The Characterisation of the Spray from a New Fine Spray Spill Return Swirl Atomiser

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Abstract

A novel high liquid pressure small orifice swirl atomizer has been developed which incorporates a spill return orifice into the rear face of the swirl chamber with the aim of giving a significant reduction in flow rate whilst maintaining spray structure and droplet size. Initial work modified a commercial fine spray swirl atomizer to add spill return. However drop sizes were considered to be too large and a new design was constructed based upon earlier work on efficient high pressure (up to 120 bar) swirl atomization. The atomizer has been characterized for different geometries, supply pressures and spill return orifice sizes. Drop size (SMD) is less than 20 microns for flow rates as low as 0.1 liter/min and with exit orifice typically 0.3mm diameter.

Introduction

Spill-return atomizers have been used in industrial burners and fuel injectors for gas turbines [1-3] with the aim of giving effective atomization for a wide turn-down. The spill-return atomizer is a simplex swirl atomizer where the liquid is injected tangentially at high pressure into a swirl chamber via small orifices or slots. The injected liquid inside the chamber is then divided into two jets in which one jet is discharge to outside at high speed and atomized, producing conical sprays and the other jet is 'spilled' via low pressure pipe to the liquid reservoir. The devices are used at a constant fuel supply pressure so that high tangential velocity is maintained in the swirl chamber for cases when around 90% of injected fuel is spilled and this gives good atomization for typically 5:1 variation in spray flow rate.

We are interested here in applications that require low flow rate (< 0.3 liters/min say) and fine sprays (SMD< 20 microns say) and these can include humidification, cooling, coating, and cleaning processes, and particularly new spray disinfection and safety processes [4,5]. Two-fluid atomizers and ultrasonic atomizers can produce such sprays however they are not always convenient to use and are relatively costly. Normal high pressure swirl atomizers, operating at 10MPa or more supply pressure, and with exit orifices less than 0.5mm say, can produce the required drop sizes [6]. However their flow rates are then of the order 1 l/min or more, which is too much for many applications. Thus there is logic in redesigning such high pressure swirl atomizers to incorporate spill return.

As far as the authors are aware there is no information on the use and design of small high pressure spill return atomizers. This paper intends to provide information on the design and performance of novel spill return atomizer [7] and briefly review, in the next section, how they might be utilized. More details of investigations of two possible applications are given in [4] and [5].

Advantages and Possible Uses of High Pressure Fine Spray, Spill-Return Atomizers [7]

One application of the atomizer uses very fine sprays for coating objects, personnel, clothing etc for fighting bacterial infections and other purposes. Fine sprays (e.g. mean drop size less than 20 microns) can deposit beneficial chemical agents and can act with more efficacy than coarser sprays, e.g. as produced by handheld pump sprays, or by safety showers, that attempt to wash off materials and are different in their modes of application.

The existing relatively uncommon current fine spray decontamination devices use either compressed air assistance to produce fine sprays, or swirl (hydraulic) atomizers: the former are inconvenient due to the need for a compressed air source, the latter can produce inconveniently high flow rates because for a swirl atomizer drop size can only be reduced by increasing supply pressure of the liquid, and thus liquid flow rate (the alternative of reducing exit orifice size, to reduce drop size, is not realistic due to erosion, blockage and manufacturing problems: sizes of 0.1mm or less would be needed.

The aim is to use spill-return swirl atomizers, which bleed liquid from inside the atomizer nozzle, back to the pump, and allow use of high pressure (thus small droplets $10\mu m < D_{32} < 25\mu m$) but with lower spray flow rates, ≤ 0.3 l/min (more convenient for most applications). Spill return swirl atomizers were introduced in some gas turbine spray nozzles (40+ years ago) and have also been used in large combustion devices: the objectives were then to give good control of flow rate, without changing drop size

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significantly. This differs from the present need which is *to produce fine sprays, at low flow rates, but without very small orifices and without compressed air*. The earlier devices were larger than those used here, and were operated at much lower supply pressures.

The new design of the spill-return atomizer here is capable of dispersing a fine spray or aerosol of liquid droplets onto surfaces, for antibacterial, disinfecting, decontamination or other hygiene purposes, or for surface or gas cooling, whereby the droplets are produced solely or principally by energy supplied to the liquid by pumping means (e.g. a gear pump or pressurized reservoir).

