

Compressed gas domestic aerosol valve design
using high viscous product

by

Amir Nourian, Ghasem G Nasr, Daniel Pillai and Mark Waters

reprinted from

**THE INTERNATIONAL JOURNAL OF
MULTIPHYSICS**

2014: VOLUME 8 NUMBER 4

MULTI-SCIENCE PUBLISHING

Compressed gas domestic aerosol valve design using high viscous product

Amir Nourian^{1*}, Ghasem G Nasr¹, Daniel Pillai² and Mark Waters²

¹Spray Research Group (SRG), Physics and Materials Research Centre (PMRC), School of Computing, Science and Engineering (CSE), University of Salford, Salford, Manchester, M5 4WT, United Kingdom

²The Salford Valve Company Ltd (Salvalco), Technology House, Lissadel Street, Salford, Manchester, M6 6AP

ABSTRACT

Most of the current universal consumer aerosol products using high viscous product such as cooking oil, antiperspirants, hair removal cream are primarily used LPG (Liquefied Petroleum Gas) propellant which is unfriendly environmental. The advantages of the new innovative technology described in this paper are:

- i. No butane or other liquefied hydrocarbon gas is used as a propellant and it replaced with Compressed air, nitrogen or other safe gas propellant.
- ii. Customer acceptable spray quality and consistency during can lifetime
- iii. Conventional cans and filling technology

There is only a feasible energy source which is inert gas (i.e. compressed air) to replace VOCs (Volatile Organic Compounds) and greenhouse gases, which must be avoided, to improve atomisation by generating gas bubbles and turbulence inside the atomiser insert and the actuator. This research concentrates on using "bubbly flow" in the valve stem, with injection of compressed gas into the passing flow, thus also generating turbulence.

The new valve designed in this investigation using inert gases has advantage over conventional valve with butane propellant using high viscous product (> 400 Cp) because, when the valving arrangement is fully open, there are negligible energy losses as fluid passes through the valve from the interior of the container to the actuator insert. The use of valving arrangement thus permits all pressure drops to be controlled, resulting in improved control of atomising efficiency and flow rate, whereas in conventional valves a significant pressure drops occurs through the valve which has a complex effect on the corresponding spray.

Keywords: Aerosol valve, Compressed gas, Bubbly flow, Effervescent, Continuous spray, High viscous

*Corresponding Author: E-mail: a.nourian@salford.ac.uk
Associated Web site: <http://www.cse.salford.ac.uk/srg>

1. INTRODUCTION

There are a number of technical challenges in replacement of the consumer aerosol valve using conventional propellant (such as butane) with safe gases such as air and nitrogen. These challenges have limited their application in the market, although they have environmental advantages:

- i. Insufficient atomisation power, leading to the spray having a large droplet size and inferior spray pattern. This becomes Significant drop off in spray 'power' as the can is depleted due to the reduced volume of liquid in the can to be sprayed causing a corresponding decrease in pressure.
- ii. Consumers notice a further reduction in spray performance as well as not having full recovery of the product.

The valve to be designed in this investigation should ideally overcome or reduce both of these problems and this done by exploiting a phenomenon known as effervescence or "bubbly flow". Bubbly flow comes about when a small proportion of compressed gas within the can is injected directly into the passing flow of product within the valve assembly. Effervescent is the process of various actively introducing gas bubbles into a liquid flow, immediately upstream of the exit orifice, thereby forming a two-phase flow. These are of interest due to their potential for using a small flow of atomising gas to produce a very fine spray [1 and 2]. Researchers and engineers have studied their use for application including household aerosols [3 and 4]. The technique has not been applied in commercial aerosols because even at the low value of Gas/Liquid mass Ratio (GLR) used (around 1%), can pressures drops too quickly if using the compressed gas in the can to atomise. Also dispensing the gas and liquid simultaneously and producing the required flow, is itself complex. In addition, effervescent atomising prediction for modelling drop size was recently made by researchers on high viscosity material such as gelatinized starch suspension [5 to 7]. Moreover, Asumin [7] designed atomiser inserts using inert gases for domestic aerosols which will be discussed in details in the next Section.

The word "domestic" and "consumer" has been used throughout this paper interchangeably as normal practice which provides a same connotation. The inventive steps of the corresponding valve designs were initially filed with a number of the interlocking patents [8 to 12]. The overall aims of this study are to design consumer aerosol valves using inert gas propellants (i.e. compressed gas, nitrogen, etc) generating "bubbly flow" inside the flow passage upstream of the atomiser insert. Thus by providing the correct geometry of orifices and mixing chamber, the flow becomes highly energised and turbulent. Specifically the prime objectives of this investigation are as follows:

- To produce sprays that look, feel, spray and perform like current consumer aerosols
- Replace butane or other Liquefied Gas Propellants (LPG) with safe inert gas propellants (i.e. air, nitrogen etc)
- Step-change in performance over current compressed gas technology
- Cover all aerosol formats including bag-on-valve aerosol
- No cost or manufacturing penalties and also utilised standard components or standard component sizes
- Constant discharge flow rate and drop size through the life of the can
- Easy filling and no requirement for VPT (Vapour Phase Tap)

Conventional aerosol valves use a hole in the housing which is called VPT (Vapour Phase Tap) to allow the propellant gas into the liquid flow upstream of the valve. However, making

a bubbly flow through a valve system is not ideal when VPT is used since a considerable pressure drop transpires through the valve.

The novel consumer aerosol valve designed and demonstrated in this study [13], using inert gas such as compressed air, Carbon dioxide (CO₂) or Nitrogen (N₂) propellants, have been applied to a wide variety of continuous aerosol valve applications using high viscous products (e.g. antiperspirant, olive oil, gels, hair removal cream, etc).

1.1 PREVIOUS WORKS

Some published works related to domestic aerosols using compressed gas are currently available in which this section intends to highlights these findings. These works include studying on to the atomiser insert designs [6, 7, 14 and 15] and also the previous study on the consumer aerosol valving arrangement using compressed gas [16 and 17].

In relation to a new atomiser insert design for domestic aerosol valves working with inert gases Asumin [6 and 7] divided the work into two different phases which were “Liquid Phase” and “Two-Fluid Phase”. Figure 1 shows the geometry of the atomiser insert and the characteristics of the bubbly flow at the downstream end of the flow channel combine to give a number of turbulent bubble-laden jets impacting on the sharp edges (6). Therefore, when the jets are developed, it makes the fluid (liquid and gas) travels along the orifice channel (4) and formed flow separation from the wall of the first part of orifice (4). The length of orifice channel (4) is such that the flow re-attaches to the wall at a downstream region thereof. The separation and re-attachment is a highly fluctuating phenomenon which is very beneficial to the atomisation into droplets of the jet emerging from the exit of orifice channel (4). The result from the device is a fine liquid spray. Furthermore, the fluctuations at the exit of expansion chamber passageway (3) provide a different hissing sound which is considered as “attractive” to users of aerosols since such a sound is expected from current liquefied gas propellant aerosols.

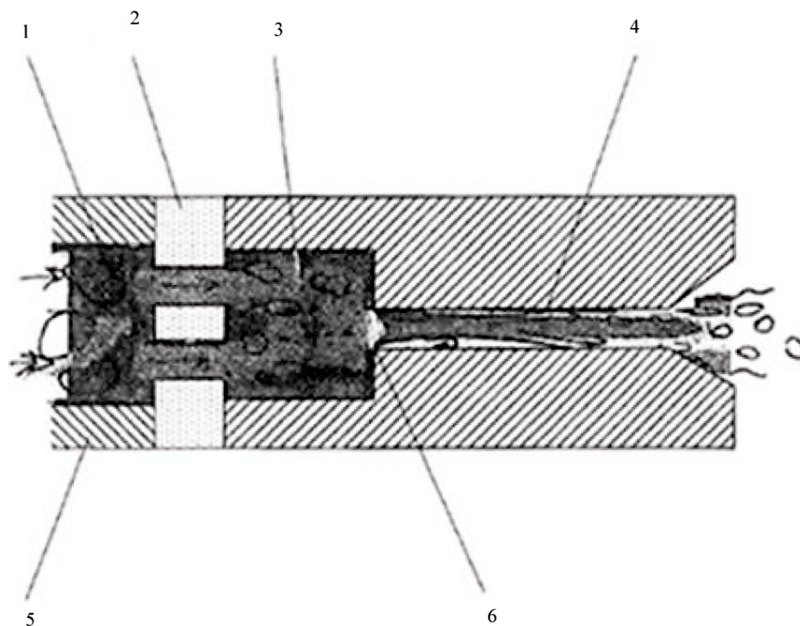


Figure 1: A new atomiser insert [6 and 7]

Yuka [14] also worked on the design of an atomiser insert using compressed gases. His designed comprised an aerosol can in which it filled up with an aerosol composition discharged. A switching mechanism which are aerosol products provided with a discharge member attached to the aerosol can, and is switched to a discharge mode which discharges the aerosol composition with misty state, and a discharge mode which is liquid drop-like and discharges the high viscous compositions (e.g. olive oil, yellow bees wax, liquid paraffin, etc). As can be seen in Figure 2, a switching mechanism (1) switches connection between route of a push button (2) and routes (3, 4) of a mist generating nozzle (5) and a droplet nozzle (6), to discharge aerosol composition in mist form or droplet form. The mist generating nozzle is inserted into a stem (7) of a valve (8) in the aerosol can (9). A buffer (10) reduces the flow viscosity of the aerosol composition through the droplet nozzle.

