A Controllable Twin- Fluid Internally Mixed Swirl Atomizer

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Abstract: The atomizer serves as an energy conversion mechanism to convert a volume of the liquid into a multiplicity of small droplets and then ejects these droplets so as to produce a high ratio of surface to mass in the liquid phase and thereby achieve high rates of mixing and evaporation. For the current needs, a compact configuration arrangement is needed to meet the design requirements of small volume and high maintenance availability. As compared with the traditional design, the new atomizer designs should possess better energy conversion efficiency (from pressure to kinetic energy). The technique of combining two or more principles has well served in the field of atomization in the past. The drawbacks of one type of atomizer can be overcome by combining it with other types of atomizer, in what is generally referred to as a "hybrid atomizer". The atomizer discussed in this paper combines the principles of twin-fluid internally mixed atomizers and conventional pressure swirl atomizers to produce a spray the characteristics of which can be controlled over a wide range of operating conditions.

Keywords: Atomization, hybrid atomizers, controllable atomizer, twin-fluid atomizer, internally mixed atomizer, swirl atomizer.

INTRODUCTION

Atomization of liquids is widely used in several applications, e.g. spray combustion, spray-painting, spray drying, crop spraying and many other applications. In some atomizer applications the control of droplet and/or particle size is very critical. In some applications, extremely small droplets are preferred (less than a micron), while in others, droplet diameters on the scale of several hundred microns are required. Spray combustion is used in domestic heating burners, industrial heating furnaces, gas turbines, diesel engines and rockets. For the different applications, a wide range of spray devices have been developed and they are generally designated as atomizers and nozzles [1-3].

Spray may be produced in various ways. The process of atomization is a process where a liquid jet or sheet is broken up by the kinetic energy of the liquid itself or by exposure to high-velocity air or gas. Some atomizers accomplish this by discharging liquid at high velocity into a relatively slow-moving stream of air or gas. Examples of this type of atomizers include various forms of pressure atomizers and also rotary atomizers that eject the liquid at high velocity from the periphery of rotating disc. An alternative approach is to expose a relatively slow-moving liquid to a high-velocity air stream. This method is generally known as twin- fluid, air-assist or air-blast atomization.

In the context of the present invention, it is worthwhile to mention about the conventional swirl atomizer and an internally mixed atomizer reported in the prior art. In swirl atomizer liquid is made to flow through a swirler before it exits from the atomizer, providing a tangential motion to the liquid. This swirling liquid forms a hollow cone outside the atomizer and this cone breaks up into droplets once the kinetic energy of the molecules of the cone overcomes the surface energy of the liquid. In an internally mixed atomizer, a small amount of gas is introduced into the liquid inside the injector forming a two-phase mixture of liquid and gas. This two-phase mixture produces liquid droplets owing to two-phase flow dynamics. However, due to the absence of any tangential velocity component in the flow (because it is a one dimensional flow), this atomizer always forms a solid cone spray.

PATENTS

Summary of Most Related Patents

Current patent applications and/ or registrations regarding atomizers have been published for (a) atomizing devices for liquid fuels/gas mixture/slurry, (b) in combined application as an atomizer and nozzle and (c) fuel metering devices. These patents have been published in several countries and are presented in Table **1**.

Table 1. Details of Most Related Patents

S. No.	Country	Patent No.	Date
1.	USA	US20036547163	15-04-2003
2.	USA	US20016186417	13-02-2001
3.	USA	US20036601776	05-08-2003
4.	Germany	DE19918120	26-10-2000
5.	USA	US20036892962	01-05-2003
6.	India	180/DEL/2004	09-02-2004

The current review, however, will focus on the patent originally registered in India [4]. The patent currently under discussion combines the principles of a simplex pressure-swirl atomizer and an internally mixed, twin-fluid, air-assisted atomizer. A schematic of the developed atomizer is shown in Fig. (**1**) and an image of the spray produced by the present invention is shown in Fig. (**2**).

