STUDY ON CHARACTERISTICS BEHAVIOR OF DEVELOPING NOZZLE FOR AEROSOL SPRAY

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ABSTRACT

A new generation of aerosol technology are expand rapidly where the research and development are focused on the analysis of propellants, packaging and ingredients to make the aerosol has a high performance product. However, there are a few main problems with pressurised aerosol spray, which are the production of VOC and the quality of spraying process. Therefore, in this study the development of an internal nozzle has been investigated to analyse the characterictics of spray by using CFD simulation. The analysis is focused on various pressure supply up to 9bar, where the n-butane and water are applied as a liquid phases material. The simulation is done based on two types of selected nozzle design. The result shows that, the values of velocity, TKE and Reynolds Number for both liquid phases are increase when the pressure supply increased. It was observed that, when comparing the two type of nozzle design, it shown that the value of velocity and Reynolds number is relatively similar for both liquid phases, while the TKE value is more difference due to the material properties and nozzle design. Therefore, the use of water is acceptable as an alternative to substitute the n-butane liquid phase in producing an aerosol spray product.

ABSTRAK

Pada masa kini, teknologi *aerosol* semakin berkembang pesat di mana penyelidikan dan pembangunan tertumpu kepada analisis *propellant*, pembungkusan dan bahan-bahan untuk membuat aerosol supaya produk yang dihasilkan berkualiti tinggi. Walau bagaimanapun, terdapat beberapa masalah utama dalam peghasilan penyemburan aerosol produk, seperti pengeluaran *VOC* dan masalah kualiti proses penyemburan. Oleh itu, dalam kajian ini, ciri-ciri semburan telah dikaji dengan menggunakan kaedah simulasi *CFD* dalam penghasilan rekabentuk *nozzle*. Analisis tertumpu pada pelbagai tekanan; sehingga 9bar, di mana *n-butane* dan air digunakan sebagai bahan fasa cecair. Simulasi dilakukan berdasarkan dua jenis reka bentuk *nozzle* yang dipilih. Hasil daripada kajian menunjukkan bahawa, nilai halaju, nilai *TKE* dan *Reynolds Number* bagi kedua-dua fasa cecair meningkat apabila tekanan meningkat. Diperhatikan bahawa, apabila membandingkan dua jenis reka bentuk *nozzle*, ia menunjukkan bahawa nilai halaju dan *Reynolds Number* adalah hampir sama untuk kedua-dua fasa cecair, manakala nilai TKE adalah lebih berbeza disebabkan oleh reka bentuk nozzle dan sifat-sifat bahan yang digunakan. Oleh itu, penggunaan air adalah diterima sebagai satu alternatif untuk menggantikan n-butane dalam menghasilkan produk semburan aerosol.

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VOC	-	Volatile Organic Compounds
CFD	-	Computational Fluid Dynamics
CFCs	-	Chlorofluorocarbons
HCs	-	Hydrocarbons
PVC	-	Precision Valve Corporation
DME	-	Dimethylether
CO_2	-	Carbon Dioxide
N_2	-	Nitrogen Dioxide
CSPA	-	Consumer Specialty Products Association
U.S.	-	United State
GLR	-	Gas/liquid Mass Ratio
DSD	-	Droplet Size Distribution
VMD	-	Volume Median Diameter
TKE	-	Turbulence Kinetic Energy
RNG	-	Renormalisation Group
I.C.	-	Internal Combustion
EU	-	Europe
N/m	-	Newton per Meter
ρ	-	Density
P	-	Pressure
T	-	Temperature
M	-	Molar Mass

$\vec{v}$	-	Velocity
p	-	Static Pressure
$\vec{g}$	-	Gravitational Force
$\vec{F}$	-	Other Forces
$\bar{\bar{\tau}}$	-	Stress Tensor
μ	-	Viscosity
$\bar{\bar{I}}$	-	Unit tensor
ε	-	Turbulent Dissipation
ω	-	Turbulent Specific Dissipation
ζ	-	Ratio of the Turbulent to Mean Strain Time Scale
σ_k	-	Turbulent Schmidt Number
L	-	Turbulent Length Scale
$\dot{m}$	-	Mass Flow Rate
A	-	Area
d	-	Diameter Nozzle

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Sprays are used in several applications, such as in industrial, agricultural, domestic and many other applications. One of the largest markets use form of spray technology is the household aerosol including personal care product. It was design in a presurized canister. These include anti-perspirants, air freshner, perfumes, deo-dorant and hair spray that are commonly used all over the world. It has been commerciallised due to the useful system which is easy and ready to use. It is convenient, effective and efficient spray.

Consumer used aerosol spray as a household product every day and not all of us noted this spray is containing volatile organic compounds (VOC) that contributes to formation of tropospheric ozone [1-2]. VOC is a large group of Carbon-based chemicals which is easy to avaporate at room temperature. It has a potential can cause health effect depending on the time exposure.