As is shown in Figure 2, when stem is in open position, there is at least a 90° bend in the upstream flow path part of the valve. Indeed, this relatively large change in direction of the flow is an inevitable reason of the pressure loss through the flow passage. This is in contrast with the design of the “low loss” valve that presented in this paper which has no convoluted passages to the direction of flow and thus causing no pressure loss within the valving arrangement which results in better spray performance.

In 1992, Satoshi and Akira [15] also carried out study on designing an atomiser insert for spraying highly viscous products. These investigators reported that their design could also be used to continuously dispense, even, highly viscous solutions by dividing, with a moveable bulkhead, inside a container into a first chamber for housing the liquid and a second chamber for housing pressure applying agent and placing a cock on a dispensing tube for communicating the first chamber with outside as shown in schematically in Figure 3.

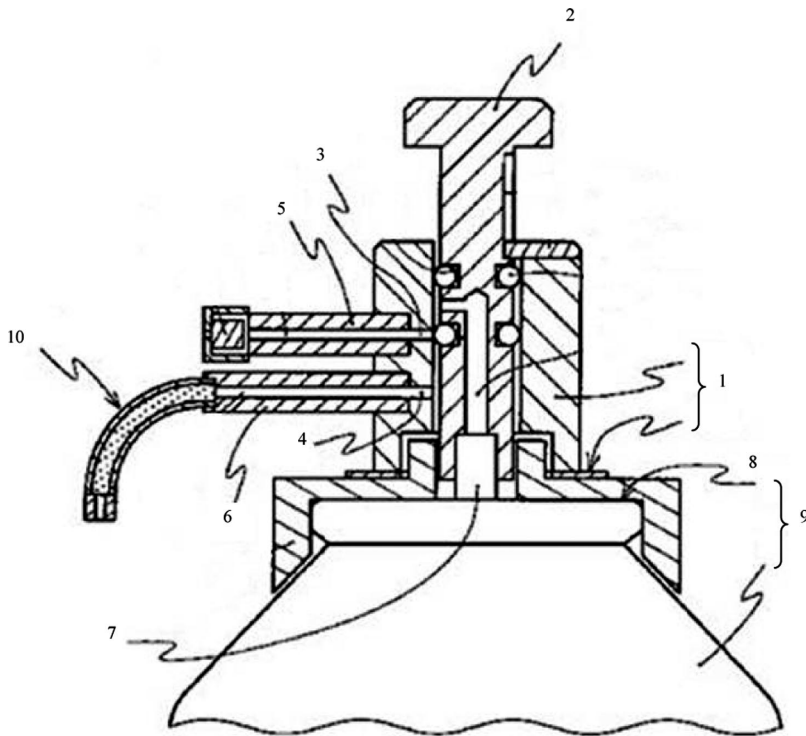


Figure 2: Schematic design of 'Aerosol Product' [14]

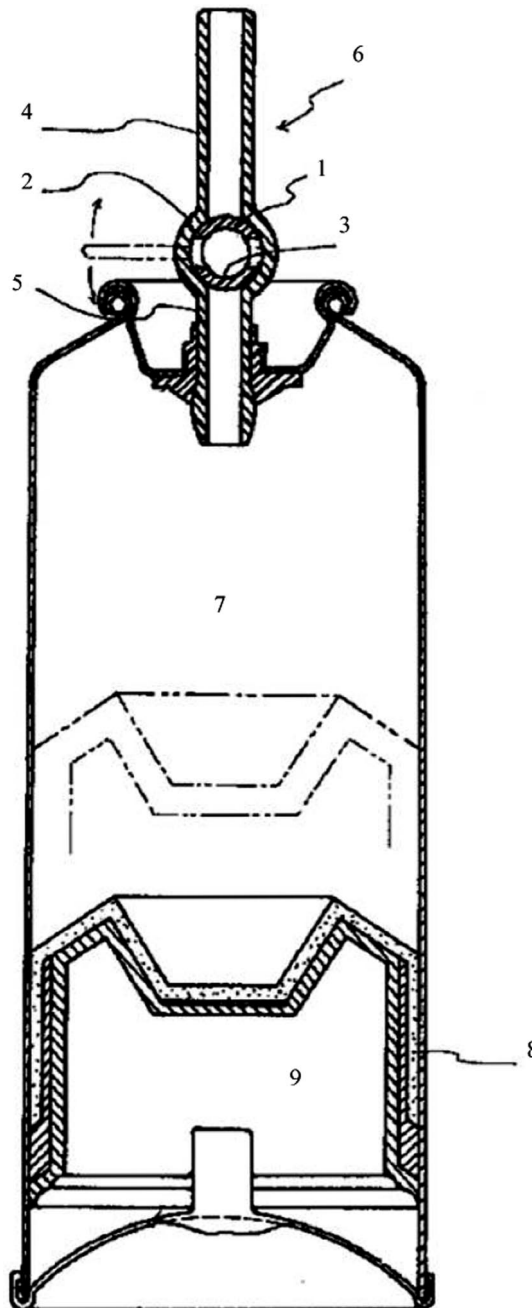


Figure 3: Schematic design of 'Highly viscous stock solution dispensing container' [15]

As can be seen in Figure 3, when a lever (1) of a lid (2) is laterally directed, a through hole (3) of the lid is also laterally directed, so that an upper tube (4) and a lower tube (5) of a two-way cock (6) are shut by a side of the lid. When highly viscous stock solution is to be dispensed, the lever is vertically directed whereby the through hole of the lid coincides with the upper tube and the lower tube so that a first chamber (7) with the highly viscous stock

solution is communicated with outside. Therefore a piston (8) rises by pressure of pressure applying agent in a second chamber (9), and the highly viscous solution is dispensed from an opening end of the upper tube. In this case the upper tube, the through hole and the lower tube make a direct tube with its inner face smooth, so that unnecessary viscosity resistance is small. Therefore a drop in pressure approximately uniformly occurs over the lower tube, the through hole and the upper tube thereby dispensing the solution smoothly.

It is not clear from the work of these authors that whether or not the upstream and downstream fluid flow path sections, being moveable relative towards each other, with operation of the actuator mechanism, are to open the valving arrangement. The design of “low loss” valving arrangement in this investigation is, however, opened by relative movement which to allow upstream and downstream flow path sections to come into register with each other. Again, this is a key to obtain consistent spray performance for the corresponding products when using inert gases.

There was also a study on the design of continuous valve using inert gases by Dunn and Weston [16] in 1990 in which the valve was attempted to improve the fineness of sprays generated by an inert gas. The main objective of this design was to bleed the gas into the liquid achieving two fluid atomisation and thus “bubbly flow” to have increase in liquid breakup and provide fine sprays. Figure 4 shows the “Flow Discharge Valve” which was granted in 1990 by Dunne et al. This valve is regulating the flow of a liquid product from an aerosol canister (1) which is pressurised by a permanent gas propellant comprises a tubular valve stem (2) formed with a liquid orifice (3) and a gas orifice (4) leading into a mixing chamber (5). Downstream of the chamber is at least one restrictor (6) through which the mixture is forced to pass to produce a choked or sonic flow, which results in the mixture expanding to form a foamy mixture.

As can be seen in Figure 4, the valving arrangement proposed by these authors, comprised of a number of restrictors in the liquid passage that are to transmit the liquid from the first passage to a mixing area and also conveying separately the pressurised gas from the second passage from the liquid into the mixing area. The severe flow blockage introduced by the Dunne et al [16] designs would provide unacceptable low flow rates unless very much higher can pressures than those in current use as well as being unsuitable for spraying high viscous products.

Smith and Gallien [17] also reported on the design of an invertible spray valve utilising container containing same [17]. As shown in Figure 5, this design is mainly related to an improved spray valve, e.g. an aerosol valve, a tilt valve, a pump spray valve, or a trigger spray valve, for use in dispensing product from a container. Specifically, the valving arrangement includes a valve body with a lower portion consist of a ball chamber having a gravity-responsive ball within enables the valve to be used with either end up.