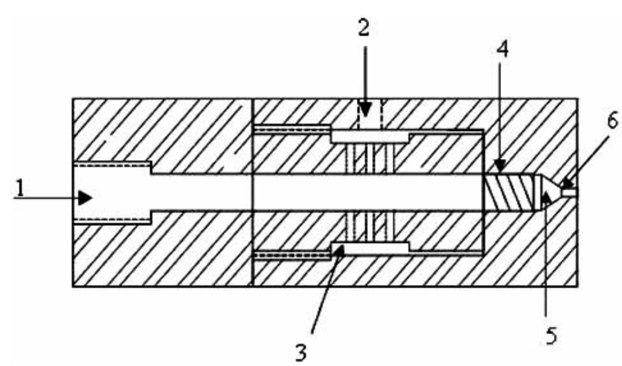

Fig. (1). Schematic of the present invention (1. Liquid inlet, 2. Air inlet, 3. Air settling chamber, 4. Helical passage, 5. Spin chamber, 6. Atomizer orifice).

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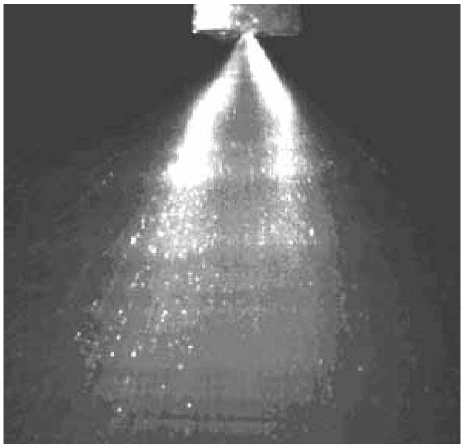

Fig. (2). Spray image of engine oil (kinematic viscosity 13.5 to 15.5 cst) at 40 psi (276 kPa) supply pressure.

Claims and Supporting Evidence Provided in the Patent

Patent claims that the liquid to be atomized can be selected from automobile fuel, paints, aviation turbine fuels (ATF), agricultural liquids (pesticides etc.), liquid medicines, water (for fire extinguishing) etc. There are also claims of providing the rate of flow liquid to the inlet port in the range between 1.8 gm/s to 8.9 gm/s. Where, the flow rate can be further increased or decreased by changing the liquid supply pressure and the device was tested for the liquid supply pressure range of 30 psi (207 kPa) to 80 psi (551 kPa). Patent claims that diameter of atomizer orifice is in the range of 0.8 mm. Where, the orifice diameter can be further increased up to 2 mm to provide larger liquid flow rate and larger cone angle or reduced to 0.4 mm for medical sprays that require very small flow rates.

Patent also claims that the rate of flow air to the inlet hole is in the range between 0.0045 gm/s to 0.06 gm/s (Fig. (**3**)), spray solidity is obtained in the range of 38 % to 100 % (Fig. (**4**)), air-liquid mass ratio is in the range of 0.0007 to 0.0117 (Figs. (**3**-**5**)). The patent also claims that the same atomizer can provide sprays with a wide range of spray cone angle as shown in Fig. (**5**). Therefore, this atomizer can be used for various applications. The patent provides evidence in its capability of producing spray cone angle in the range of 16° to 75°. This is the range obtained for the conditions for which the atomizer was tested. As shown in Fig. (**6**), the cone angle can be further increased by operating at higher liquid supply pressure or by having a larger atomizer orifice diameter or by changing the internal angle of the swirl chamber.

Furthermore, patent describes several in-house experiments and results, suggesting that the atomizer can provide sprays with a wide range of spray angle, provide sprays with wide range of spray solidity, obtain various spray cone angle while maintaining a constant liquid flow rate, maintain a constant spray angle for a range of liquid flow rates. As shown in Fig. (**7**), it can obtain various spray solidity while maintaining a constant liquid flow rate as well as maintain a constant spray solidity for a range of liquid flow rates, vary the spray cone angle independent of the spray solidity and vary the solidity independent of the spray cone angle.

Related Patents

Several patents in relation to atomizers, published during the last few years, have been screened for relevance to the current review. About six of them were relevant to the current topic (see Table **1**).

Patent [5] discloses a Hybrid Atomizing Fuel Nozzle. In this, air is provided in the mixing chamber after the swirler so that two phase flow does not pass through the swirler. This is an air blast and not an air assisted atomizer.

Patent [6] discloses an atomizer jet for dispensing liquid with disc shaped helical element upstream of outlet aperture. This is similar to traditional pressure swirl atomizers and cannot be considered as twin fluid atomizer.

Patent [7] discloses a front pressure swirl atomizer which is applied to a fuel atomizer of a micro gas turbine engine which is different from the atomizer of the present invention.

Patent [8] discloses the liquid atomization methods and devices which are different from the twin-fluid atomizers of the present invention. This is an electrostatic atomizer and uses electrical heating of the liquid inside the atomizer, thus changing the surface tension and viscosity of the liquid.

