSPT Male threads.
	AE	70° – 90°	1/8"-1" BSPT Male and BSPP Female threads.
	AF	100° – 120°	1/8"-1" BSPT Male and BSPP Female threads.
	WR	45° – 155°	3/8" NPT Male and Female threads.
	WRW	110° – 140°	1/4" and 3/4" NPT Male threads.
	RA	120° – 140°	1/4" and 3/4" NPT Male threads.
	BE	55° – 90°	1 1/2"-4" BSPT Female threads.
	WRA-WRS	50° – 100°	1 1/2" BSPT Male thread or Quick Coupler Adaptor connection.
	WRA-RD WRS-RD	100° – 135°	1 1/2" BSPT Male thread or Quick Coupler Adaptor connection.

NOZZLE RANGE & INDEX

SOLID CONE NOZZLES

	Nozzle Type	Spray Angles	Basic Description
SOLID CONE	**WDB**	30°,45°,60°,70°,80°,90°	3/16" UNEF thread for use with special Male and Female BSP threaded adaptors.
	BL	45°,60°,90°	1/8" BSPT Male thread.
	BP	45°,60°,90°	1/8" BSPT Male thread.
	WL	45°,60°,90°	Flanged tip design for use with standard bodies and caps.
	BF	30°,60°,90°,120°	Flanged tip design for use with standard bodies and caps.
	BI	35° – 100°	1/8"-1" BSPT Male and BSPP Female threads.
	BN	85° – 130°	1/8"-1" BSPT Male and BSPP Female threads.
	CT	45° – 90°	1/8"-1/2" NPT Male and Female threads.
	CU	45° – 80°	1/4"-3/8" NPT Male threads.
	BK	20° – 105°	1/8"-1" BSPT Male and BSPP Female threads.
	CJM	30°	1/8"-2" BSPT Male threads.
	CJF	30°	1/8"-1" BSPP Female and 1¼"-4" BSPT Female threads.
	CM	45° – 110°	1¼"-8" BSPT Female threads.
	BY	70° – 130°	1¼"-3" BSPT Female threads.
	CA	45° – 98°	1"-4" BSPT Female threads.
	CB	45° – 96°	1"-3" NB welded connection.
	BC	50°,65°,80°,90°,120°	3/8" BSPP Female thread.
	BX	50°,65°,80°,90°,120°	3/8" BSPP Female thread.
	BQ	35° – 100°	1/8"-1" BSPT Male and BSPP Female threads.
	BT	85° – 130°	1/8"-1" BSPT Male and BSPP Female threads.
	CU/SQ	60° – 65°	1/4"-1/2" NPT Male threads.
	CBI	35° – 100°	1/8"-1" BSPP Male threads. More compact than BI type.
	CBN	85° – 130°	1/8"-1" BSPP Male threads. More compact than BN type.
	CBQ	35° – 100°	1/8"-1" BSPP Male threads. More compact than BQ type.
	CBT	85° – 130°	1/8"-1" BSPP Male threads. More compact than BT type.
	RBI	35° – 100°	1/8"-1" BSPT Male and BSPP Female threads. Right angle design.
	RBN	85° – 130°	1/8"-1" BSPT Male and BSPP Female threads. Right angle design.
	NBI	41° – 100°	1/8"-1" BSPT Male and BSPP Female threads. Right angle design.
	NBN	110° – 120°	1/8"-1" BSPT Male and BSPP Female threads. Right angle design.
	QFQN/ QQ/QT	42° – 120°	Quick attach connection to 1¼" and 1½" NB eyelets.

ACCESSORIES

	Item Type	Basic Description
ACCESSORIES	**NOZZLE BODIES**	1/8"-3/8" BSPT Male and BSPP Female threads for use with flanged and dovetail type nozzles.
	NOZZLE CAPS	3/8" BSPP and 11/16"-16 UN threaded for use with the above bodies.
	SWIVELS	1/8"-1/4" NPT Female and 1/4" NPT Male inlets with outlet for above caps with flanged type nozzles.
	EYELETS BODIES	1/2"-1½" N.B. Eyelets with various outlet connections for nozzles.
	TIP FILTERS	Flanged filters with various mesh sizes for use with the above.
	T-LINE STRAINERS	1/2"-1½" T Line Strainers with various mesh sizes. Polypropylene & Nylon.
	PRV'S	Pressure relieve vlves upto 700 PSIG (48 Bar). Brass & Nylon.
	BALL VALVE	1/2"-3" in Polyglass.
	HIGH PRESSURE SPRAY GUNS	Various high pressure handguns, lances and accessories.
	ADJUSTABLE JOINTS	1/8"-1" Male/Female adjustable joint with various angles of inclination.
	HNS - HEADER NOZZLE SOCKETS	1/8"-1" BSPP Female threaded sockets for use with threaded nozzles.
	ADAPTORS	1/8"-1" BSPT Male and BSPP Female x 90° adaptor for use with threaded nozzles.
	PIPE SUPPORT CLIPS & CLAMPS	Clips 1¼" and 1½". Clamps ½" - 1½".

SPECIAL PURPOSE

	Nozzle Type	Spray Angles	Basic Description
SPECIAL PURPOSE	**AJ150**	0°	1/4" BSPT or 1/4" NPT Male thread.
	BB	0°	3/8"-3/4" BSPT Male thread.
	7505	0°	Flat disc for use with standard bodies and caps.
	RO	0°	1/4"-1" BSPT Male thread.
	CON	0°	Flanged tip design for use with standard bodies and caps.
	BYPASS	75° – 85°	3/4"-1/2" NPT Male threads. Used with special adaptors.
	KIT ONE	115° – 130°	3/4"-1" hosetail connections with 1/2 or 1 metre risers.
	FN	180°	1/2" BSPP Female thread.