To avoid this situation become critical, nowadays a lot of manufacturers are focus to develop some kind of water based aerosol product. However the contents are still used aerosol more than water. Based on a few research found that, the performance of aerosol spray is drop if the VOC content was reduced [3]. Toward for resolve the problem and to safe our environment in the future, an improvement of the product design should take an action.

The fields of household aerosols have a marked commonalty with their needs to produce fine sprays using portable devices. These devices generally are designed as atomiser or nozzles and it has been developed in a wide range of the different applications. The success of a spray job is depending on the product chosen, application timing and correct operation of the spray equipment. However, for the effective spraying the most important are the correct nozzle selection, speed and pressure. The behavior of the spray aerosol is analysed through simulation to make an improvement for the new future design spray that not only has same characteristic with existing product but also friendly to the environmental.

1.2 Aerosol Spray

Aerosol is a fine particles of liquid or solid subtances in air which contained three element of dispensing system such as active ingredients (soap or disinfectant), inert or inactive ingredients (water) and propellant. The propellant is a gaseous compound which pushes the product out of the container and produces a spray or foam. A spray is generated when a fluid is caused to flow through a nozzle arrangement under pressure. In most cases, the propellant also acts as a solvent to keep the product at the proper strength.

Formerly, the first aerosol spray used chlorofluorocarbons (CFCs) as a propellant until scientist observe that it utilize will damage the Earth's ozone layer. Therefore, in 1978, the use of CFCs is strictly banned especially in the United States then follows by others countries such as Canada, Mexico, Australian and many European nations. Awareness among the countries, drag others developing countries took place avoid to use CFCs. Today a variety of different propellants are used in aerosol cans to replace CFCs, where liquefied petroleum gas being among the most popular. In the United States, the most common propellants are naturally occurring hydrocarbons (HCs).

1.2.1 History of the Aerosol

The first use for an aerosol package arose during World War II but, the idea of using low-pressure liquefied gas to atomise droplets of liquid in the air was developed in 1924. Canisters filled with insecticide and propellants were used to protect U.S. servicemen from insects carrying diseases such as malaria. Shortly after the war, Robert Abplanalp, founder of Precision Valve Corporation (PVC), invented the first mass-produced aerosol valve. Then, the patent was filed in September 1949 and was issued on March 17, 1953. From that invention, the aerosol industry quickly developed in the United States and around the world.

1.2.2 Alternative Aerosol Propellants

Typically, there are four main alternative types of propellant such as:

- Hydrocarbons (HCs)
- Dimethyl ether (DME)
- Compressed gases (e.g. CO_2, N_2, compressed air, nitrous oxide)
- HFCs

HCs have established a dominant position in the aerosol market. The HCs used are usually mixtures of propane, butane and iso-butane. The mixture proportions are chosen to provide the appropriate vapour pressure. HCs are effective and cheap propellants. The main disadvantages are flammability and VOC emissions. Manufacturers have managed to redesign the nozzles of aerosols to minimize the impact of flammability.

1.2.3 How an Aerosol Works

An aerosol package is an air-tight, pressurised container that including the three main elements mention before. All of these pieces work together based on simple scientific principles. Just pressing the actuator button, the aerosol spray will function and due to that pressing effect, the valve will open. Since the pressure outside the can is less than the pressure inside, the propellant expands, pushing the product up the dip tube and out through the valve to nozzle. The nozzle itself is constructed such that to ensure it atomise the product as it is sprayed out making tiny little drops. This system allows the product to be applied in a variety of way such as in a fine mist; a metered spray delivering just the right amount, foam, or even a long distance spray.

1.2.4 Household Aerosol Spray

The pressurised household aerosol can is found universally in the developed world and in most homes in the developing world. The expression “household aerosol” is used to describe pressurised cans for household purposes such as cleaning, polishing, disinfectant etc., and include the used term “personal care” area, i.e. deodorants, hair sprays etc. Furthermore the use of these devices extends into other areas, such as for lubrication, paint application and de-icing of vehicles. Figure 1.1 shows a typical aerosol cans which is pressurised, typically to 4 to 5 bar, using a liquefied gas. That is, the propellant is a low boiling point fluid (b.p. typically between 220K and 270K) [4].

Figure 1.1: Typical household aerosol sprays, from left to right: air freshener, body spray and insecticide spray [5]

1.2.5 Household Aerosol Production

Aerosol Pressurised Products Survey by Consumer Specialty Products Association (CSPA) has revealed 2010 as the highest year ever for U.S. aerosol production. The estimated total units filled in 2010 were 3.745 billion, which establishes the historical high for fillings in the United States. Household and personal care products rank as the two highest production product categories, with household products reporting a 9.2% increase in 2010 over 2009 [6].