A device may include one or more atomizing nozzles, each nozzle containing a chamber with one or more tangential inlets and a spray outlet from which the spray is formed. Each nozzle to include a second outlet to bleed liquid from the chamber such that this liquid is not atomized and may be re-circulated to the pumping means, and such second outlet to be so positioned in a low pressure region of the chamber such that the angular momentum of the liquid in the chamber is not reduced in a manner that would reduce the drop size produced by the nozzle from that drop size produced for the case of no second outlet.

Supply liquid is pumped at sufficiently high pressure for a fine spray dispersion to be provided suited for even coating of surfaces without excessive liquid deposition, as an example for aqueous liquid, such pressure to be not less than 30 atmospheres and, in this design, to be more than 80 atmospheres, and the mass median drop size to be not more than 80 microns and preferably, not more than 40 microns.

In order that the spray flow rate from a nozzle is reduced to a level convenient to coating surfaces in a controlled and even manner without excessive deposition, and in order that this flow rate limiting is provided with the spray orifice diameter large enough to be manufactured by routine conventional means, a proportion of the liquid flow is bled from the chamber without being atomized, this proportion being determined by the cross-sectional area of the second outlet and also by any restrictions of this bled-off flow outside the nozzle. The exit orifice might thus be no less than 0.3mm diameter and the spray flow rate not more than 0.3 liters per minute and with at least half the liquid flow, that enters through the swirl inlets, being bled off.

The atomizing nozzles may incorporate pintle on/off valves [7] incorporating a central conically tipped device in the chamber, that can be moved axially to shut off the spray flow but which is arranged such that the liquid continues to flow through the chamber and through the second outlet, without the need for switching off the pumping means or bypassing the liquid flow before it reaches the nozzle. A central conically tipped handheld device, for example, can be operated by an external trigger apparatus which may be spring loaded such that an operator may easily switch the spray on and off whilst carrying out cleaning, coating or other operations.

The atomizers can be used in a portable device [7] for which the operator holds the spraying nozzle, the pumping means and liquid reservoir being part of the portable device, e.g. on a trolley. Furthermore, the atomizers can be utilised in “spraying towers” [4,7] that can be positioned in a room that requires disinfection treatment, and easily moved from room to room, the sprays from this tower being directed in order to coat surfaces within the room.

The high pressure fine spray spill return atomizers can also be used in decontamination chambers or tents [5] containing the atomisers such that persons or objects passing through the chambers are coated by neturalising liquid droplets, the sprays being switched on either manually or automatically by infra red or other detection means.

A different use for these fine sprays is in the cooling of the ambient atmosphere in hot outdoor surroundings [7]. For example in one format downward spraying atomizers are positioned at the periphery of a large parasol and fed from a central pump and reservoir: the outer sheath of fine water drops vaporize and cool (via latent heat absorption) the surrounding air, thus providing a cool environment (existing environmental cooling systems produce droplets that are too large and thus give severe wetting of the surroundings).

Atomizer type (Delavan)	**Material**	**Spray Angle (deg)**	**Pressure (bar gauge)**	**Flow Rate (Liters /hour)**
WA054	Stainless Steel	40	8	2.46
WA204	Stainless Steel	40	8	9.37

Table 1 Specification of the Delavan commercial atomizers

Apparatus

The Atomizers

It was considered to be of interest to establish whether commercially available pressure swirl hollow cone atomizers could be modified in order to give satisfactory spill return fine sprays. The smallest in the range of atomizers manufactured by Delavan Ltd [8] were chosen, with nominal performance given in Table 1. (note that these atomizers were found to operate satisfactorily at up to 10MPa although performance data up to 0.8 MPa is provided by the manufacturers). Two types of pressure swirl hollow cone atomizers were selected, one with the lower flow rate and the second one with higher flow rate nozzle. The specifications for both of the atomizers are represented in Table 1.