All nozzles depicted in this brochure are subject to a manufacturing tolerance of +/- 5% of rated capacity and within +/- 5° of rated spray angle when tested with water.

SOLID CONE NOZZLES

Producing uniform distribution across a wide pressure range

TYPICAL SPRAY PATTERN

TYPICAL APPLICATIONS

Aerating water, brine sprays, chemical processing, coil defrosting, dust control, evaporative condensers, evaporative coolers, industrial washers, roof cooling, spray coating, gas scrubbing and washing, cooling towers, coal washing, degreasing, gravel washing, dishwashing, foam control, industrial washing and water fountains.

BI Type Nozzle

BI 6 – 193 available. One-piece body with pressed in cross-milled core, which is removable. Spray angles from 35° to 100° dependent upon flow size and pressure. See chart for available thread sizes.

BQ Type Nozzle

BQ 6 – 193 available. One-piece body with pressed in cross-milled core, which is removable. Spray angles from 35° to 100° dependent upon flow size and pressure. See chart for available thread sizes. Produces a square pattern.

BN Type Nozzle

BN 6 – 200 available. One-piece body with pressed in cross-milled core, which is removable. Spray angles from 85° to 135° dependent upon flow size and pressure. See chart for available thread sizes.

BT Type Nozzle

BT 6 – 200 available. One-piece body with pressed in cross-milled core, which is removable. Spray angles from 85° to 135° dependent upon flow size and pressure. See chart for available thread sizes.

CT Type Nozzle

CT 2 – 40 available. Two-piece body design available in flow sizes from 2 – 40 with spray angles from 45° to 90°. See chart for available thread sizes.

Unless otherwise stated, all nozzles and tips are available in Brass and Stainless Steel as standard.

SOLID CONE - BI/BQ CAPACITY CHART

NOZZLE NUMBER MALE &FEMALE	THREAD SIZE	FLOW RATE IN LITRES/MIN AT BAR G 0.35	1	1.5	2	3	4	7	FLOW RATE IN GPM AT PSIG 5	15	20	30	40	60	100
6	1/8 & 1/4	0.88	1.50	1.88	2.18	2.65	2.87	3.54	0.23	0.40	0.47	0.58	0.66	0.76	0.91
8	1/8 & 1/4	1.30	2.28	2.84	3.23	4.00	4.55	5.72	0.34	0.60	0.71	0.85	1.00	1.20	1.48
11	1/8 & 1/4	1.63	2.87	3.62	4.05	4.87	5.36	6.74	0.42	0.76	0.90	1.07	1.21	1.42	1.74
12	1/8 to 3/8	2.09	3.41	4.09	4.55	5.30	5.91	7.58	0.54	0.90	1.02	1.20	1.32	1.56	1.96
16	1/4 & 3/8	2.50	4.41	5.30	6.14	7.27	8.00	10.04	0.65	1.16	1.32	1.62	1.81	2.11	2.59
20	1/4 & 3/8	3.11	5.46	6.50	7.54	9.06	10.00	12.63	0.80	1.44	1.62	1.99	2.26	2.64	3.25
22	1/4 & 3/8	3.58	6.24	7.51	8.32	9.78	10.91	14.24	0.92	1.64	1.87	2.20	2.44	2.88	3.67
27	3/8 & 1/2	4.23	7.42	9.01	10.10	12.32	13.64	17.47	1.09	1.96	2.24	2.68	3.07	3.60	4.50
32	3/8 & 1/2	5.81	8.88	10.81	12.32	14.44	15.96	20.40	1.50	2.34	2.70	3.24	3.59	4.20	5.28
42	1/2 & 3/4	6.74	11.82	14.44	15.96	19.29	21.41	27.37	1.74	3.12	3.60	4.20	4.80	5.64	7.08
49	1/2 & 3/4	8.17	14.24	16.36	18.69	23.13	25.05	32.52	2.11	3.76	4.08	4.92	5.76	6.60	8.40
63	1/2 & 3/4	10.20	17.07	20.50	23.84	28.89	32.22	41.31	2.64	4.50	5.16	6.30	7.20	8.53	10.70
77	3/4	12.32	20.50	23.94	29.09	34.96	38.68	49.29	3.18	5.40	6.36	7.69	8.70	10.20	12.70
89	3/4	13.94	23.74	29.39	33.63	40.00	44.54	56.26	3.60	5.24	7.32	8.88	9.96	11.80	14.50
102	3/4	14.85	27.37	33.73	38.68	46.26	50.00	64.54	3.84	7.20	8.40	10.20	11.50	13.20	16.70
105	1	16.26	27.78	33.73	39.79	48.18	52.32	67.37	4.20	7.32	8.40	10.50	12.00	13.80	17.40
123	1	19.49	34.64	42.32	46.56	57.77	63.63	80.40	5.04	9.12	10.60	12.30	14.40	16.80	20.80
140	1	22.73	38.18	45.25	53.23	62.12	68.18	85.95	5.88	10.10	11.30	14.00	15.50	18.00	22.20
162	1	25.55	44.64	53.03	61.41	72.22	79.08	101.00	6.60	11.80	13.20	16.20	18.00	21.00	26.20
193	1	28.79	50.10	60.70	73.23	87.57	99.08	128.27	7.44	13.20	15.10	19.30	22.60	26.20	33.00