Briefly, the valve shown in Figure 5 comprised of a housing (1), defining a longitudinal axis, with a circular side wall (2) extending down beyond a floor (3) of the body to define a socket. Into this socket is frictionally engaged an attachment (4) having a circular upper end and a nipple (5) at its lower end. The attachment is partitioned into a primary product passage, communicating with a product outlet extending through the floor of the valve body, and a ball chamber, the lower of which is provided with a valve seat with a bypass opening communicating with the primary product passage. A ball chamber passage (6) is formed in the ball chamber above the valve seat (7) and a ball (8) is normally seated, via gravity, on the valve seat when the container is in a normal upright position. When the container is inverted, the ball drops away from the seat and permits passage of product through the ball chamber passage, through the bypass opening into the primary product passage and up into the valve

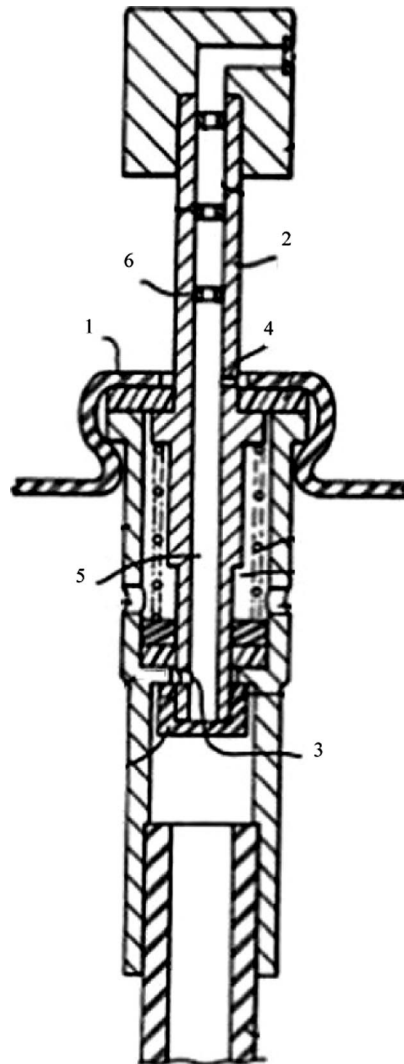


Figure 4: Schematic design of “Flow Discharge Valve” [16]

body for discharge. At least one of a ball chamber longitudinal axis and a ball chamber plane is inclined relative to the longitudinal axis defined by the remainder of the valve to alter the degree of permissible tilt of a container containing the valve before the ball becomes unseated.

As can be seen in Figure 5, the liquid passage experiences at least two twist passages (i.e. through the dip tube and also around the ball). These restricted and intricate passages cause severe pressure drop coefficient in the valving system and will be detrimental to the direction of the flow and that subsequently affect the required spray performance. In comparison, the new design of the valve used in the present investigation does not include such restrictors or complicated flow routes which can therefore provide better atomisation quality and flow rate “constancy”.

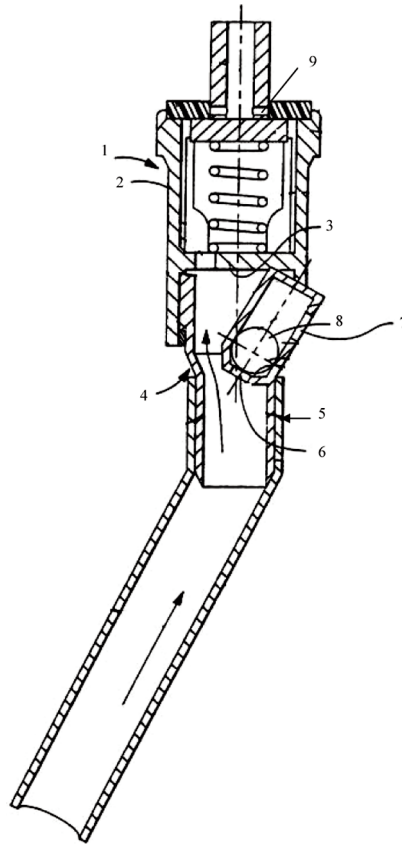


Figure 5: Schematic designs of 'invertible spray valve and container containing same' [17]

2. NOVEL AEROSOL VALVE DESIGN USING HIGH VISCOUS PRODUCTS

This section introduces a novel domestic aerosol valve called "Low Loss" valve for use in continuous spraying high viscous products (up to 400 cP) such as hair removal cream, antiperspirants and cooking oil. This uses the concept of completely removing all restrictions on the liquid flow between the dip tube and the actuator-insert assembly so that there are no blockages caused by small orifices, except of course that of the atomiser insert.

Figure 6 shows the prototype design of the "Low Loss" valve in which there is a light stainless steel spring behind the ball to push the ball back and seal the liquid inlet passage to the stem when the stem is in closed position. "Low Loss" valves that are proposed here, when the valve is fully opened there is no change in liquid passage direction and also no changes in cross sectional area neither of the liquid passage nor for bubbly flow if gas is injected into the liquid upstream of the valve. For pipe systems the equivalent to a low loss valve is a ball valve for which a cylindrical hole in the ball has the same internal diameter as that of the pipe so that when the valve is opened the fluid flow experiences no restrictions and the valve has an extremely small pressure drop coefficient. The design for evaluation and spray testing was chosen on the bases of:

- Relatively simplicity and thus low cost
- Novelty and thus ease of IPR protection
- Perceived high chance of good reliability.

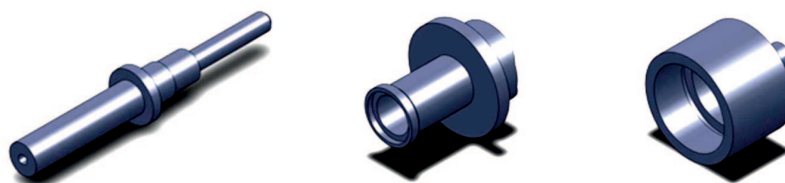
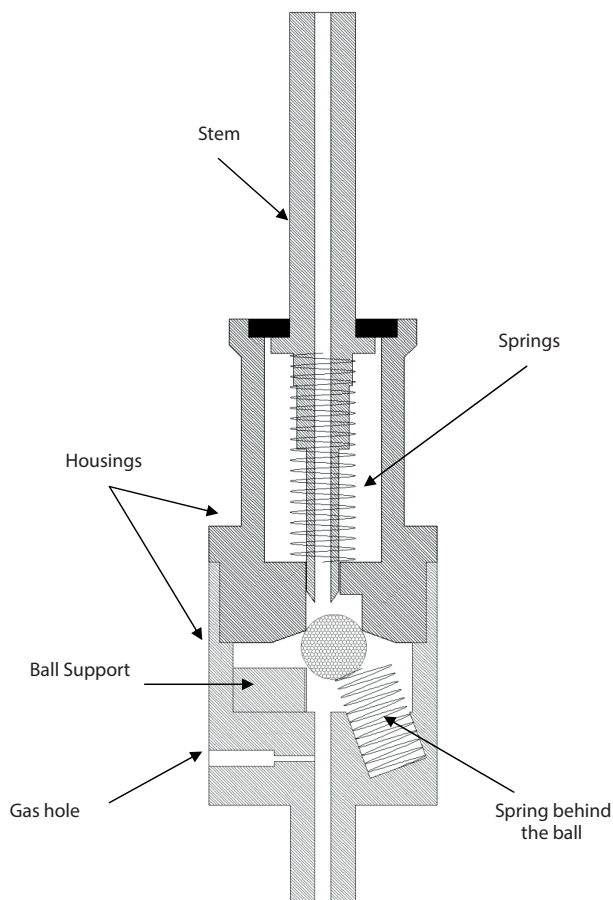


Figure 6: Prototype design of new domestic aerosol valve called “Low Loss”

3. APPARATUS AND METHODS OF DATA PROCESSING

This Section generally discusses all experimental apparatus used and the test procedures they were used in. The author’s work used almost entirely unsteady sprays from conventional metal aerosol cans and also a special commercially available glass pressurised reservoir.

3.1 VALVE MOUNTING

There were two different types of aerosol containers for mounting valves which were used in this investigation. A commercially available glass aerosol research container (the “glass can”) was available for more trials this valve because it was more convenient to use and

could be used to measure liquid flow rate by the weighting method. The “Glass Can” has 100ml volume capacity and it was used to model as a conventional can with pressure up to 10bar. The valve assembly could easily be used again and again with easy refilling and re-pressurising. In the later stages commercial aluminium and tinplate cans (see Figure 7), of various volumes and pressure ratings, were used for testing the valves in real conditions. In these cases it was found that once a valve was crimped in a cup and onto a can the valve could not be dismantled for maintenance and cleaning.

3.2 Crimping method

Crimping method was one of the major apparatus in this investigation in which aerosol valve components attach together and into mounting valve cups, and subsequently into the cans in some cases. This machine uses collets to expand and push the metal of the valve cup under the curl of the can. The machine includes of a filling chamber for propellant and collets for crimping and “swaging” the assembled valve into a can. Collets move into the mounting cup and spread to a specific diameter and depth.

3.3 FILLING METHOD

One of the most major methods in aerosol filling is the “Gasser Shaker” in which the can is vacuumed and the assembled valve is crimped to the can and then the propellant is injected into the can with a plainly shakes [18 to 20]. In this investigation, when the assembled valve was used in the aluminium can or tinplate can, this method was used to fill the can with an inert gas. Figure 7 shows the method of filling in this investigation. The sample can is vacuumed and there is no liquid into the can. The “brass can” is filled with required liquid and it is pressurised. When the valve is opened, the liquid into the brass can is pushing into the trial can till the required ratio is gained. Then the valve is closed. Subsequently, the can is pressurised as shown in Figure 7 with an inert gas. Then the pressure is checked with the pressure gauge.