Figures 1 and 2 show how the atomizers were modified. The supply route for the water was changed to go through the outer of concentric supply tubes and the holes that normally allowed a central water supply to reach the outer part of the atomizers, were blocked. As shown in the Figure 5 spill return orifices of 0.5 mm to 1.5 mm were drilled for the liquid to be spilled. A central hypodermic tube led into the atomizer to bleed the water back to the tank.

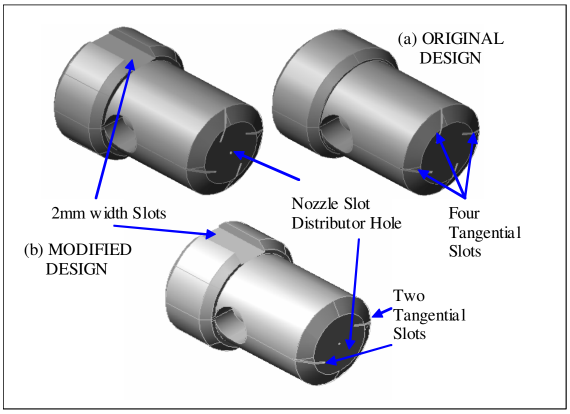


Figure 1 Delevan atomizer (a) original design
(b) modified design

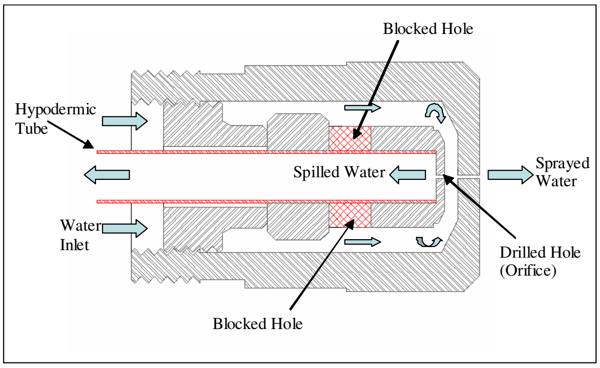


Figure 2 Cross-sectional view of the modified commercial atomizer

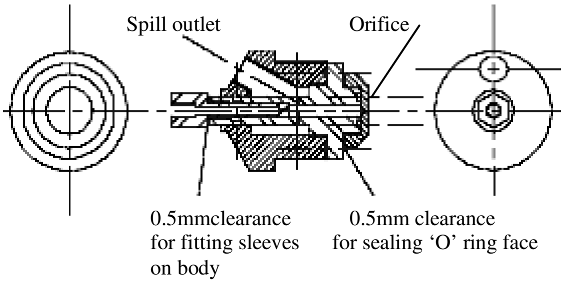


Figure 3 Cross-section of the new spill-return atomizer assembly [7]

The performances of the modified commercial atomizers were considered to be good but not ideal and thus a family of purpose built spill return atomizers were developed and figures 3 and 4 illustrate the key points. The internal geometry followed the design principles for high pressure fine spray pressure swirl atomizers that were described in [6]. These included the use of a long swirl chamber, two tangential inlets, a relatively long spray orifice and other features that are not always in agreement with published recommendations for the design of swirl atomizers. Most data were obtained for two exit orifice sizes, 0.2mm and 0.3mm, and with a range of spill return orifice sizes.