Patent [9] discloses the fuel oil atomizer and method for atomizing fuel oil. It describes a sprayer plate flow restrictor assembly of a fuel oil atomizer, which in combination with other atomizers can provide better distribution of spray inside a combustor.

Description of the Patent

The function and the outcome of the twin-fluid internally mixed swirl atomizer of the present invention are different from all the above mentioned prior arts. In the atomizer of the present invention, a two-phase air liquid is created by injecting a small amount of air into liquid inside the atomizer. Then this two-phase mixture is made to flow through a helical swirler, which imparts a tangential motion to the two-phase flow. This creates a two-dimensional flow of air-liquid mixture in the spin chamber of the atomizer, thus providing flow dynamics of a two-dimensional two-phase flow which is different from a one-dimensional two-phase flow or a two-dimensional single phase flow. The two dimensionality achieved, brings in the differences in the performances of the present invention with respect to the prior art atomizers. In addition, the flow inside the atomizers lies in different flow regimes of two-phase flow for different ratios of air and liquid flow rates and thus, produces different types of spray at different operating conditions. Chigier [10] & Lefebvre [11] suggest that the proper order and combination of the components of the atomizer is also critical in the present invention to obtain a two-dimensional two-phase flow, which has not been achieved by any of the prior art atomizers.

This atomizer utilizes the principles of a simplex pressure-swirl atomizer [12,13] and an internally mixed, twin-fluid, air-assisted atomizer [14,15]. A schematic of the developed atomizer is shown in the Fig. (**1**). The first half of the present invention is similar to a traditional internally mixed atomizer in which a small amount of air is introduced into liquid flow inside the atomizer, creating a two-phase air-liquid mixture. The center core of this atomizer consists of a simplex type pressure swirl atomizer through which the air-liquid mixture flows. The swirling motion to the mixture is provided by a properly designed helical passage. The helical passage was fabricated by inserting a double-ported, double turn, screw element with specified acme thread machined onto it. The mixture flows inside the passage between the thread, and thus a helical motion is imparted to the two-phase flow. In the absence of atomizing air, the liquid, with a spinning motion, feels the spinning chamber inside the atomizer, when an air core develops due to the free vortex created by the swirling motion of the liquid. This swirling liquid, with an axial and a tangential velocity component, forms a hollow cone liquid jet outside the atomizer. Owing to the increased surface area of the hollow-cone jet, the surface forces cannot keep the jet intact and it breaks into liquid droplets. This atomizer provides reasonably good atomization in the absence of

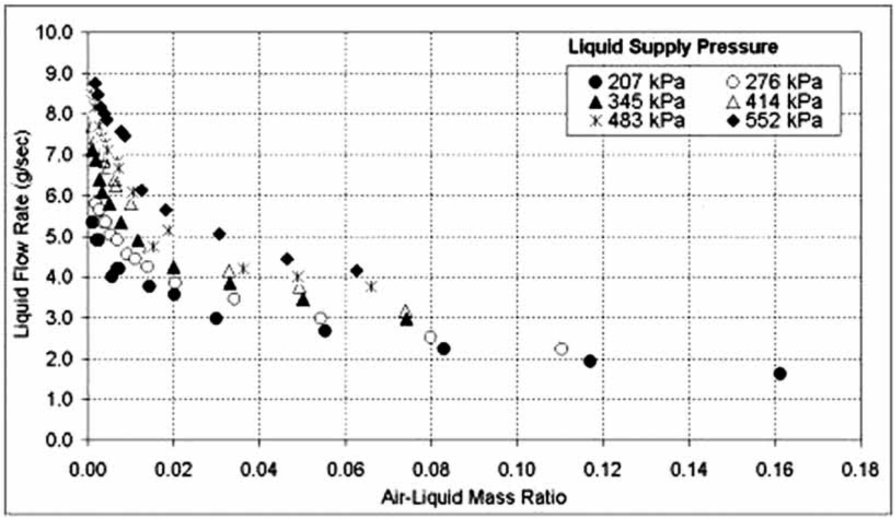

Fig. (3). Liquid flow rate vs. ALR for different liquid supply pressures.