3.4 EXPERIMENTAL ERRORS

3.4.1 Droplet size

The laser family and its family of light scattering instruments are accepted as benchmark particle sizing devices and usually an accuracy of $\pm 1.0\mu\text{m}$ for $D_{(v,50)}$ is reasonably assumed, provided that the spray meets certain conditions which include:

- Obscuration of laser beam to be between 5 and 60% approximately: this was the case for the current measurements
- Beam steering effects of vapour are either negligible or can be obviated by the “kill data” routine that removes its effects.

3.4.2 Liquid flow rate

Apart from when using the “brass can” reservoir, the liquid flow rate during spraying is measured by using a stopwatch to spray for periods of, usually, 10s or 20s, and weighing the can and its contents before and after this period. Error contributions are:

- Time duration is measured to within $\pm 0.5\text{s}$ approximately. In addition there are unknown transient effects because spraying start up and shut down when pressing and releasing the actuator to activate the valve, cannot be truly instantaneous.
- The weight is measured to within $\pm 0.1\text{g}$, a typical sprayed mass being 5-10gr in 10s
- The measured Liquid Flow rate is estimated to be accurate to within $\pm 10\%$ at the worse.

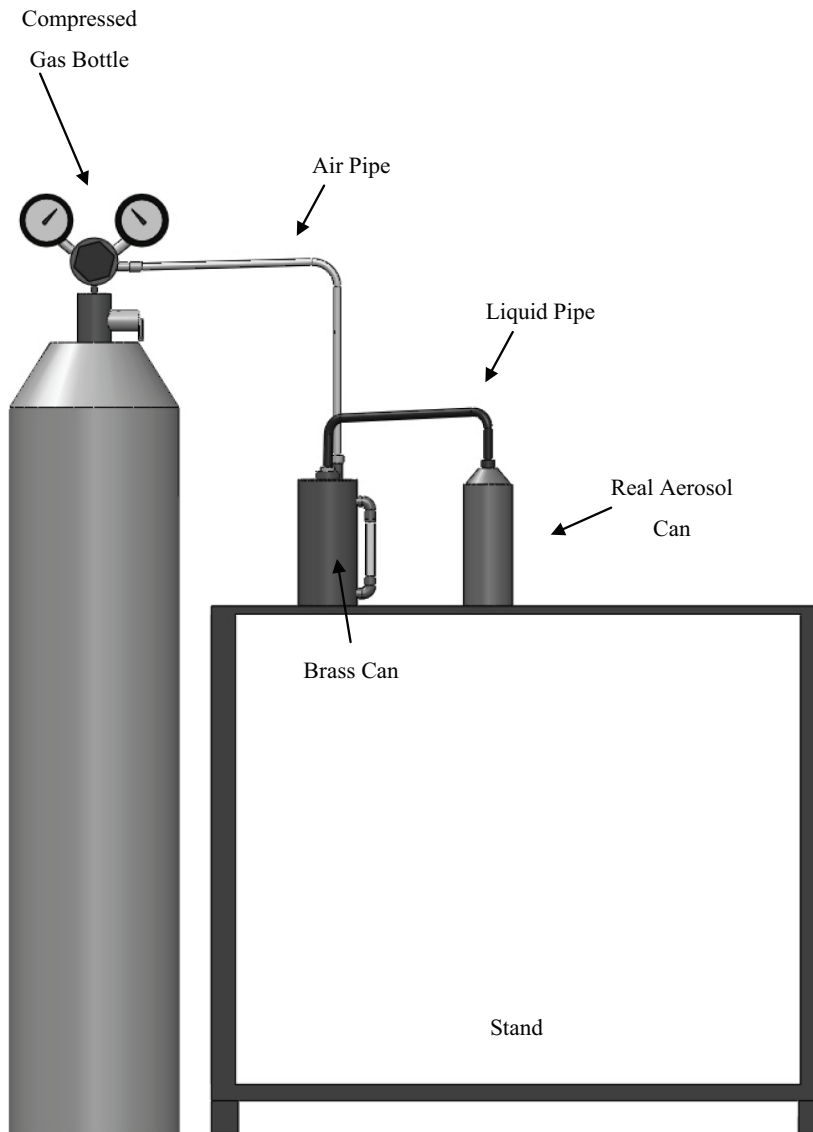


Figure 7: Filling method

3.4.3 Other error sources

The above errors should usually be random and would manifest themselves as scatter in data. When measurements were taking there are other potential sources of error that are more systematic for a given set of data. For example if the spray is positioned so that it does not project centrally across the laser beam of the laser instrument, there would be systematic errors as the can is evacuated with it remaining in the same position. During the experiments the development device nature of some of the valves led to slight jamming of the stem and, as mentioned in the appropriate sections, this can affect the spray and the measured flow rate.

4. PRESSURE LOSS COEFFICIENT MEASUREMENT

Referring to Figure 8 the valve to be tested is mounted vertically with the outlet C (at top). The inlet B (at bottom) is connected to 3-5mm internal diameter flexible tubing using adaptor fittings if required. The length of tube linking the valve with the pressure measurement position A should not exceed 0.5m. It is essential that the pressure drop measured is representative of the valve itself and the pressure drop should not be influenced by additional loss creating components that may form part of an aerosol delivery device or by the supply conduit to the valve. If such components, that do not form part of the valve, cannot be removed, their contribution to the pressure drop is taken into account by the procedure described below.

The outlet and inlet of the valve is supplied with water, via a flow meter, from a steady supply source at 15-25°C, and this water can be clean mains water but is preferably distilled water. The flow meter should be capable of providing measurements of water volume flow rate with 0.02 ml/sec accuracy, or better, and should cover at least the range from 0.2ml/sec to 2ml/sec. At point A there is a junction at which a pressure measurement instrument is connected. This is preferably an electronic transducer type of device, designed for use with water, and should have an accuracy of 1.0mbar (100Pa) or better with a range from zero up to at least 5bar (5kPa). The outlet for the water at point C should be at the same height as point A.

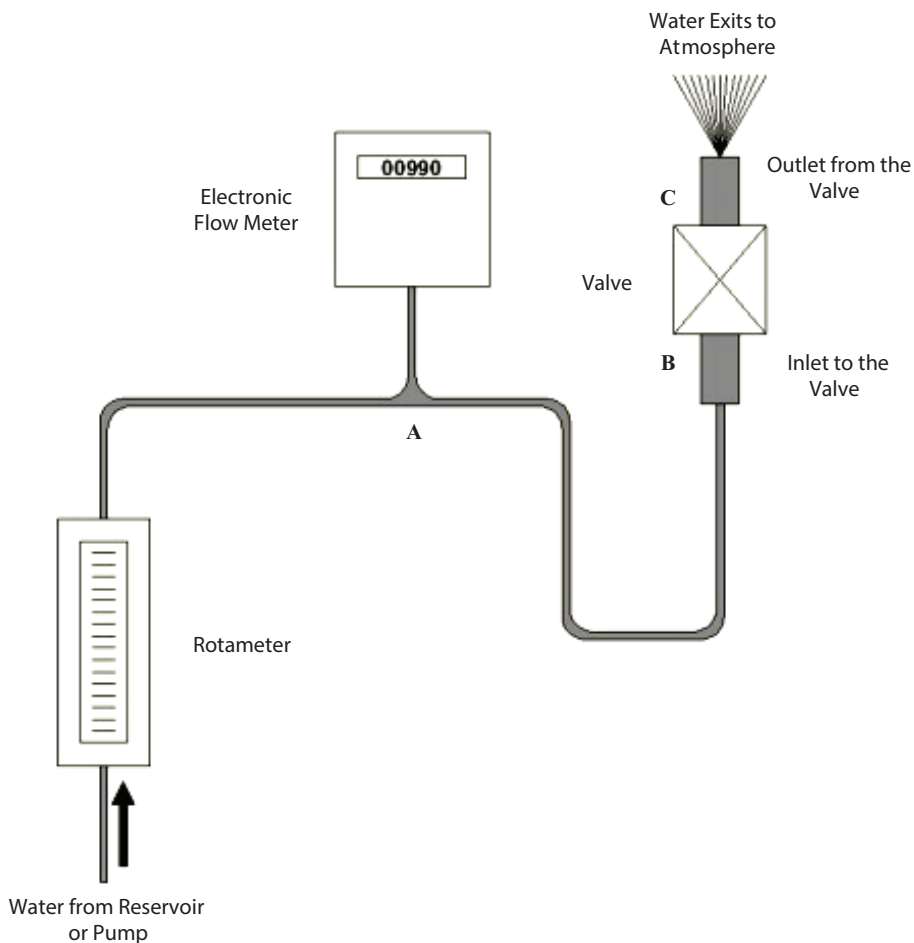


Figure 8: Schematic diagram of pressure loss coefficient measurement with using a valve

In order to compare different valves a common liquid volume flow rate Q should be used at the valve, and a flow rate $Q = 1.0 \text{ ml/sec}$, is used, this being representative of that found in the stem in many consumer aerosol devices. In order to calculate a characteristic velocity V for a valve, the internal diameters of the inlet B and outlet C should be measured. If these are not equal then the smaller value, C , should be used to calculate the representative cross-sectional area, where A has unit m^2 and D has unit m . The flow rate is Q , and the characteristic velocity, V , can be calculated from this relationship.