1.3 Problem Statement

Aerosols improve our quality of life in many ways. They provide benefits in medical treatment, health care, pest control, disease prevention, personal care and hygiene, household, automotive and industrial cleaning maintenance. However, there are three main problems with pressurised aerosol spray, which are the production of VOC, the use of oil based energy and the danger of explosion after disposal because of flammability [7]. Besides, the protection of the environment has become a European key issue since the early 90s. Legislation controlling VOC use is becoming incresingly strict and is already affecting the household aerosol market.

Therefore, a new generation of aerosol technology are expand rapidly where the research and development are focused on the analysis of propellants, packaging and ingredients to make the aerosol has a high performance product. Currently market interest is looking towards reducing the amounts of propellant or by replacing it completely with a lower cost and more environmentally friendly means of creating the spray. [3].

This study is focus on investigation of internal nozzle geometries for the aerosol spray by CFD modeling. Design from previous study and combination with the conventional nozzle is chosen to analyse since nozzle design is one of the characteristic to ensure the efficient of spraying. Besides, to reduce the VOC content of existing aerosol can, water is used to replace the propellant. However, this application will produce poor atomisation of the spray. Hence, the flow of spraying product is analysed by implement the high turbulence flow where high turbulence flow can resolve the atomisation problem. Then, based on that, further prediction for the nozzle design of fine spray which can control in liquid viscosity and spray flow rate can be done for developing a design rules.

1.4 Research Objective

This research focused on the simulation of flow for conventional household aerosol nozzle for future developing nozzle design. Here, the characteristic of the flow is determined by Computational Fluid Dynamics (CFDs). The main purposes of the research are:

1. To analyse internal nozzle geometries at atomiser exit(s) for single liquid phases.
2. To extend the above analysis of the internal nozzle geometries that produces conditions for dissolved gas release for further prediction.
3. To predict turbulence kinetic energy.

1.5 Scopes of Study

In order to achieve the goal of this research, the analysis preferred to uses ANSYS software; CFX version 14 as a design tool due to the trusted and proven software for simulation of fluid flows. Besides, the analysis is focused on the turbulence flow with pressure supply up to 9bar for n-butane and water liquid phase.

1.6 Thesis Outline

To accomplish this study, simulation by ANSYS CFX will carried out based on chosen nozzle design. Through this analysis, the volume of the thesis is divided into five chapters. The outlines of each chapter are as follows:

- Chapter 1 expresses the introduction of aerosol spray, it history, production and little bit about operation. A brief explanation regarding the concern of aerosol content and it application also described. Then the detail about objectives and scope of this study are determined.
- Chapter 2 consists of literature reviews on spray characteristic by a few researchers. The topics in the literature are related in order to analyse the characteristic of the spray.
- Chapter 3 explains the method to achieve the study. These are including the way to construct the design, equation involve and simulation process.
- Chapter 4 discusses the result from the simulation. Comparisons data are explain for further prediction and better future development design.
- Chapter 5 presents the general conclusions and recommendation of the study based on the result with the current and future perspectives.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A spray is a collection of moving droplets that usually are the result of atomisation and it moving in a controlled fashion. Atomisation refers to the process of breaking up bulk liquid into droplet, often occurs after the liquid passes through a nozzle. The type of nozzle selected is depending on the application of the spray and it will determine the effectiveness of the spray. Therefore understanding in spray characteristics is essential to select and develop the optimal nozzle. The details construction of the aerosol can as shown in Figure 2.1. Moreover, Figure 2.2 show the typical aerosol can were the actuators is that part that fits on the valve. Most actuators are in two parts, the main body and the exit orifice insert as a nozzle.

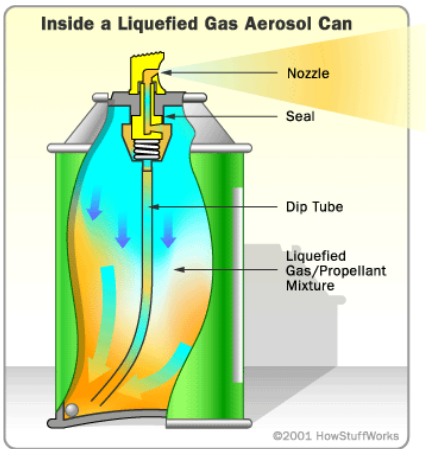

Figure 2.1: Aerosol can [5]

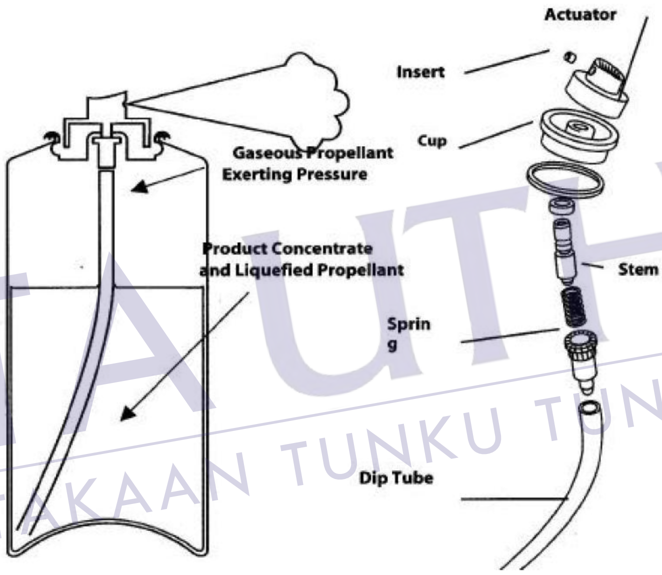

Figure 2.2: Generic aerosol can, courtesy British Aerosol Manufacturers Society [4]