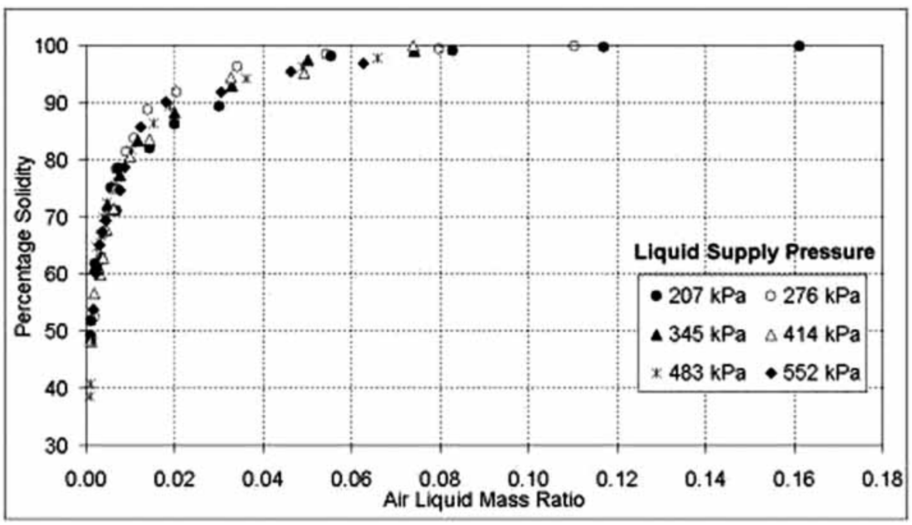

Fig. (4). Spray solidity versus ALR.

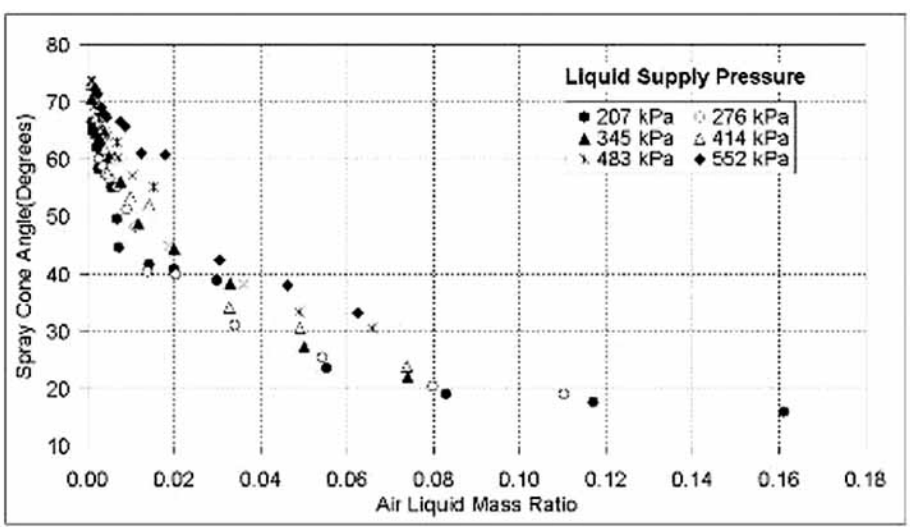

Fig. (5). Spray cone angle vs. ALR for different liquid supply pressures.

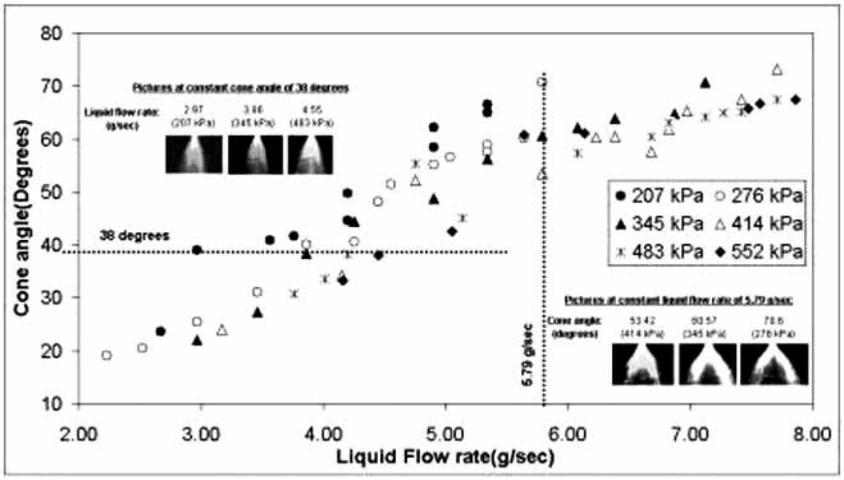

Fig. (6). Independent control of cone angle and liquid flow rate.