Applying conversions from metres to mm and from m^3/s to ml/s , it is conveniently found that:

$$Q = V.A \rightarrow Q = \frac{\pi}{4} d^2 V \frac{\text{ml}}{\text{s}} \quad \text{if } Q = 1 \frac{\text{ml}}{\text{s}} \text{ and } d = 1 \text{ mm } V = 1.27 \frac{\text{m}}{\text{s}}$$

To carry out a test the valve is fully opened and the test flow rate is set up. When steady conditions have been established the pressure P_1 is recorded. It is important to ensure that there are no bubbles or airlocks in the flow path or in the valve. The test should be repeated at least 5 times and an average value of P_1 should be used. In order to remove the effects of pressure drops caused by other features of the flow between points A and C , that are not part of the valve, a second test should be carried out. As shown schematically in Figure 9 the valve is removed however the supply conduit to the valve is retained. For a conventional aerosol valve, as shown in Figure 8, the valve housing is kept in place and

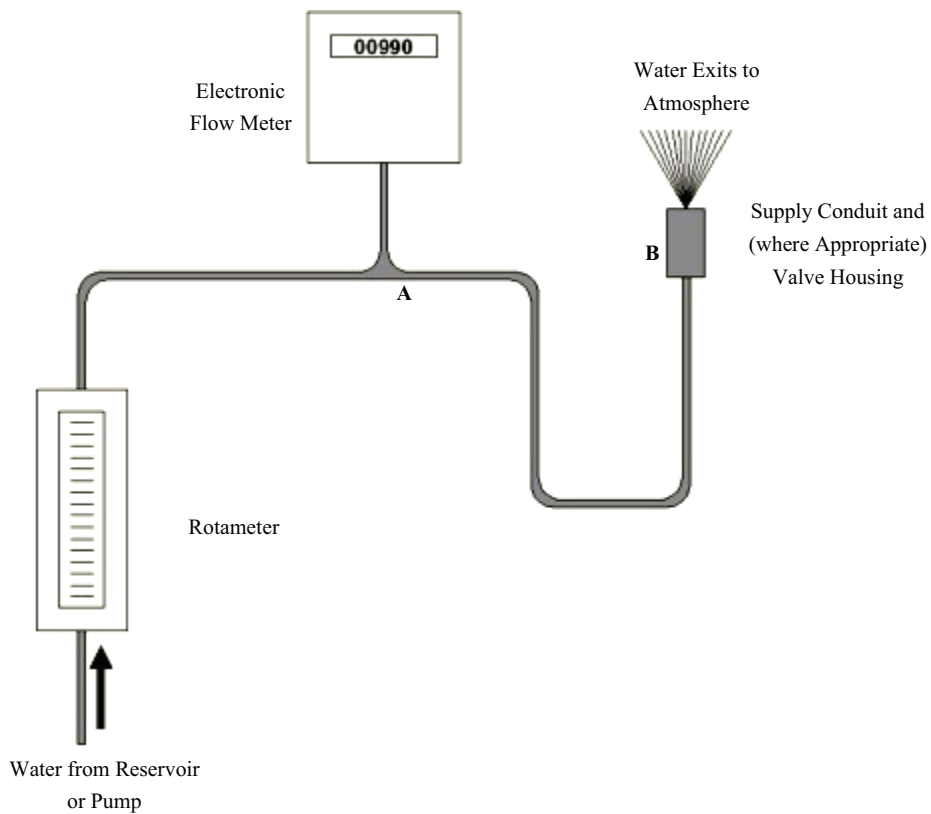


Figure 9: Schematic diagram of pressure loss coefficient measurement without using a valve

connected to the water supply; however the valve stem, spring, sealing gasket and metal aerosol cap (into which the valve housing is normally crimped) are removed. A second test is carried out at the same flow rate as for the first test and a pressure P_2 is recorded.

The representative pressure drop for the valve is then found from $\Delta P = P_1 - P_2$.

The loss coefficient C of the valve is found by dividing this pressure drop by the dynamic head of the flow at the valve, the dynamic head being $\frac{1}{2} \rho V^2$ where ρ is the density of the water, so:

$$C = \frac{2 \times \Delta P}{\rho V^2}$$

Where ΔP has units bar, ρ has units kg/m^3 , and V has units m/s . As examples of actual testing using this procedure by the Inventors:

1. A new low loss cylindrical valve, with cross section similar to that shown in Figure 8 and with conduit and exit each of 1mm diameter, was tested and yielded a loss coefficient: $C = 3.40$
2. A conventional valve was tested of the type used with liquefied propellant hairspray aerosols. This had a single outlet for the stem with diameter 0.5mm. The characteristic diameter was the internal diameter of the stem which had $D = 1.8\text{mm}$. This test yielded a loss coefficient: $C = 1750$
3. A conventional valve, similar to that in, was modified by drilling six holes of 0.5mm diameter as stem inlets, and also widening the channels through which the liquid must pass inside the valve. Tests with this modified conventional valve yielded a loss coefficient: $C = 35.1$.

The result obtained using this testing procedure the specify that an aerosol valve may be termed a Low Loss valve if it achieves a value of loss coefficient, that is less than or equal to 10, and preferably, less than or equal to 5.

5. RESULTS AND DISCUSSIONS

Ideally the new consumer aerosol valve design should be capable of performing in a similar way to current conventional (liquefied gas propellant) aerosol valves, and certainly have better spraying performance for a wide range of high viscous products. The spray performance can be best described by characteristics describing drop size, liquid flow rate, constancy of drop size and flow rate during can lifetime, and the capability of fully evacuating the can of liquid. The required performance should be achievable using existing commercially available cans and ideally using 12 bar cans which would be filled at 9 to 10bar.

This Section presents a spray performance of the "Low Loss" valve with using olive oil and describes the results of this test. Also, it shows a comparison of olive oil spray performance of "low loss" valve and a conventional domestic valve which was provided from a major company in which because of the strict confidentiality imposed the authors cannot mention its name. Furthermore, this Section provides some qualitative spray performance with using some different high viscous products to show the capability of this new design valve. The sprays were characterised using the laser instrument. The downstream distance between the atomiser insert and the laser beam was kept at 15cm. This downstream distance was selected as being the furthest downstream that could be used without the risk of the spray impingement on the lens. All images were also captured using a digital still camera which provided qualitative information and also data on cone angle.

At this stage it is apparent that some consistent definition is required in order to quantify the "constancy" of liquid flow rate and droplet size in order to give meaningful comparisons

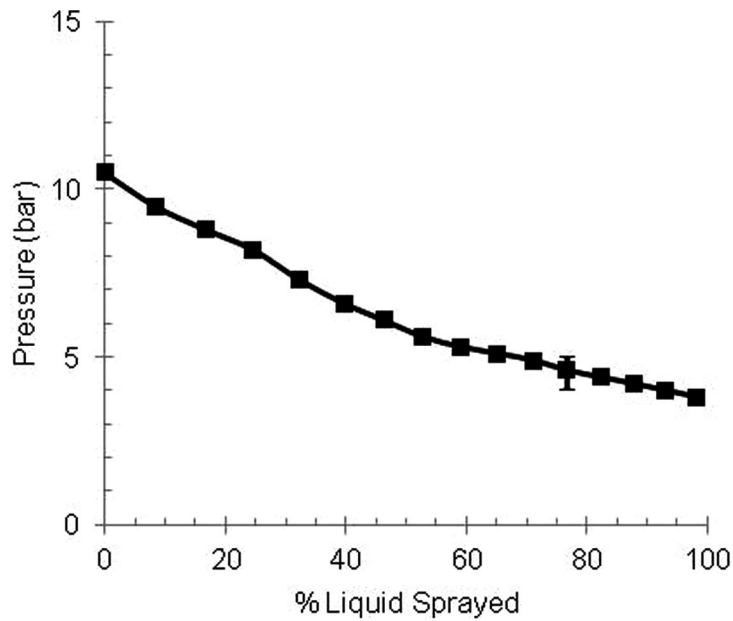
between various aerosols (here, by aerosols means that the combination of can-product-valve-insert). It was apparent that simply taking the difference between the first measured value of liquid flow rate (full can) and last value (empty can), and dividing by the first value, although seemingly the obvious definition for consistency, was not ideal because the initial value could occasionally suffer from effects such as the initial priming of the valve, and more importantly the final value often included “spluttering” effects as the can emptied. Thus it is here proposed to use the 90% and 10% points in the can emptying results: these are arbitrary choices made by examining many sets of results. Thus the definition of flow rate constancy (C_Q) and drop size constancy (C_D) are:

$$C_Q \% = \frac{(\text{Flow rate for 10\% liquid sprayed} - \text{flow rate for 90\% liquid sprayed})}{\text{Flow rate for 10\% liquid sprayed}} \times 100$$

$$C_D \% = \frac{(\text{Drop size for 10\% liquid sprayed} - \text{drop size for 90\% liquid sprayed})}{\text{Drop size for 10\% liquid sprayed}} \times 100$$