2.2 Spray Characteristics

Spray characteristics were quantified in terms of spray properties such as drop size distribution, mean drop size, cone angle and penetration. It is analysed in terms of the gas/liquid mass ratio (GLR) [8]. The spray characteristics were investigated to determine the optimum aerosol spray while considering volatile organic carbon (VOC) reduction. An optimal effective aerosol spray nozzle can be developed by measuring the spray characteristics near the spray nozzle and it is necessary to consider the droplet quality and efficiency. Thus, it shows that evaluated the spray characteristics near the nozzle is the most important parameter when developing aerosol sprays [7].

2.2.1 Drop Size Distribution

The droplet size distribution (DSD) in sprays is the crucial parameter needed for the fundamental analysis of the transport of mass, momentum and heat in engineering systems. Moreover, the DSD determines the quality of the spray and consequently influences to a significant extent the processes of fouling and undesired emissions in aerosol spray.

According to R.A Sharief [3], the size of the aerosol droplets produced by conventional nozzle arrangements is dictated by a number of factors, including the dimensions of the outlet orifice and the pressure with which the fluid is forced through the nozzle. However, problems can arise if it is desired to produce a spray that comprises small droplets with a narrow droplet size distribution, particularly at a low pressure. It happened especially when fluids contains in the can reduced or depleted levels of propellant, or a relatively low-pressure propellant such as compressed gas or a low pressure systems is used. He analysed that, the problem of providing a high quality spray at low pressures is further exacerbated if the fluid used has a high viscosity because it becomes harder to atomise the fluid into sufficiently small droplets.

Figure 2.3 shows the guidelines for spray nozzle selection, where:

- Air atomizing nozzles produce the smallest drop sizes followed by fine spray, hollow cone, flat fan and full cone nozzles
- Higher pressures yield smaller drops and lower pressures yield larger drops
- Lower flow nozzles produce the smallest drops and higher flow nozzles produce the largest drops
- Increases in surface tension will increase drop size
- Drop velocity is dependent on drop size. Where:
    - Small drops may have a higher initial velocity, but velocity diminishes quickly.
    - Larger drops retain velocity longer and travel further

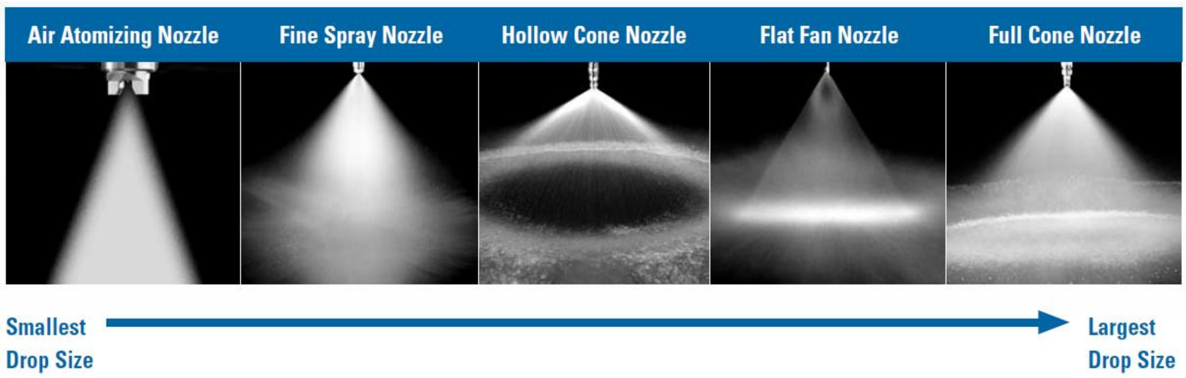

Figure 2.3: Drop Size Basics [9]

The range of drop sizes for aerosols spray is less than 100 microns which is fall in fine spray. Figure 2.4 shows the graph for classification of the test nozzle relative to droplet size by categories. Droplets smaller than 100 microns in size is obtain a horizontal trajectory in a very short time and evaporate very rapidly.