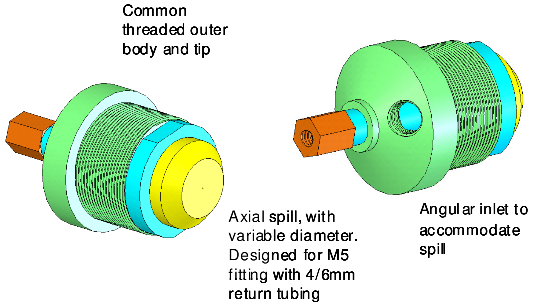


Figure 4 The new atomizer with spill- return

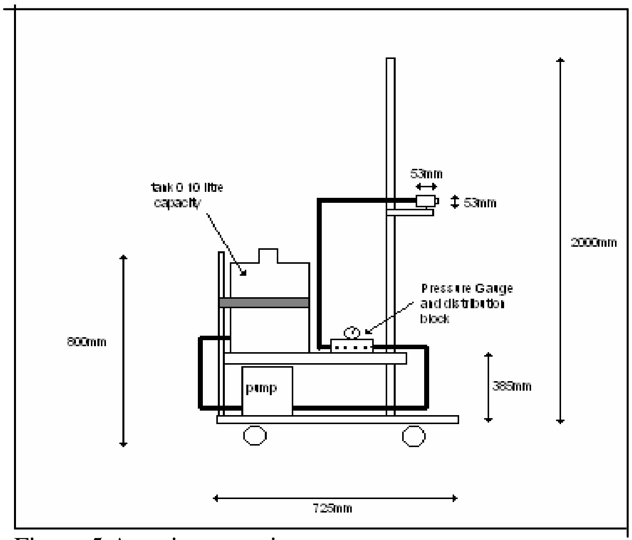


Figure 5 Atomizer test rig

Spray characterisation apparatus and set up

Sprays were characterised using a Malvern Mastersizer-X. The spill-return atomizer was attached to a slider on a vertical aluminum extruded section, fixed to a trolley. The liquid reservoir tank was mounted on the trolley together with a high pressure water pump, capable of producing up to 150bar, at the flow rate of 8 l/min, manufactured by Interpump Group. A pressure gauge, distribution block, and a high pressure hydraulic pipe were used for delivery of the liquid from the pump to the atomizer. Also see Figure 6 for a schematic of the system. The apparatus also comprised of a spill-return pipe that returns the liquid from the spill orifice to the tank. Water flow rate was measured separately by carrying out pressure/flow calibrations using collection methods. The Malvern light beam was positioned at 150mm downstream for most drop size measurements. Care was taken to apply suction from an extract such that the fine spray did not recirculate into the beam and cause biasing of drop size measurements. In general the drop size distributions were single peaked and gave reasonable fit to a Rosin Rammler shape with an exponent value around 2.0.

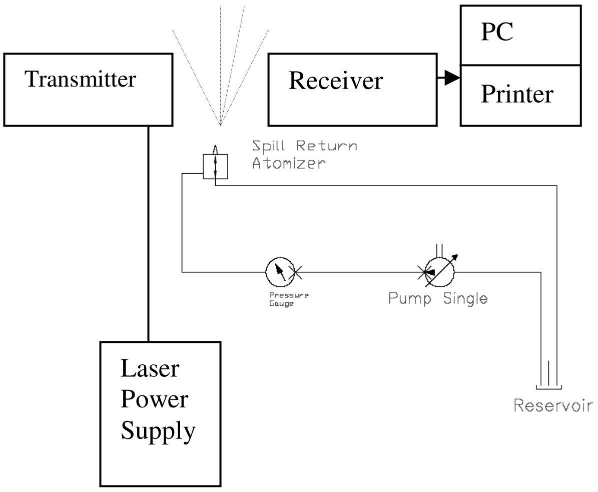


Figure 6 Experimental arrangement

Results and Discussion

Figure 7 shows the typical variation of the SMD of the droplets with spray flow rate for the modified WA 054 commercial atomizer and supply pressure up to 12MPa and for a spill return orifice diameter of 0.5mm. The exit orifice diameter was 0.4mm for this atomizer. These initial tests with the modified commercial atomizers showed that fine sprays were successfully produced at very low flow rates and with high water supply pressure. Typically the spill return was recirculating more than 80% of the input water flow for the example shown. However it became clear that the drop sizes being produced were significantly smaller than those expected from the results published in [6] for non-spill-return atomizers specially developed for use at high water pressure. Therefore the investigation moved on to using the specially constructed atomizers, shown in Figures 3 and 4.

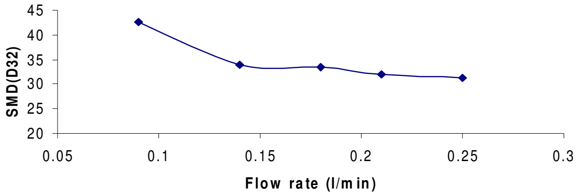


Figure 7 Variation of SMD for commercial atomizer with addition of 0.5mm spill return orifice

Figure 8 summarises a large body of experiments for two exit orifice diameters, 0.2 and 0.3mm, and for spill orifices from 0.2mm to 1.0mm in steps of 0.1mm. It is seen that D_{32} <15μm is achieved at flow rates around 0.2 l/min for the 0.2mm exit orifice. In al cases drop sizes are finer than for the modified commercial atomizers operating at similar flow rates and pressures. It is clear that exit orifice diameter is important in determining drop size at a given spray flow rate. However the 0.3mm exit orifice was very much less liable to blockage than the 0.2mm orifice and thus the larger orifice was used in most subsequent experiments.