SOLID CONE - CT CAPACITY CHART

NOZZLE NUMBER FEMALE	MALE	THREAD SIZE	FLOW RATE IN LITRES/MIN AT BAR G 0.35	0.7	1.5	3	5	7	FLOW RATE IN GPM AT PSIG 5	10	20	40	80	100
2	2	1/8	0.53	0.76	1.10	1.58	1.98	2.29	0.14	0.20	0.28	0.40	0.56	0.60
3	3	1/8	0.84	1.14	1.70	2.37	2.88	3.43	0.22	0.30	0.43	0.60	0.80	0.90
3.5	3.5	1/8	0.95	1.34	1.98	2.69	3.32	3.82	0.25	0.35	0.50	0.68	0.92	1.00
4	4	1/8	1.07	1.53	2.21	3.16	3.97	4.77	0.28	0.40	0.56	0.80	1.10	1.25
5	5	1/8	1.37	1.91	2.77	3.75	4.69	5.72	0.36	0.50	0.70	0.95	1.30	1.50
6.5	6.5	1/4	1.79	2.48	3.56	5.14	6.13	7.25	0.47	0.65	0.90	1.30	1.70	1.90
9.5	9.5	1/8, 3/8	2.63	3.63	5.14	7.11	9.02	10.69	0.69	0.95	1.30	1.80	2.50	2.80
10	10	1/4	2.78	3.82	5.53	7.50	9.74	11.45	0.73	1.00	1.40	1.90	2.70	3.00
15	15	3/8	4.20	5.72	8.30	11.45	14.42	16.79	1.10	1.50	2.10	2.90	4.00	4.40
16	16	1/2	4.60	6.10	8.69	12.25	15.50	17.94	1.20	1.60	2.20	3.10	4.30	4.70
22	22	3/8	6.10	8.40	11.85	16.60	20.92	24.42	1.60	2.20	3.00	4.20	5.80	6.40
25	25	1/2	6.87	9.54	13.83	18.96	24.16	28.24	1.80	2.50	3.50	4.80	6.70	7.40
32	32	1/2	8.78	12.20	17.38	24.10	30.65	35.87	2.30	3.20	4.40	6.10	8.50	9.40
40	40	1/2	11.07	15.26	21.73	30.00	38.22	45.03	2.90	4.00	5.50	7.60	10.60	11.80

SOLID CONE - BN/BT CAPACITY CHART

NOZZLE NUMBER MALE &FEMALE	THREAD SIZE	FLOW RATE IN LITRES/MIN AT BAR G 0.35	1	1.5	2	3	4	7	FLOW RATE IN GPM AT PSIG 5	15	20	30	40	60	100
6	1/8, 1/4	0.88	1.50	1.88	2.18	2.65	2.87	3.54	0.23	0.40	0.50	0.58	0.70	0.76	0.93
8	1/8, 1/4	1.30	2.28	2.84	3.23	4.00	4.55	5.72	0.34	0.60	0.75	0.85	1.06	1.20	1.51
11	1/8, 1/4	1.86	3.23	3.86	4.31	5.15	5.45	7.43	0.48	0.85	0.96	1.14	1.28	1.44	1.92
15	1/4	2.60	4.50	5.26	5.59	6.64	7.24	9.16	0.69	1.19	1.39	1.48	1.75	1.91	2.42
18	1/4	3.10	5.39	6.30	6.70	7.96	8.68	10.98	0.82	1.42	1.66	1.77	2.10	2.29	2.90
22	1/4, 3/8	3.95	6.84	8.00	8.50	10.10	11.01	13.94	1.02	1.80	1.99	2.24	2.52	2.93	3.60
25	3/8	4.27	7.24	8.43	9.32	11.01	12.32	15.76	1.10	1.91	2.10	2.46	2.76	3.24	4.08
32	3/8	5.90	9.15	10.80	11.92	14.30	15.78	19.90	1.56	2.42	2.85	3.15	3.78	4.17	5.25
39	3/8	7.20	11.15	13.14	14.52	17.40	19.20	24.25	1.90	2.94	3.47	3.83	4.59	5.07	6.40
46	3/8, 1/2	8.13	13.64	15.86	17.27	19.29	22.32	27.88	2.10	3.60	3.96	4.56	4.80	5.88	7.20
48	3/8, 1/2	8.33	15.25	16.87	18.18	23.13	24.54	32.52	2.28	4.02	4.20	4.80	5.76	6.48	8.40
59	1/2	9.29	15.96	19.29	22.32	26.06	28.18	37.67	2.40	4.20	4.80	5.88	6.48	7.44	9.72
65	1/2	12.00	18.60	21.92	24.21	29.00	32.05	40.40	3.17	4.91	5.79	6.39	7.66	8.46	10.67
73	1/2	13.50	20.88	24.50	27.19	32.60	36.00	45.40	3.56	5.51	6.47	7.18	8.61	9.50	11.99
82	3/4	15.35	23.74	27.98	30.91	37.07	40.91	51.61	3.96	6.24	6.96	8.16	9.24	10.80	13.30
94	3/4	16.77	26.87	32.72	35.45	41.92	45.96	59.89	4.32	7.08	8.16	9.36	10.40	12.10	15.50
98	3/4	18.08	27.78	34.24	37.27	44.34	50.00	64.54	4.68	7.32	8.52	9.84	11.00	13.20	16.70
136	1	24.14	42.32	48.18	51.41	60.20	67.77	86.86	6.24	11.20	12.00	13.60	15.00	17.90	22.40
153	1	27.88	46.97	53.93	57.97	67.47	76.36	98.07	7.20	12.40	13.40	15.30	16.80	20.20	25.30
200	1	29.69	51.41	62.62	75.96	88.68	99.59	130.29	7.68	13.60	15.60	20.00	22.10	26.30	33.60

LARGE SOLID CONE NOZZLES

Producing uniform distribution at low pressures

TYPICAL SPRAY PATTERN

TYPICAL APPLICATIONS

Aerating water, brine sprays, chemical processing, coil defrosting, dust control, evaporative condensers, evaporative coolers, industrial washers, roof cooling, spray coating, gas scrubbing and washing, cooling towers, coal washing, degreasing, gravel washing, dishwashing, foam control, industrial washing and water fountains.