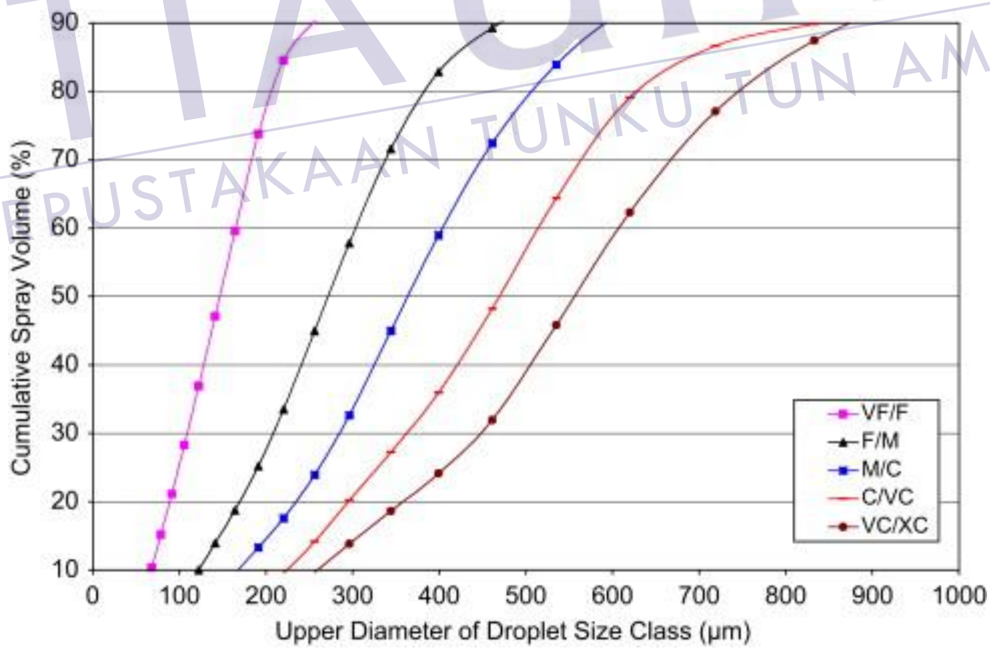

Figure 2.4: Classification of Nozzle Relative to Droplet Size Categories [10]

2.2.2 Mean drop size

The quality or fineness of an atomisation process is usually described in terms of a mean drop size. The most widely used is the Sauter mean diameter which represents the volume/surface ratio of the spray [11]. The volume median diameter (VMD or Dv0.5) is commonly used to characterize droplet size spectra. VMD is the droplet size (in microns) at which half of the spray volume is composed of larger droplets and half the spray of smaller droplets [10].

2.2.3 Cone angle

The cone angle is often given by as the angle formed by two straight lines drawn from the discharge orifice to cut the spray contours at some specified distance from the atomiser face [11].

2.2.4 Penetration

The penetration of a spray may be defined as the maximum distance it reaches when injected into stagnant air. It is governed by the relative magnitudes of two opposing forces; the kinetic energy of the initial liquid jet and the aerodynamic resistance of the surrounding gas [11]. Turbulence models had pronounced effects on vapor penetration while effect on liquid spray penetration was negligible. The best vapor penetration results were predicted by the RNG k-ε model using CONVERGE and realizable k-ε model using OpenFOAM.

2.3 Atomisation

The atomisation process is essentially one in which bulk liquid is converted into small drops. Basically it can be considered as a disruption of the consolidating influence of surface tension by the action of internal and external forces. Surface tension is the property of a liquid that causes droplets and soap bubbles to pull together in a spherical form and resist spreading out. This property causes sheets or thin ligaments of liquid to be unstable; that is, they break up into droplets, or atomise. Besides surface tension, the viscosity and density also take a part in affecting a droplet size [12].

2.3.1 Surface Tension

Surface tension tends to stabilize a fluid, preventing its breakup into smaller droplets. Everything else being equal, fluids with higher surface tensions tend to have a larger average droplet size upon atomisation. Table 2.1 lists a number of common materials and their surface tensions.

Table 2.1: Surface Tension of Familiar Liquids [12]

Surface Tension of Common Fluids	
Liquid	**Surface Tension (N/m @20°C)**
Ethyl alcohol	0.022
Soapy water	0.025
Benzene	0.029
Olive Oil	0.032
Lubricating oil	0.037
Glycerine	0.063
Water	0.073
Mercury	0.465

2.3.2 Viscosity

A fluid's viscosity has a similar effect on droplet size as surface tension. Viscosity causes the fluid to resist agitation, tending to prevent its breakup and leading to a larger average droplet size. Figure 2.5 represents the relationship among viscosity, droplet size, and when atomisation occurs.