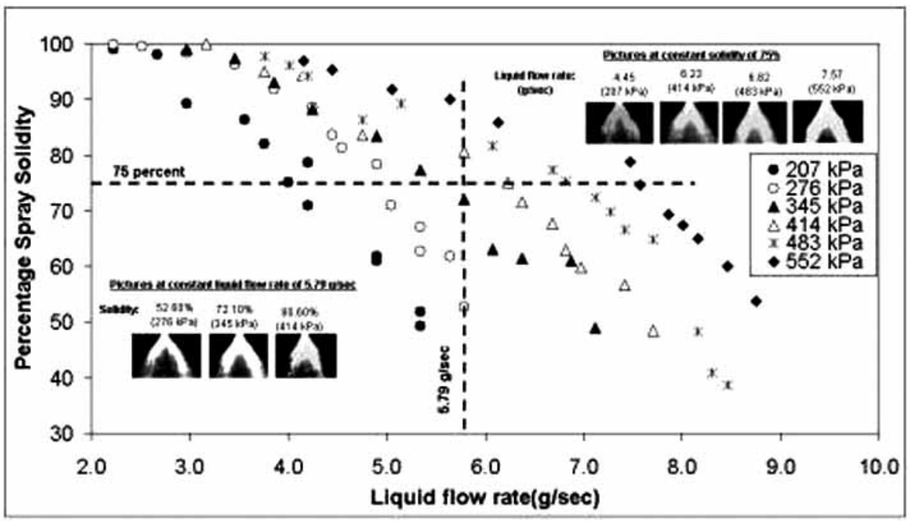

Fig. (7). Independent control of liquid flow rate and spray solidity.

atomizing air, but, introducing a small amount of air into the liquid stream upstream of the helical passage (as shown in Fig. (**1**)) significantly improves the atomization.

The improvement in the atomization depends on the amount of air added to the liquid flow. The introduction of air forms a two-phase air-liquid mixture inside the atomizer, whose flow is governed by two-phase fluid dynamics. When a very small amount of air is introduced in the internally mixed atomizer, the mixture produced is a bubbly mixture with air bubbles embedded inside the liquid flow. This mixture goes through the helical passage and gets a swirling motion and comes out of the atomizer as a hollow cone spray. Since the air bubbles occupy a finite area inside the atomizer, the liquid is squeezed to a smaller available area. This causes an increase in the liquid velocity or kinetic energy and helps in the atomization process. Secondly, the increase in air core reduces the sheet thickness of the hollow-cone spray and thus improves atomization. Thirdly, the air bubbles, which are at higher pressure than the ambient pressure, explode when they emerge from the atomizer. This bubble explosion introduces localized instabilities to the liquid jet and improves atomization. Therefore, introduction of a small amount of air improves the atomization to a greater extent. By varying the air flow rate, the flow structure inside the atomizer can be changed from bubbly flow to slug to frothy flow and finally to an annular flow. When the air-liquid flow becomes annular, the air flows in an outer annulus over the liquid core. This pushes the liquid in, and reduces and finally eliminates the air core inside the injector. Secondly, the squeezing of liquid core in the axial direction increases the axial velocity of the liquid. These two effects collapse the hollow-cone jet into a solid cone jet. But, owing to the large kinetic energy of the liquid jet and the large shear stresses acting on the liquid core due to annular flow of air, the atomization is of very good quality.

Though the product utilizes the principles of swirling atomization and twin-fluid atomization, the final product gives much better spray than the one achieved by using either one of them. Hence, the atomizer of present invention can find application in many fields, where an atomizer of prior art cannot perform the same when used in isolation or by a using it in combination with another atomizer.

In the context of the patent currently under discussion, it is worthwhile to mention about the main advantages it has over prior art including:

(1) It provides good atomization with small pressure drop

(2) Both hollow-cone and solid cone spray from single atomizer assembly. This is made possible by varying air-liquid ratio (ALR) into the atomizer Fig. (**8**).

(i) (ii) (iii)

Fig. (8). Evolution of spray structure with increase in ALR at 207 KPa liquid supply pressure; (i) ALR = 0.001: Hollow cone, (ii) ALR = 0.02: Mixed cone, (iii) ALR = 0.16: Solid cone.