CM Type Nozzle

CM 16 – 105 available. One piece cast body with removable vane type core. Spray angles of 45 to 110° dependent upon flow size and pressure. See chart for available thread sizes.

Unless otherwise stated, all nozzles are available in Cast Iron, Stainless Steel and Gunmetal as standard.

BY Type Nozzle

BY 23 – 96 available. One-piece cast body with removable vane type core. Spray angles of 70 to 130° dependent upon flow size and pressure. See chart for available thread sizes.

LARGE SOLID CONE - CM CAPACITY CHART

NOZZLE NUMBER FEMALE	THREAD SIZE	FLOW RATE IN LITRES/MIN AT BAR G							FLOW RATE IN GPM AT PSIG						
		0.35	0.7	1	2	3	5	7	5	10	15	30	40	80	100
16	1 1/4	33.30	45.70	53.60	72.30	87.60	110.00	127.00	8.74	12.00	14.40	19.50	22.20	30.50	33.40
22	1 1/4	44.00	59.90	70.10	96.40	115.00	145.00	168.00	11.60	15.70	18.00	25.90	29.20	40.40	44.20
27	1 1/4	55.80	76.40	89.30	121.00	146.00	184.00	213.00	14.70	20.00	24.00	32.50	37.10	51.00	55.80
33	1 1/4	67.70	91.90	108.00	146.00	177.00	222.00	259.00	17.80	24.10	29.10	39.40	44.80	61.60	68.10
29	1 1/2	57.60	79.60	94.20	128.00	154.00	197.00	229.00	15.1	20.90	25.30	34.50	39.20	54.60	60.20
35	1 1/2	70.00	96.50	114.00	156.00	187.00	238.00	278.00	18.40	25.30	30.60	42.00	47.60	66.20	72.90
42	1 1/2	86.00	117.00	137.00	191.00	229.00	289.00	339.00	22.60	30.70	36.90	51.30	58.10	80.20	89.00
48	1 1/2	96.50	133.00	158.00	216.00	259.00	326.00	381.00	25.30	34.90	42.40	58.10	66.60	90.60	99.90
54	1 1/2	108.00	148.00	175.00	241.00	288.00	367.00	427.00	28.30	38.90	47.00	64.90	73.10	102.00	112.00
64	2	126.00	175.00	206.00	284.00	341.00	437.00	503.00	33.10	45.90	55.40	76.40	86.50	121.00	132.00
71	2	142.00	195.00	231.00	321.00	335.00	488.00	572.00	37.30	51.20	62.20	86.30	97.80	136.00	150.00
81	2	161.00	222.00	261.00	362.00	436.00	553.00	650.00	42.10	58.20	70.30	97.40	111.00	154.00	171.00
90	2	181.00	250.00	294.00	408.00	492.00	618.00	723.00	47.40	65.70	79.00	110.00	125.00	172.00	190.00
98	2	195.00	270.00	316.00	451.00	526.00	670.00	782.00	51.20	71.00	84.90	121.00	133.00	186.00	205.00
105	2	209.00	288.00	339.00	473.00	568.00	718.00	833.00	54.90	75.80	91.10	127.00	144.00	199.00	219.00

LARGE SOLID CONE - BY CAPACITY CHART

NOZZLE NUMBER FEMALE	THREAD SIZE	FLOW RATE IN LITRES/MIN AT BAR G							FLOW RATE IN GPM AT PSIG						
		0.35	0.7	1	2	3	5	7	5	10	15	30	40	80	100
23	1 1/4	49.40	64.00	75.40	103.00	117.00	147.00	173.00	13.04	16.90	19.90	27..19	29.61	38.81	45.67
28	1 1/4	59.50	78.20	91.50	118.00	145.00	179.00	206.00	15.71	20.64	24.16	31.15	36.70	47.25	54.38
35	1 1/4	75.90	101.10	115.00	137.00	179.00	225.00	274.00	20.04	26.69	30.36	36.17	45.31	59.40	72.33
37	1 1/2	80.50	106.00	125.00	166.00	199.00	252.00	294.00	21.25	27.98	33.00	43.82	50.37	66.53	77.61
42	1 1/2	89.20	119.00	138.00	187.00	218.00	275.00	323.00	23.55	31.41	36.43	49.37	55.18	72.60	85.27
47	1 1/2	98.80	133.00	154.00	210.00	254.00	319.00	373.00	26.08	35.11	40.65	55.44	64.29	84.21	98.47
52	1 1/2	110.00	146.00	170.00	227.00	277.00	353.00	-	29.04	38.54	44.88	59.93	70.11	93.19	-
66	2	137.00	188.00	219.00	294.00	355.00	-	-	36.17	49.63	57.81	77.61	89.85	-	-
73	2	149.00	204.00	240.00	325.00	390.00	-	-	39.33	53.85	63.36	85.80	98.71	-	-
78	2	161.00	220.00	256.00	347.00	420.00	-	-	42.50	58.08	67.58	91.61	106.30	-	-
89	2	183.00	247.00	291.00	403.00	486.00	-	-	48.31	65.21	76.82	106.39	123.01	-	-
96	2	197.00	270.00	313.00	441.00	515.00	-	-	52.01	71.28	82.63	116.42	130.35	-	-

SMALL SOLID CONE NOZZLES

Producing uniform distribution with fine atomisation

TYPICAL SPRAY PATTERN

TYPICAL APPLICATIONS

Aerating water, brine sprays, chemical processing, coil defrosting, dust control, evaporative condensers, evaporative coolers, industrial washers, roof cooling, spray coating, gas scrubbing and washing, cooling towers, coal washing, degreasing, gravel washing, dishwashing, foam control, industrial washing and water fountains.