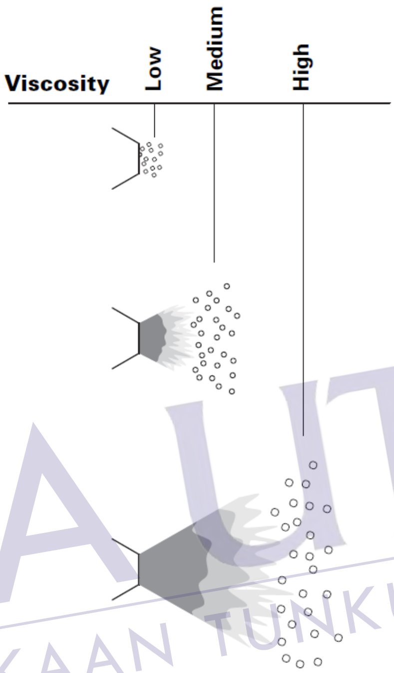

Figure 2.5: Viscosity, droplet size, and when atomisation occurs [12]

2.3.3 Density

Density causes a fluid to resist acceleration. Similar to the properties of both surface tension and viscosity, higher density tends to result in a larger average droplet size.

2.4 Atomiser

Numerous devices to generate spray flows have been developed and they are generally designed as atomisers or nozzles [13]. An atomiser is a device which converts a stream of liquid into a fine spray. The experiments carried out by R.A Sharief & G. Eales proved that, flow control devices permit control of droplet size, control of flow rate, spray pattern manipulation, the production of narrower droplet size distributions and reduction of can VOC content.

2.4.1 Atomiser Requirement

An ideal atomiser would posses all the following characteristics:

a) Ability to provide good atomisation over a wide range of liquid flow rates.
b) Rapid response to changes in liquid flow rate.
c) Freedom from flow instabilities.
d) Low power requirements.
e) Capability for scaling to provide design flexibility.
f) Low cost, light weight.
g) Low susceptibility to damage during manufacture and installation.
h) Low susceptibility to blockage by contaminants.
i) Uniform radial and circumferential spray distribution.

2.4.2 Type of atomiser

The type of atomiser is depending on the spray application. Most commonly atomiser used in industrial are as follows:

a) Plain-orifice atomiser

The plain orifice may operate in single phase or cavitating flow regime. It is a simple circular orifice that is used to inject a round jet of liquid into the surrounding air. Finest atomisation is achieved with small orifices but in practice the difficulty of keeping liquids free from foreign particles usually limits the minimum orifice size to around 0.3mm.

b) Pressure-swirl Atomiser

A circular outlet orifice is preceded by swirl chamber into which liquids flows through a number of tangential holes or slots. The swirling liquid creates a core of air or gas that extends from the discharge orifice to the rear of the swirl chamber. The liquid emerges from the discharge orifice as an annular sheet, which spreads radially outward to form a hollow conical spray.

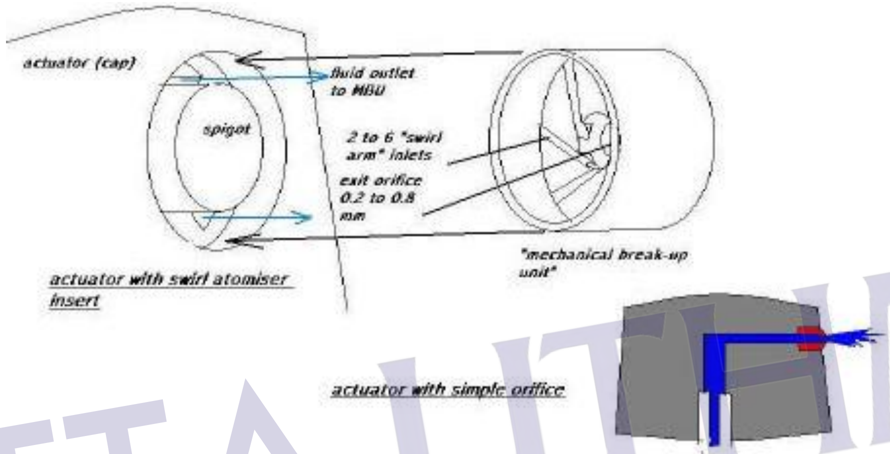

Figure 2.6: Actuator with Simple Orifice [4]

c) Effervescent flow atomizer

Effervescent atomisers are becoming more and more commonplace in numerous engineering applications in which a liquid must be fragmented into droplets. Major advantage of effervescent atomisers is their relative insensitivity to fuel physical properties and ability to perform over a wide range of liquid flow rates and can provide good atomisation over a wide range of operating conditions. Furthermore the E-atomisers can have larger orifice than conventional atomisers which alleviates clogging problems and facilitates atomiser fabrication [14].

2.5 Effervescent Atomisation

Effervescent atomisation is a method of twin-fluid atomisation that involves bubbling a small amount of gas into the liquid before it is ejected from the atomiser. Effervescent atomisation has been used successfully in a number of applications since its inception over ten years ago. It has been well studied during this period, and the published literature includes experimental and analytical investigations of both atomiser performance and the fundamental mechanisms involved in the atomisation process.