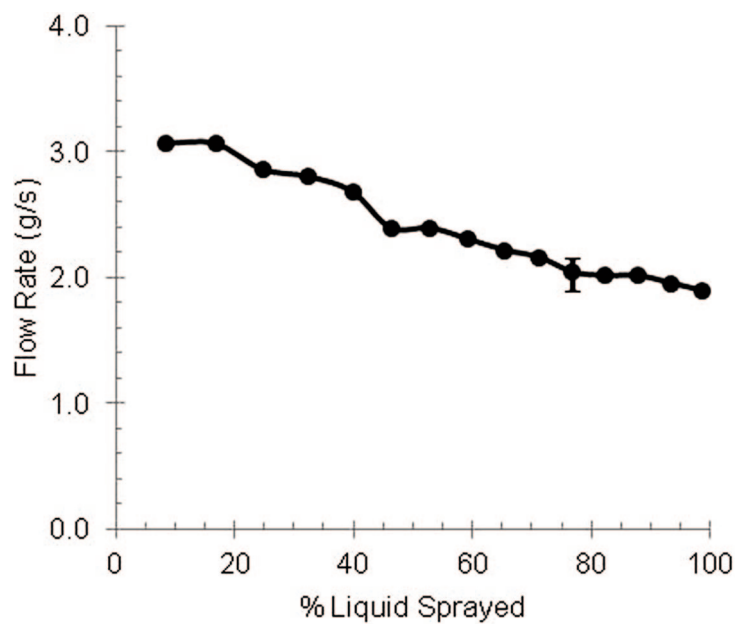
Figure 10 shows the result fusing 50% fill ratio of olive oil in a 250 ml metal can pressurise with carbon dioxide to 10 bar and using a 0.75 mm Aqua insert. Such a large insert was found to be necessary to permit full opening of the spray cone. As is shown, there is a steady decrease in pressure with about 17% of the can gas injected into the valve mixing chamber. Also the discharge flow rate decreased steadily with constancy of $C_Q = 33\%$. The particle size shows that there is a good drop size constancy with $C_D = 19\%$. Drop size is high with $D_{(v,50)}$ around $450\mu\text{m}$ but this is acceptable for the coating process that the oil spray is used for.

Figure 11 shows the spray performance result of “low loss” valve filled with 50% fill ratio of olive oil in a 250 ml metal can pressurise with nitrogen to 10bar and using a 0.75 mm Aqua

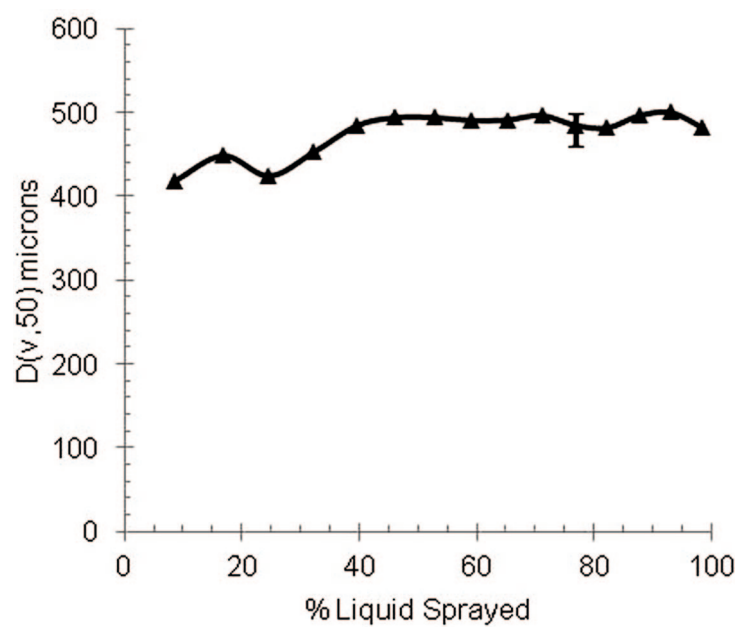


(a) Pressure drop

Figure 10: (Continued)

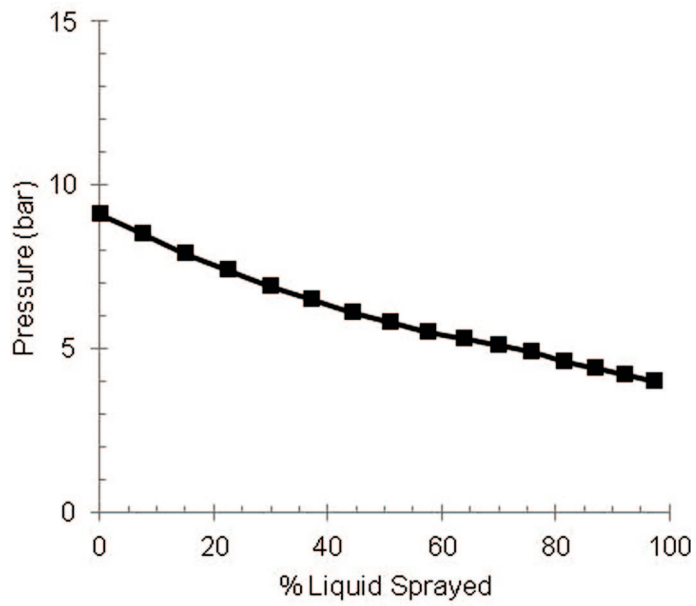


(b) Discharge flow rate

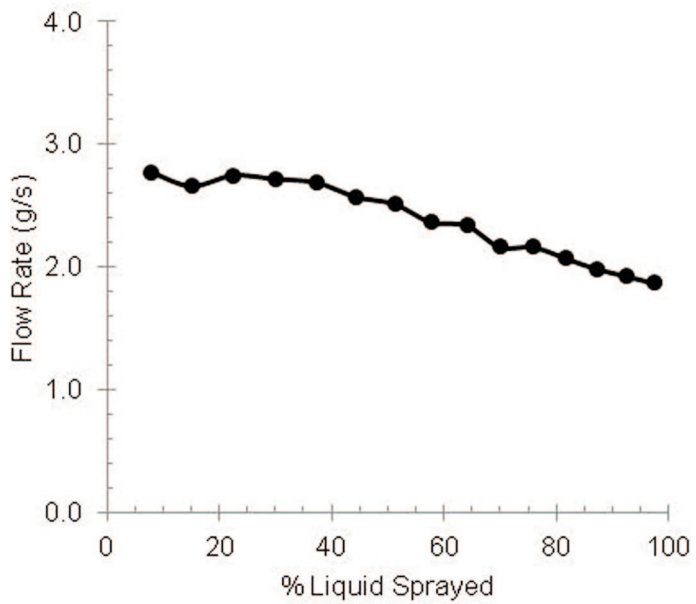


(C) Particle size

Figure 10: Spray performance of “low loss” valve with 50% fill ratio of olive oil and pressurised with CO₂ to 10bar at initial with using 0.75mm Aqua insert

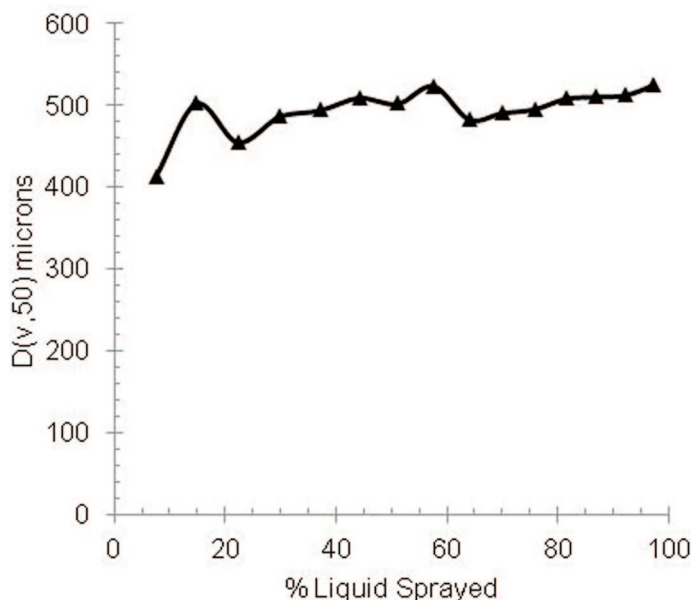


(a) Pressure drop



(b) Discharge flow rate

Figure 11: (Continued)



(C) Particle size

Figure 11: Spray performance of “low loss” valve with 50% fill ratio of olive oil and pressurised with N_2 to 10bar at initial with using 0.75mm Aqua insert

insert. As is shown, there is a about 10% of the can gas injected into the valve mixing chamber. Also the discharge flow rate decreased smoothly with constancy of $C_Q = 28\%$. The particle size increased very steadily with constancy with $C_D = 25\%$. Figures 12 shows the spray image of “low loss” valve using olive oil and pressurised with carbon dioxide and nitrogen.