WDB Type Nozzle

Basic nozzle thread 9/16" – 24 UNEF, with optional adaptors providing 1/8" and 1/2" pipe threads. Flow sizes from 0.5 to 20 with spray angles of 30°, 45°, 60°, 70°, 80° and 90°.

WL Type

Flanged tip design for use with standard threaded bodies and caps, available in flow sizes from 3 – 20 with spray angles of 45°, 60° and 90°. One-piece body with removable screwed core, using allen key.

BL Type Nozzle

One-piece body with removable screwed core, using allen key. Available only with 1/8" BSPT thread and in flow sizes from 3 – 20 with spray angles of 45°, 60° and 90°.

BF Type

Flanged tip design for use with standard bodies and caps in sizes from 1 - 16. Spray angles of 30°, 60°, 90° and 120°.

Unless otherwise stated, all nozzles and tips are available in Brass and Stainless Steel as standard.

SMALL SOLID CONE - WDB CAPACITY CHART

NOZZLE NUMBER	FLOW RATE IN LITRES/HOUR AT BAR G							FLOW RATE IN GPH AT PSIG						
	3	5	7	10	15	20	35	40	75	100	125	150	300	500
0.5*	-	1.45	1.72	2.05	2.51	2.87	3.82	-	0.39	0.45	0.55	0.63	0.77	1.00
0.75*	-	2.16	2.56	3.05	3.74	4.32	5.72	-	0.58	0.67	0.75	0.82	1.16	1.50
1	-	2.87	3.40	4.10	5.02	5.77	7.63	-	0.77	0.89	1.00	1.10	1.55	2.00
1.5	-	4.32	5.11	6.15	7.53	8.64	11.40	-	1.16	1.34	1.50	1.65	2.32	3.00
2	-	5.77	6.83	8.19	10.00	11.60	15.30	-	1.55	1.79	2.00	2.20	3.10	4.00
2.5	-	7.19	8.56	10.20	12.50	14.50	19.10	-	1.93	2.24	2.50	2.74	3.88	5.00
3	-	8.64	10.20	12.30	15.10	17.30	22.90	-	2.32	2.68	3.00	3.30	4.65	6.00
4	8.69	11.50	13.70	16.40	20.10	23.10	30.50	2.20	3.10	3.60	4.00	4.40	6.20	8.00
5	11.10	14.50	17.20	20.50	25.10	28.70	38.20	2.80	3.90	4.50	5.00	5.55	7.70	10.00
6	14.20	17.50	20.60	24.60	30.10	34.60	45.80	3.60	4.70	5.40	6.00	6.60	9.30	12.00
8	17.80	23.10	27.50	33.10	40.60	46.20	61.10	4.50	6.20	7.20	8.00	8.90	12.40	16.00
10	22.10	28.70	34.00	41.00	50.20	57.70	76.30	5.60	7.70	8.90	10.00	11.00	15.50	20.00
12	26.90	34.60	40.80	49.20	60.20	69.30	91.60	6.80	9.30	10.70	12.00	13.20	18.60	24.00
14	31.20	40.20	47.70	57.00	69.80	80.80	107.00	7.90	10.80	12.50	14.00	15.30	21.70	28.00
16**	35.60	46.20	54.60	65.20	79.80	92.40	122.00	9.00	12.40	14.30	16.00	17.50	24.80	32.00
18**	39.90	51.80	61.40	73.40	89.90	104.00	137.00	10.10	13.90	16.10	18.00	19.70	27.90	36.00
20**	44.60	57.80	68.30	81.60	99.90	115.00	153.00	11.30	15.50	17.90	20.00	21.90	31.00	40.00

SMALL SOLID CONE - WL/BL CAPACITY CHART

NOZZLE NUMBER	MESH SIZE	FLOW RATE IN LITRES/HOUR AT BAR G								FLOW RATE IN GPH AT PSIG							
		0.7	1	1.5	2	3	4	6	7	10	15	20	30	45	60	90	100
3	200	7.40	8.70	10.40	11.90	14.20	16.20	18.90	20.70	1.82	2.17	2.64	3.06	3.75	4.33	5.31	5.73
4	200	9.90	11.60	13.90	16.00	19.00	21.70	25.30	27.70	2.43	2.88	3.54	4.09	5.02	5.79	7.08	7.66
5	200	12.30	14.40	17.30	19.90	23.70	27.00	31.50	34.60	3.04	3.62	4.44	5.13	6.26	7.24	8.85	9.56
6	100	14.80	17.30	20.70	23.90	28.40	32.40	37.80	41.50	3.62	4.33	5.31	6.13	7.50	8.67	10.62	11.47
7	100	17.30	20.30	24.20	27.90	33.20	37.80	44.20	48.50	4.23	5.05	6.21	7.16	8.77	10.12	12.39	13.39
8	100	19.70	23.10	27.70	31.80	37.90	43.20	50.40	55.30	4.83	5.79	7.08	8.19	10.01	11.57	14.16	15.30
9	100	22.20	26.00	31.20	35.90	42.70	48.70	56.80	62.30	5.44	6.50	7.98	9.19	11.28	13.02	15.93	17.22
10	100	24.60	28.90	34.60	39.80	47.40	54.00	63.00	69.20	6.05	7.21	8.85	10.22	12.52	14.45	17.70	19.13
16	50	39.50	46.30	55.40	63.80	75.90	86.50	101.00	111.00	9.70	11.54	14.16	16.35	20.05	23.14	28.27	30.64
20	50	49.30	57.80	69.20	79.60	94.80	108.00	126.00	138.00	12.10	14.45	17.70	20.45	25.04	28.80	35.40	38.31