The literature also includes application-oriented studies that report the development of effervescent atomisers for gas turbine combustors, consumer products, furnaces and boilers, I.C. engines, and incinerators. Through these studies a fair appreciation of the capabilities of the technique has been achieved. Continuing work is aimed at exploring the use of effervescent atomisation in new areas, as well as acquiring a better understanding of current applications. More in-depth studies are also in progress on the various basic mechanisms that contribute to the overall atomisation process.

2.6 Internal Nozzle Cavitations

The study of the internal nozzle flow includes turbulence, developing pipe flow, and cavitations. Cavitations phenomenon can be defined as the formation of vapor bubbles in a fluid [15]. The generation of the cavitations was affected by the shape and dimension of the nozzle orifice.

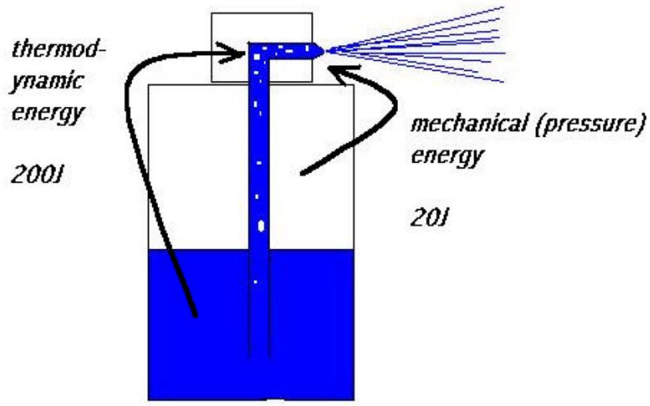

Figure 2.7: Energy sources for flashing propellant [4]

Figure 2.7 indicates bubbles in the dip tube and the actuator including nozzle. This is inevitable because the pressure drops with the flow along the tube, through the valve and around the bend in the actuator and nozzle: every drop in pressure changes more of the propellant into the gas phase. An inevitable result of this pressure drop and phase change is that heat is removed to provide the latent heat and this heat comes from the liquid and also the actuator. Thus aerosol cans and their sprays are always cool to the touch when spraying. This cooling action may be important when the sprayed formulation contains oils, such as silicone oil found in antiperspirants: these oils will increase in viscosity and may thus result in larger droplets [4].

2.7 Problems in Reduction of VOC

The reduction of VOC leads to two major problems, plus a range of ancillary difficulties related to these problems [4].

These major problems are:

(1) *Reduction of VOC inevitably means using less flashing propellant:*

This leads to less thermodynamic energy for atomizing and probably a lower can pressure, so less mechanical energy. An ancillary problem is that for most sprayed formulations, there is significant non vaporized liquid propellant in the emerging spray so that these “carrier droplets” contain significant (usually HC) propellant. In practice it is likely that removed liquid phase propellant from the can must be replaced, and the only acceptable replacement is water. With its high surface tension, and high viscosity, compared with liquid HC, this gives greater demands on achieving good atomisation efficiency. There is also a marketing reason for such replacement: the customer may resist purchasing products that do not appear to have much liquid in the can.

(2) The can contents of ethanol and certain solvents will need removal or reduction.

Ethanol is the main carrier fluid for many important applications. The problems caused by replacing it with water, which appears to be inevitable as there are no other replacements that are not targeted by legislation, have been described already.

The summary of current aerosol products by previous study is shown on Table 2.2. It provides the present main formats of pressurised aerosols including typical current spray characteristics, with the main emphasis on the Europe (EU) marketplace.

Table 2.2: Summary of Current Aerosol Products [4]

Product Category	CARB VOC limit	Current Products (Europe)	Typical Current Spray Characteristics	Problems
Hair spray	55%	European formulations 80% - 90% VOC (+), butane/propane, polymer in ethanol. European moves to restrict VOCs. Also DME or DME/butane at 30% propellant; 50% alcohol and 15% water.	Vol Med Dia. 50-80 Microns spray angle 30 degrees (+), hollow cone. Flow rate 0.3 to 1.2g/sec.	Require good atomisation, negatively affected by viscosity increase with water addition. Fast drying rate negatively affected by water and increased droplet size. Products must wet out hair effectively.
Air fresheners	Progressive-ly, 30% to 18% (liquid/ pump sprays)	Typically around 30% butane 68% water, plus fragrance, and emulsifier. Simple orifices common.	Vol. Med Dia. 30 to 45 microns. Flow rate 0.8g/s. 30 degree full cone. 1.5m minimum throw (penetration)	Finer sprays preferred, but must have adequate penetration (throw), difficult to get finer than 30-40 micron with aqueous formulation. Larger particle sizes rapidly settle, taking fragrance with them.
Anti-perspirants	HVOC 40% and MVOC 10%	Simple orifice with "bullnose" & VPT. Typ.composition: silicones 13%, hydrocarbon propellant 75%, Aluminium chlorohydrate powder 10%.	Vol Med Dia 10-20 microns. Flowrate 0.75-1g/s. Spray angle 20-30degrees full cone.	Interest in reducing inhalable fraction (sub-7 microns say) currently 20%+. Particulates + silicone = high viscosity: Non flashing spray would be coarse. Cool feel attractive to customer.
Personal Deodorants	HVOC 0% and MVOC 10%	Powder-free often essentially 97% VOC: 50% ethanol plus propellant plus perfume etc. MBU (Swirl) insert common.	Vol Med Dia up to 40 microns. Flowrate 0.6g/s. Spray angle up to 40 degrees, full or hollow cone.	Replacing ethanol with water can give poor "feel" to spray.