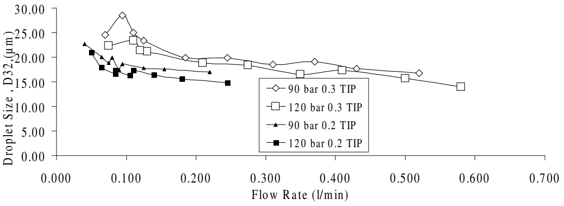


Figure 8 Drop size and spray flow rate for exit orifice diameters of 0.2 and 0.3mm, at two supply pressures and with variation of spill orifice diameter

As can be seen in Figure 8, the SMD deceases, as the spray flow rates increases. This is because at the higher spray flow rates for a given supply pressure, the spill orifices are smaller so that there is an increase in the axial velocity component of the liquid at the exit. In most applications that the authors have reported separately [4, 5], flow rates around 0.2-0.3 l/min, and supply pressures of 9-12MPa have been used with exit orifice diameter 0.3mm and spill return orifice 0.5mm.

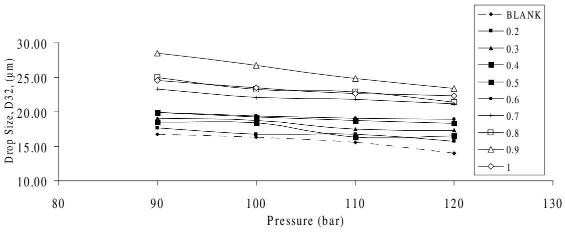


Figure 9 Variation of drop sizes with supply pressure for different spill diameters for orifice diameter 0.3mm.

Figure 9 shows the variation of the SMD with water supply pressure for different spill orifices where the exit orifice diameter was kept at 0.3mm. The "blank" spill represents a separately constructed atomizer with identical internal geometry but with no spill return. Although there is a tendency for drop size to increase as the spill orifice is increased, at a given water pressure, the process is not monotonic so that larger spill orifices can provide finer sprays than expected. This is presumably because of some unknown change in the internal flow pattern in the swirl chamber, that is beneficial for drop formation.

An effect of increasing spill diameter, as well as the reduction in spray flow rate, is that the total flow rate into the atomizer is increased for a given supply pressure. As can be seen in Figure 10, as the spill diameter increases both the spill flow rate and total flow rate are increased, whilst the difference between these curves, giving the spray flow rate, is decreased. These results were obtained at two supply pressures, with the exit orifice diameter of 0.3mm.

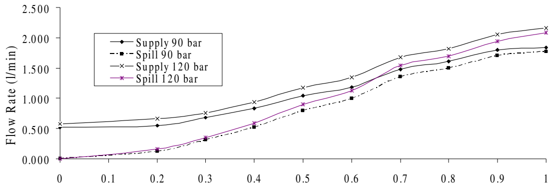


Figure 10 Variation of flow rates with spill diameter at different supply pressures.

Figure 11 also typified the effect of spill diameter on the sizes of droplets. The droplets increases as the spill diameter increase for various supply water pressures and different exit orifice diameters.

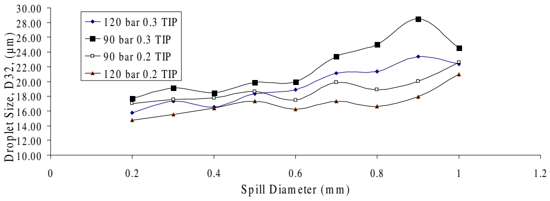


Figure 11 Effect of spill diameter on droplet sizes.