Moreover, Figure 13 shows the comparison of the spray performance results between “low loss” valve and “control valve” which was provided from a company with specific interest in the constancy of discharge flow rate in respective of the particle size distribution. The results were obtained using these valves filled with 50% olive oil and pressurised with nitrogen to 10bar at initial and using a conventional actuator which was supplied from the company. As is shown, “low loss” valve has a very smooth constancy of discharge flow rate with $C_Q = 24\%$ but using “control valve” shows that the discharge flow rate decreased more rapidly with about $C_Q = 35\%$. However, looking at Figure 14, shows that spray angle of “low loss” decreased about 33% from beginning of the can to the end of the pack life, but this is about 50% with using “control valve”.

As discussed before, “low loss” valve is suitable for spraying the high viscous products like hair removal and olive oil and the particle size of these products will be higher than using water or ethanol based products. Therefore the companies which were cooperated with the author, interested to see the images of this valve during the spray performances. A major problem with the conventional consumer aerosol valve(s) using high viscous product is the liquid hole on the stem could block out due to the crystallisations imposed by the formulation on the actuator or insert. Hence the valve completely malfunctions. Figures 14 to 16 demonstrate that the “low loss” valve is functioning similar to those using antiperspirants products (i.e. conventional “Sure Roll On” or “Soltan”).

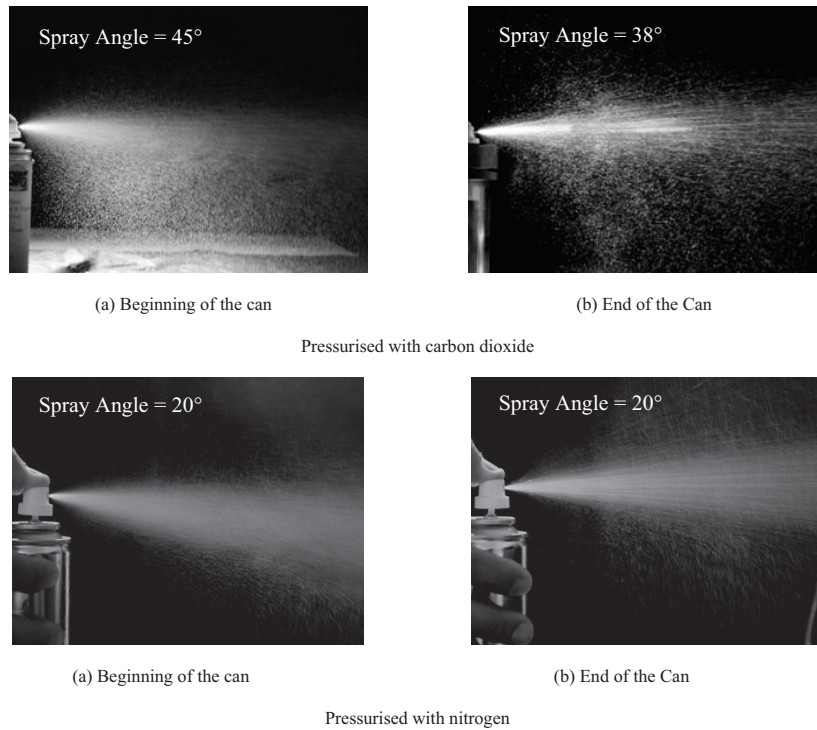
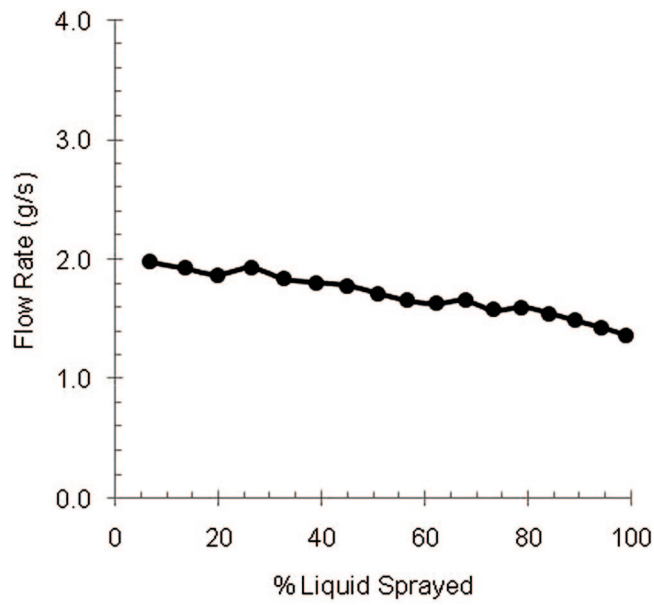
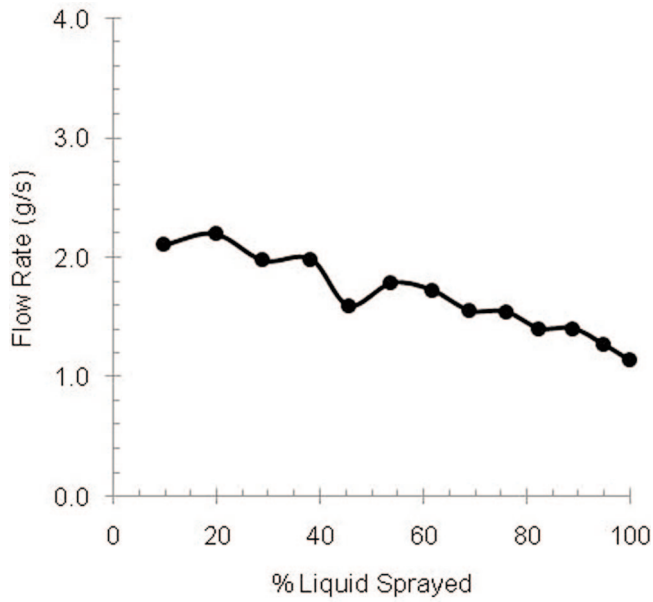


Figure 12: Spray image of “low loss” using olive oil and 0.75mm Aqua insert



(a) “Low Loss” discharge flow rate

Figure 13: (Continued)



(b) "Control Valve" discharge flow rate

Figure 13: Comparison of discharge flow rate between "low loss" valve and a "control valve" using olive oil pressurised with N₂ and using a conventional actuator

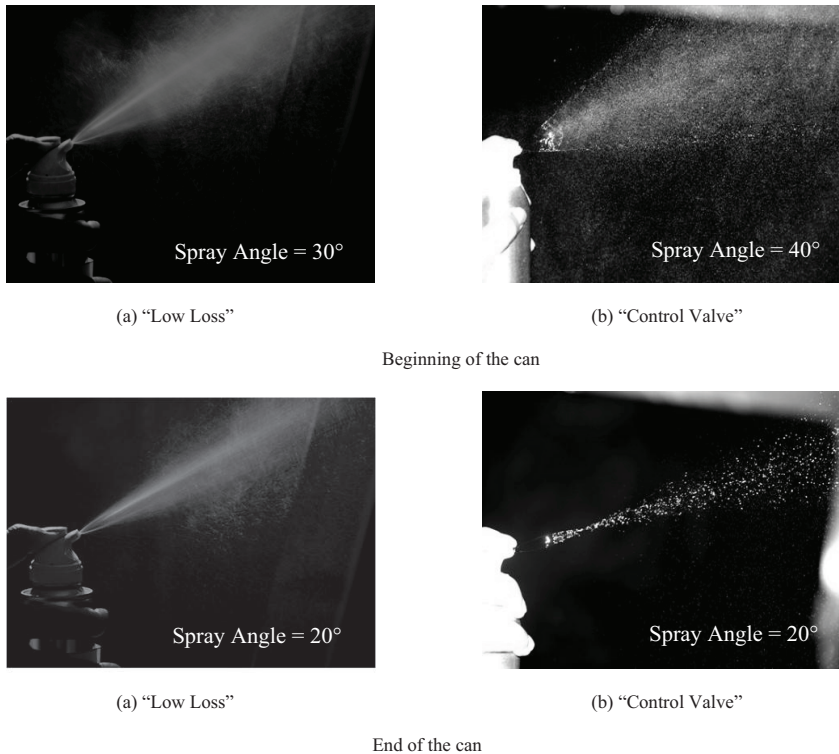


Figure 14: Comparison of spray image between "low loss" valve and a "control valve" using olive oil and a conventional actuator

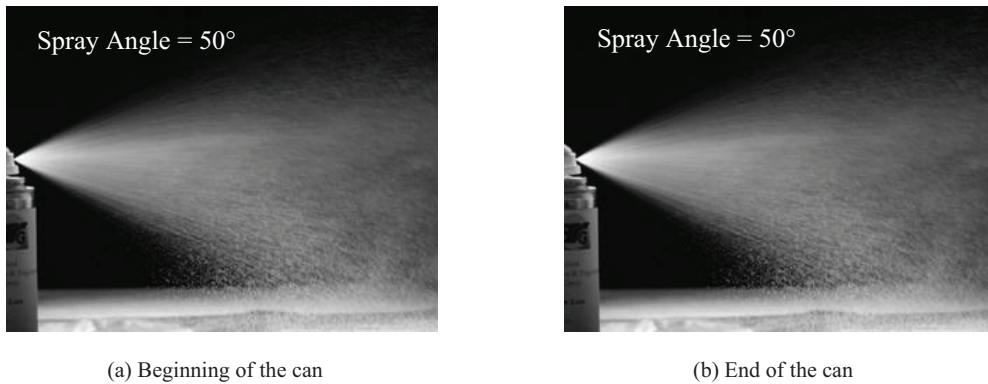


Figure 15: Spray image of “low loss” valve using hair removal cream and pressurised with compressed air up to 12bar with using 0.75mm Aqua insert