SMALL SOLID CONE - BF CAPACITY CHART

NOZZLE NUMBER	FLOW RATE IN LITRES/MIN AT BAR G							FLOW RATE IN GPM AT PSIG						
	1	1.5	2	3	4	5	7	15	20	30	45	60	70	100
1	0.45	0.56	0.64	0.78	0.86	0.94	1.14	0.12	0.15	0.17	0.21	0.23	0.25	0.30
2	0.89	1.11	1.26	1.54	1.71	1.87	2.27	0.24	0.29	0.33	0.41	0.45	0.49	0.60
3	1.34	1.67	1.90	2.32	2.57	2.81	3.41	0.35	0.44	0.50	0.61	0.68	0.74	0.90
4	1.79	2.22	2.53	3.10	3.42	3.75	4.54	0.47	0.59	0.67	0.82	0.90	0.99	1.20
5	2.23	2.78	3.15	3.86	4.28	4.68	5.68	0.59	0.73	0.83	1.02	1.13	1.24	1.50
6	2.68	3.34	3.79	4.64	5.13	5.62	6.81	0.71	0.88	1.00	1.23	1.36	1.48	1.80
8	3.57	4.44	6.28	6.18	6.84	7.49	9.08	0.94	1.17	1.66	1.63	1.81	1.98	2.40
10	4.40	5.56	6.31	7.72	8.56	9.36	11.35	1.16	1.47	1.67	2.04	2.26	2.47	3.00
12	5.36	6.67	7.58	9.28	10.27	11.24	13.62	1.42	1.76	2.00	2.45	2.71	2.97	3.60
16	7.14	8.90	10.10	12.37	13.73	14.98	18.16	1.89	2.35	2.67	3.27	3.63	3.96	4.80