All of the data reported up to this point are at 150mm downstream. However it is emphasised that drop size information, as with all swirl atomizer sprays, is sensitive to the downstream measurement position. Some measurements were repeated with the atomizer moved with respect to the laser beam as shown in Figure 12 for the 0.3mm exit orifice and zero spill return, with three supply pressures. As can be seen in Figure 12, the measured SMD increases as downstream distance increases, at the different water supply pressures. The reasons for this increase include:

(a) preferred vaporization of the smaller drops
(b) coalescence
(c) because the larger drops tend to concentrate towards the centre of the spray, the laser beam measures proportionally more than for the wider spray further downstream
(d) velocity biasing effects change with distance downstream as the larger drop adapt more slowly to the local gas velocity

It is considered that (c) and (d) are the more important phenomena.

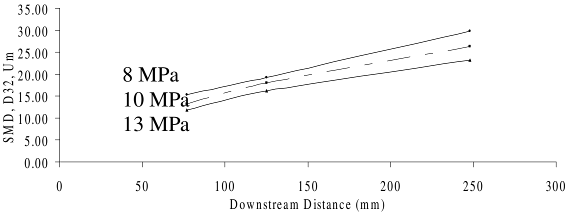
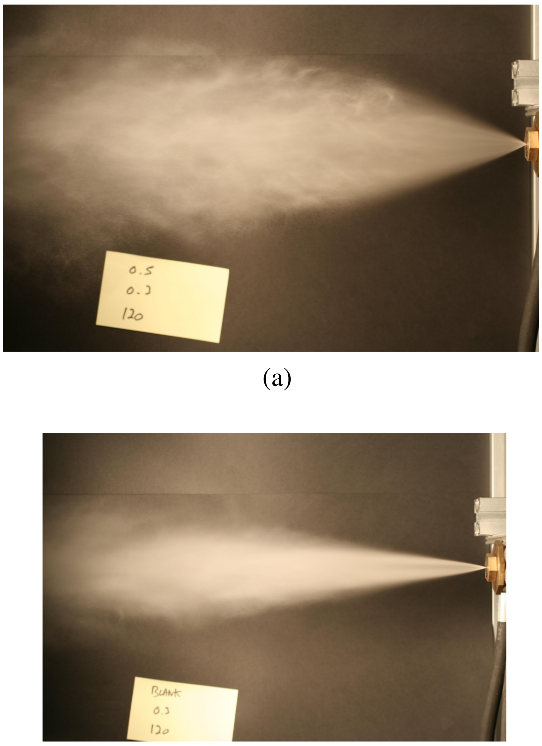


Figure 12 Effect of downstream distance on SMD.

Spray angle was estimated using images from the Cannon digital and Kodak high speed cameras, as illustrated typically in Figure 13. The total angle of the spray was typically found to increase between approximately 25-45 degrees for increasing spill orifice diameter, where the atomizer was designed for a very narrow initial spray angle.



(a)

(b)

Figure 13 Spray images, 0.3mm exit, 12 MPa at (a) 0.5mm spill orifice diameter and (b) no spill

The velocities of the droplets are also being measured using PDA, the results of which will be published. However, the initial velocity of the droplets was estimated to be 57m/s to 73m/s for the cases between 17µm<D32<22µm and for spill diameter of 0.4-0.5mm, at 10MPa.

Comparative comments

Table 2 highlights some previous work of Yule and Widger [6] and Bayvel and Orzechowski [3] on high pressure swirl atomizers, merely to demonstrate how the present flow rates differ

Author	**Water supply pressure (MPa)**	**Spray Flow rate (l/min)**	**Spray angle (deg.)**	**SMD, D_{32}, (µm)**
Yule and Widger [6]	15.2	10	45^0-90^0	22
Bayvel and Orzechowski [3]	5	6	30^0-90^0	30-50
Present design, with spill (example)	10	0.25	40^0	20

Table 2 Typical parameters of high pressure swirl atomizers

Conclusions and Future Work

The new design of spill-return swirl atomizer presented here can be operated at very low liquid flow rates and high supply pressure whilst maintaining the required fine spray structure with conveniently sized exit orifices. The resulting fine sprays can be used for various applications such cleaning, coating, cooling and decontamination.

Future work will provide detailed characterisation of sprays using PDA and will report on various applications using the atomizers.

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