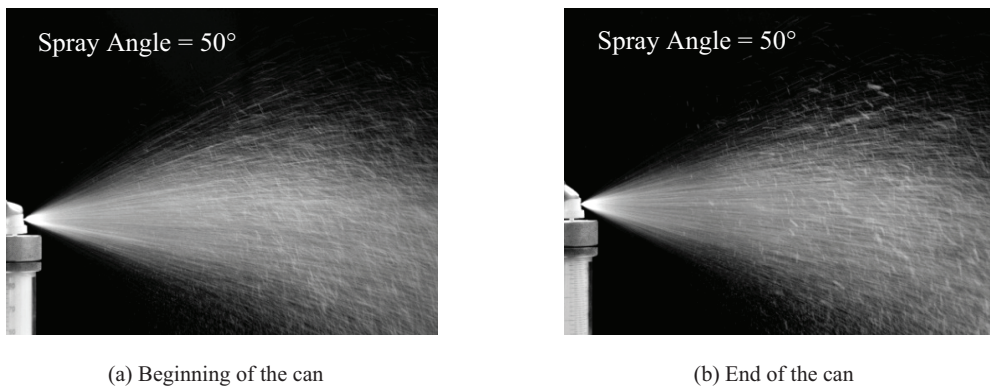


Figure 16: Spray image of “low loss” valve using Sure Roll-On and pressurised with compressed air up to 12bar with using 0.75mm Aqua insert

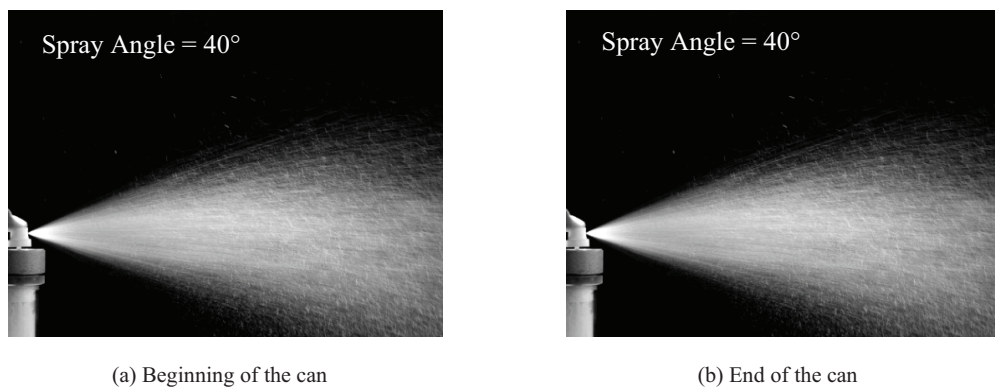


Figure 17: Spray image of “low loss” valve using Soltan and pressurised with compressed air up to 12bar with using 0.75mm Aqua insert

6. CONCLUSION AND FUTURE WORK

1. Consumer aerosol valves design has not changed significantly for a many decades and new domestic aerosol valve design will be required if inert gas propellants can replace liquefied gas propellants. The challenge of this replacement is inert gas propellants have relatively little atomising energy and also sufficient power as the can empties.
 - a. This makes obtaining fine sprays relatively very difficult.
 - b. In addition flow rate and drop size may vary unacceptably during can life time when current conventional valves are used.
2. The new aerosol valve design presented in this paper has been successfully addressed the modification of flow rate with bleeding inert gas from the can into the stem to assist atomisation with constructing of “bubbly flow” in a mixing chamber upstream of the actuator cap and insert. This concept is totally different with using VPT (Vapour Phase Tap) which has been used in conventional aerosol valves for many years.
 - a. The conventional VPT arrangement passes a two-phase flow through small valve stem orifices and a conventional path which causes pressure losses upstream of the insert and thus reduces flow rate and gives non-optimal atomisation.
 - b. The new valve arrangements do not suffer from the above restrictions.
3. The requirement for as steady flow rate and drop size as possible, during the pack life of an aerosol, has been quantified successfully using the new definitions of “Constancy” parameters for liquid flow rate, C_Q , and volume median drop size, C_D . Use of these parameters permits quantifying the performances of valve-insert combinations and comparing performances with conventional valves and products.
4. The reason for the achievement of such good constancy is not fully understood and requires a thorough fundamental study:
 - a. It involves complex interactions as the bubbly mixing chamber flow passes through the insert and results in changes of pressure differences set up between mixing chamber, internal can volume and external atmosphere, as a can is emptied.
5. “**Low Loss**” valves that use an unconventional method of shutting off and opening the flow such that there is essentially no pressure loss even for a bubbly flow passing through the valve.
 - i. This valve is more bulky than conventional valves and has two additional components.
 - ii. However this investigation has shown that the valves spray viscous liquids and suspensions such as olive oil and hair removal creams, which cannot be sprayed well or with good constancy by current compressed gas aerosols.

6.1 FUTURE WORKS

Fundamental study of the formation and properties of the “bubbly flow” systems possibly including the use of “scale up” experiments could be part of the future study. In addition, the application of CFD to the flow in the can-valve- insert system needs further investigation. Moreover, further work could include the understanding of how the properties of the two phase flow leaving an insert affect atomisation quality and also on how the internal insert geometry affects the spray. Explore the use of the valves in bag-in-can or bag-on-valve systems could also provide wide applicability of the new valve that presented throughout this paper.

7. ACKNOWLEDGMENT

The authors wish to thank Salvalco Ltd for their financial support and all the team at University of Salford for their constant support and encouragement throughout this investigation.

REFERENCES

- [1] Swithenbank, J., *Characterisation and evaluation of a CFD model of effervescent atomisation*, Swithenbank J., GR/L74460/01.
- [2] Catlin, C. A. and Swithenbank, J., *Physical processes influencing effervescent atomiser performance in the slug and annular flow regimes*, *Atomisation and Sprays*, 11, 575, 2001.
- [3] Kuta, T. J., Plesniak, M. W. and Sojka, P. E., *Entrainment control for ligament controlled effervescent atomiser sprays*, *Atomisation and Sprays*, by 13, 561, 2003.
- [4] Bush, S. G. and Sojka, P. E., *Entrainment by conventional effervescent sprays*, *Atomisation and Sprays*, 13, 605, 2003.
- [5] Lefebvre, A. H., *Atomisation and Sprays*, Taylor & Francis, USA, 1989.
- [6] N. Asmuin, *Investigation Into Novel Matched Valve-Actuator Atomiser Insert Design for Compressed Gas Aerosol*, PhD Thesis, University of Salford, Manchester, January 2011.
- [7] Martin L. Burby, Ghasem G. Nasr, Gary Hawthorne and Norzelawati Asmuin, *Novel aerosol insert design utilising inert compressed gas*, *Atomisation and sprays*, 2014
- [8] Nasr, G. G., Yule, A. J. and Burby, M. L., 2009, *Spray Discharge Assembly*, Patent No. WO2011/061531, April 2011.
- [9] Nasr, G. G., Yule, A. J. and Burby, M. L., 2009, *Aerosol Spray Device*, Patent No. WO2011/128607, April 2011.
- [10] Nasr, G. G., Yule, A. J. and Burby, M. L., 2009, *Low Loss Valve*, Patent No. WO2011/061481, April 2011.
- [11] Nasr, G. G., Yule, A. J. and Burby, M. L., 2009, *Liquid Dispensing Apparatus*, Patent No. WO2011/042751, April 2011.
- [12] Nasr, G. G., Yule, A. J. and Burby, M. L., 2009, *Liquid Dispensing Apparatus*, Patent No. WO2011/042752, April 2011.
- [13] Nourian. A., *Next generation of consumer aerosol valves using inert gases*, PhD Thesis, University of Salford, Manchester, March 2013
- [14] Yuka. Y., 2003, *Aerosol Product*, Patent No. JP2003230853 A.
- [15] Satoshi, M. and Akira, W., 1994, *Highly Viscous Stock Solution Dispensing Container*, Patent No. JP6092381 A.
- [16] Weston, T. E., Willow, B. L., Dunne, S. T. and Sawyers, E. I., 1989, *Flow Discharge Valve*, Patent No. PCT/WO 90/05580.
- [17] Smith, J. and Gallien, W. R., 1997, *Invertible Spray Valve and Container Containing Same*, Patent No. WO 97/26213.
- [18] British Aerosol Manufacturer's Association (BAMA), "Aerosol the inside history", UK, 2001.
- [19] Website: http://www.bama.co.uk/the_history_of_aerosols/ (Accessed on 20th April 2012).
- [20] T. Yerby, *Aerosol Valves*, Precision Valve Corporation, Aerosol 101, Accessed on March 2012.