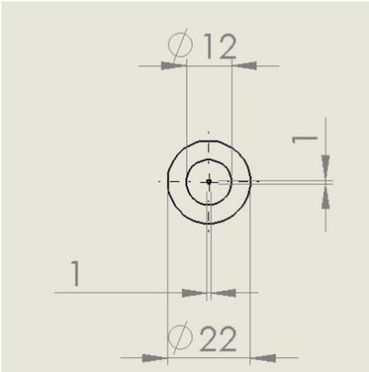
* Not available in 30 or 45 degree

** These sizes are supplied without strainers

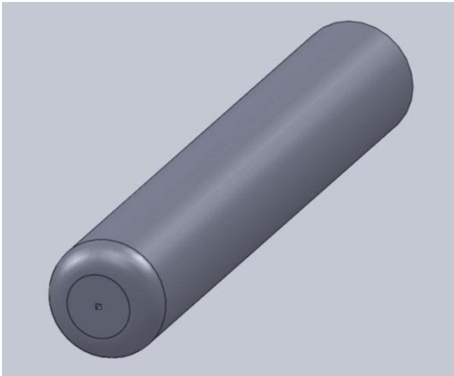
APPENDIX B2

Nozzle with Designed Internal Flow

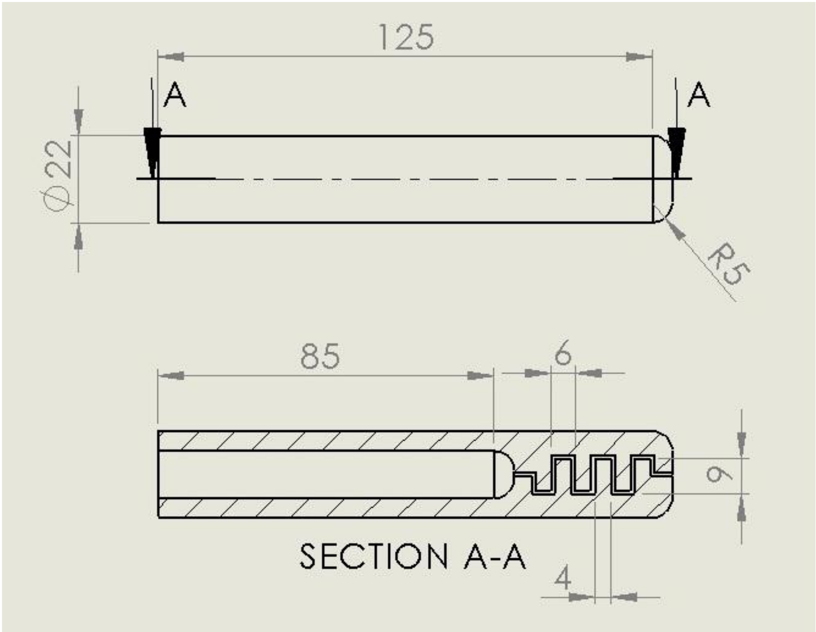
1) Diameter 1.0mm



(a) Front View



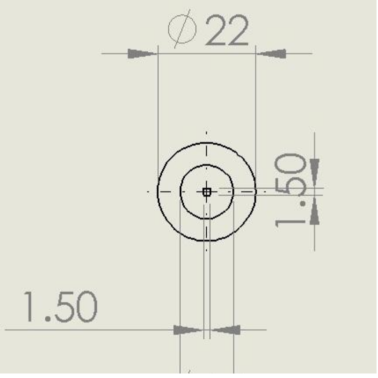
(b) Dimetric View



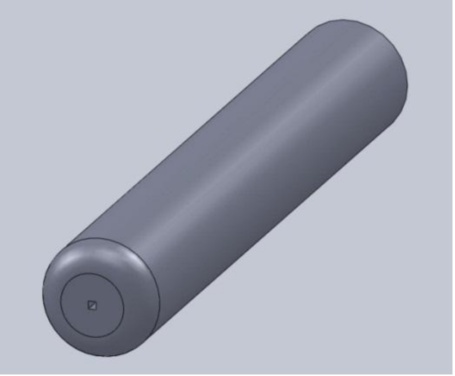
(c) Horizontal View

Figure 1: Dimension of the Nozzle with Designed Internal Flow, diameter 1.0mm from different side of view, (a) Front, (b) Dimetric and (c) Horizontal View

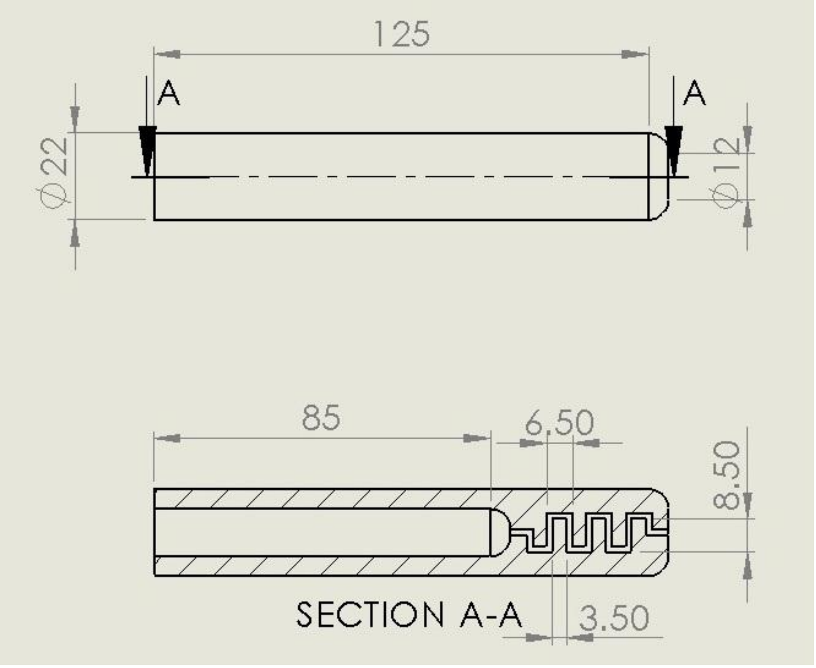
2) Diameter 1.5mm



(a) Front View



(b) Dimetric View

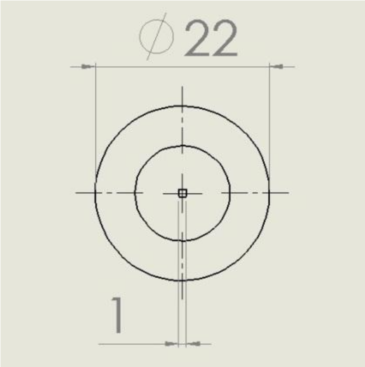


(c) Horizontal View

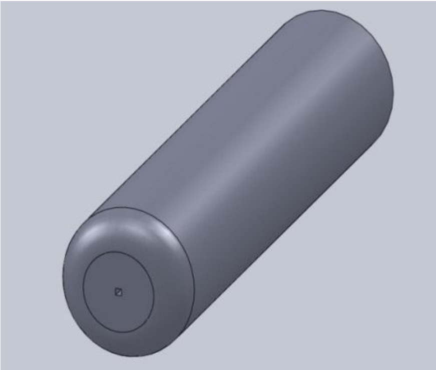
Figure 2: Dimension of the Nozzle with Designed Internal Flow, diameter 1.5mm from different side of view, (a) Front View, (b) Dimetric View and (c) Horizontal View