Spray Paints	88% but reducing	Hydrocarbon and/or DME propellant. Typically acrylic resins plus solvent. Solids 10-15%, HC 25-30% solvent 55%. MBU (Swirl) insert, or fan jets.	Ideally Vol Med Dia 40-50 micron. Flowrate 1g/s (+) Spray angle wide rages used.	Water based products for low VOC have drop size challenges. Narrow size distribution ideal: less than 30 microns = drift, greater than 60 microns = runs.
Insecticide	crawling bug 15%. flying bug 25%	Hydrocarbon propelled, aqueous or solvent formulation. MBU or simple orifice, with VPT.	For flying insects Vol Med Dia 30-40 microns. Flowrate 0.5-1.0g/s (+). For crawling insects larger droplets and narrow coverage, 1-2.5 g/s	Good penetration with no “fall out” of large drops plus low inhalable fraction: low VOC aqueous formulations have difficulty in achieving this.
Furniture Polish	25% (01/01/94) 17% (31/12/04)	Butane propellant, water, butane and solvent, usually MBU insert. Compressed air-driven systems: wax, solvent, surfactant, water: MBU Vol Med Dia 110 (HC propellant) to 150 microns (+) compressed gas. Flowrate 1.5 g/s (+) Spray angle 30 to 90 degrees	Vol Med Dia 110 (HC propellant) to 150 microns (+) compressed gas. Flowrate 1.5 g/s (+) Spray angle 30 to 90 degrees hollow cone.	Wax-water solution is viscous and non- Newtonian, problems with reduced solvent and no flashing.

2.8 Nozzle Design in Reduction of VOC

From the experiments carried out by Raj designs on reduced VOC hair spray, its designs has proven that great improvements on reduction of drop sizes and crucial reduction on inhalable by keeping the flow rate the same with comparison to the original cap. More advanced designs of actuators have been made depending on the inventions related to shape chambers, multiple passages of flow and throttles. The flow of improve atomisation produces is illustrated in Figure 2.8. It is now possible to manufacture household can aerosols such as air fresheners, body sprays and hair sprays with massive reduction in hydrocarbons or volatile organic compounds (VOC). Also some of these designs can help to atomise viscous fluids such as oil, polish and paint. Also these designs can work with compress gas can products. From the experiments carried out it is obvious that these designs helped several products which was rather difficult not a long time ago. It is also helped to reduce the inhalable of these cans especially with the anti-perspirant, oil and paint [3].

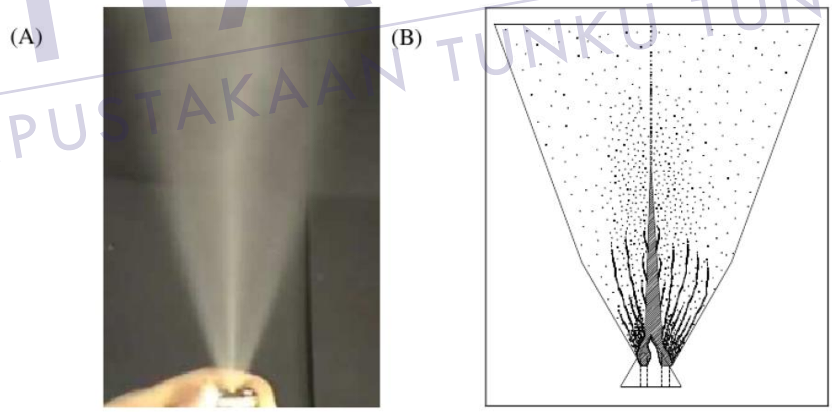

Figure 2.8: Flow Schematic of Atomisation
Flow Visualization of Improved Atomizing Nozzle (A) &
Photograph of Spray Plume (B)

Based on the further development in actuator design and investigation into domestic household aerosols studied by R.A Sharief, the new nozzle design can be predicted using his design because nowadays, it is possible to incorporate a wide range of flow control devices and orifice designs into a single injection moulded part. Since a new injection moulding technique allows the actuator and exit orifice to be made as one part [16].

The designs that studies by author are illustrated in Figure 2.9, where the selection of the different throttle and exit stages that have been tested for different products. The description of the design has been used is shown in Table 2.3. While, Figure 2.10 shows there is a “throttle” stage leading to a pre-chamber followed by an exit orifice stage.

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