Nozzle with Normal Internal Flow

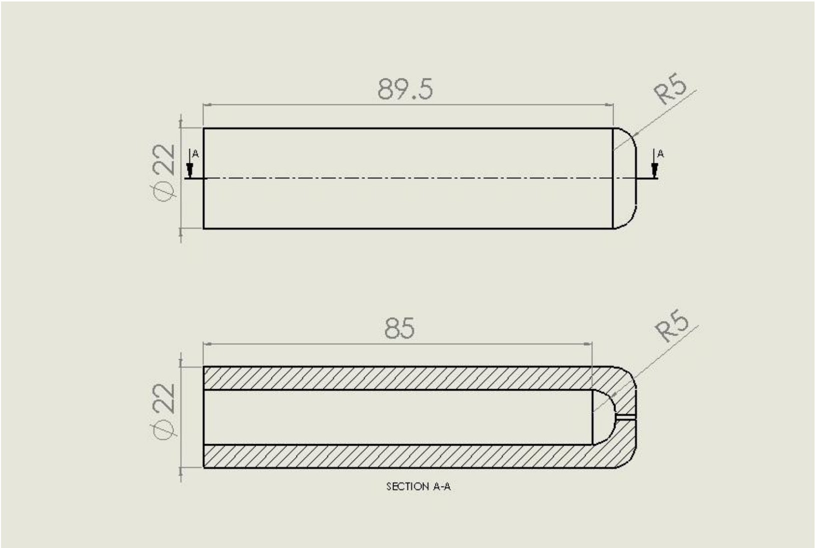
1) Diameter 1.0mm



(a) Front View



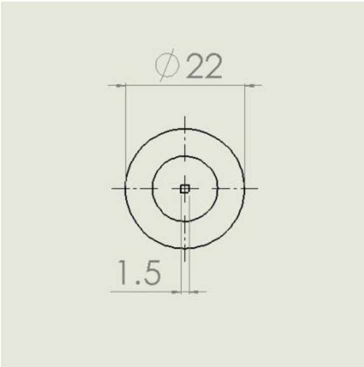
(b) Dimetric View



(c) Horizontal View

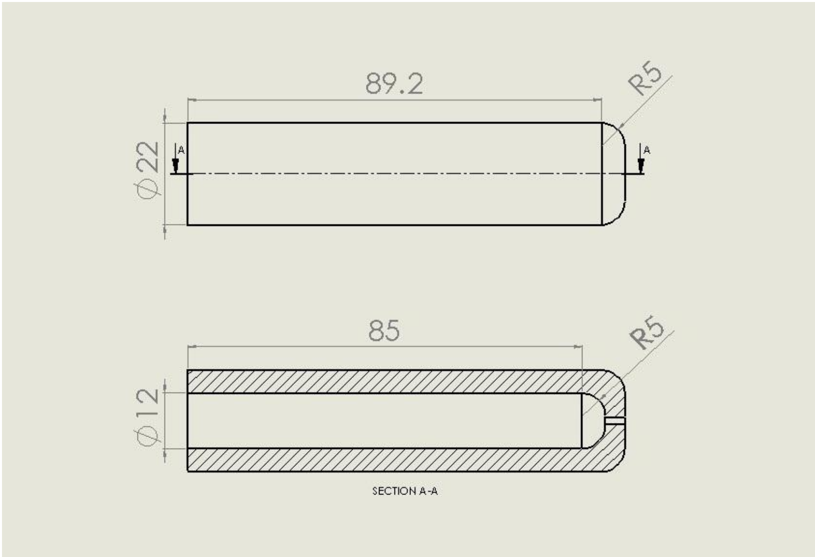
Figure 3: Dimension of the Nozzle with Normal Internal Flow, diameter 1.0mm from different side of view, (a) Front View, (b) Dimetric View and (c) Horizontal View

2) Diameter 1.5mm



(a) Front View

(b) Dimetric View



(c) Horizontal View

Figure 4: Dimension of the Nozzle with Normal Internal Flow, diameter 1.5mm from different side of view, (a) Front View, (b) Dimetric View and (c) Horizontal View

Making a Base in a Insight^{TM}software

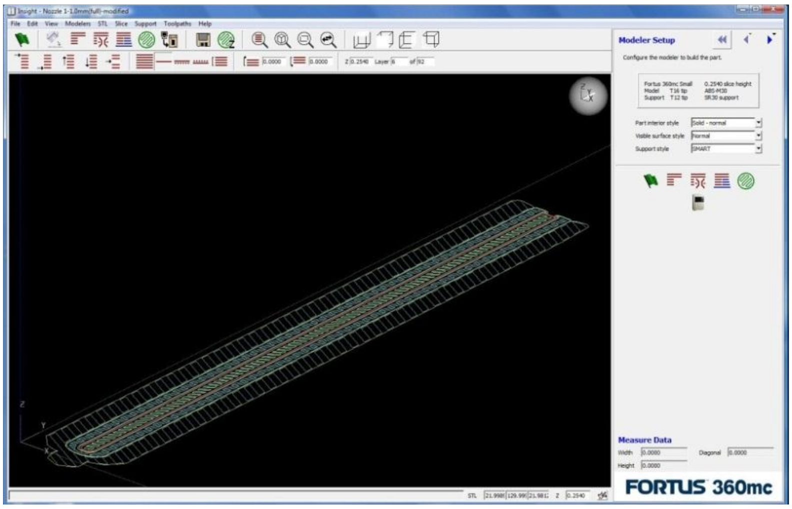


Figure 5: Base for 1.0mm Nozzle by using Insight^{TM} Software.

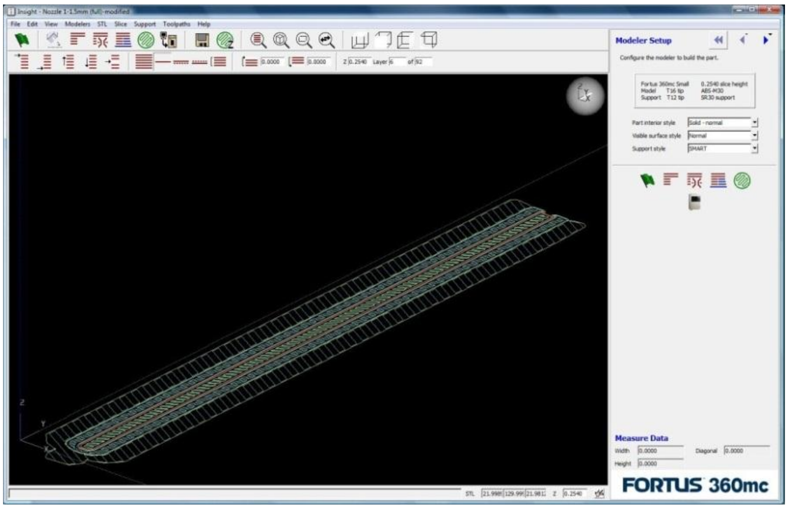


Figure 6: Base for 1.5mm Nozzle by using Insight^{TM} Sofware.