(3) Possible to atomize very viscous liquid because of large kinetic energy available by introduction of small amount of air. Fig. (**2**) shows an image of the spray created by the present invention of very viscous engine oil (kinematic viscosity 13.5 to 15.5 cst at a liquid supply pressure of 40 psi (276 kPa).

(4) Clogging due to solid impurities in the liquid is avoided because of self cleaning provided by the atomizing air.

(5) The liquid flow rate and atomization quality can be controlled independent of each other by simultaneously varying liquid and air supply pressures.

The present invention can have following possible applications:

a. Automobile fuel injectors:

1. Fine atomization at low supply pressures
2. Self tuning if engine exhaust gases are used as atomizing gas.
3. Particularly beneficial during start-up and idling conditions because of finer atomization for lower flow rates.
4. Can control atomization to suit different operating conditions and thus make the engine more fuel efficient.

b. Gas turbine fuel injectors:

1. Same benefits as points 1, 3 and 4 above.
2. Ideally suited for air-craft applications because of low pressure and low atomizing air flow rate required.
3. Hollow cone spray for larger combustion volume and hence, better combustion.

c. Drug Delivery (nebulisers):

1. Controlled atomization and flow rate. Same apparatus for all age groups and various degree of ailment.
2. Solid cone spray for better concentration.
3. Fine atomization at low flow rates.

d. Spray painting:

1. Controlled atomization and flow rate. Same atomizer can be used for various coatings. Reduction is spray wastage.
2. Solid cone spray for better surface coverage.
3. Fine atomization at low flow rates (particularly beneficial for final surface finish).

e. Agricultural Sprays:

1. Controlled atomization: can be used for different densities of foliage.
2. Both hollow come and solid cone sprays can be used for general and concentrated delivery of pesticides.

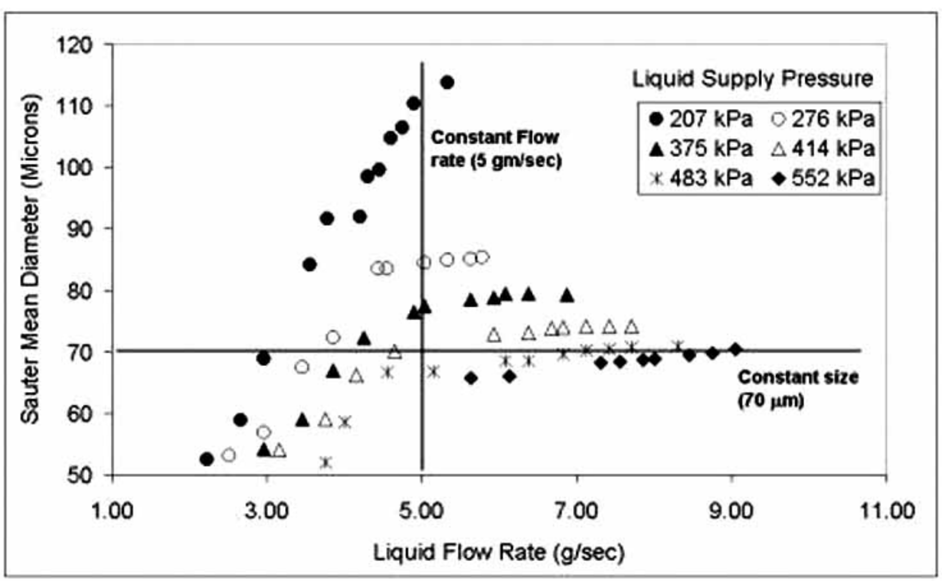

Fig. (9). Independent Control of droplet diameter

CURRENT AND FUTURE DEVELOPMENTS

Atomization physics in all its applications is more than just a matter of spray or supply of liquid/mixture/slurry by changing its kinetic energy. Control in the whole atomization process, by simultaneous coordination and step-by-step feedback has been crucial to research. It needs no discussion that the above presented highlights and outlook provide fascinating new possibilities for research in the coming decade. New developments and techniques, which follow the scope of applicability of atomizers in current scenario, will allow the detection of otherwise invisible drawbacks and deficiencies they may have.

In summary, it is generally appreciated that enormous progress has been made on the mode of action of atomizers in all type of applications including low precision and high precision working in medical purposes and fuel supply in rocket engines. Application of this knowledge in designing controlled atomization devices is the current requirement, and it is generally expected that in the next decade improved techniques and methods will be developed based on the current development. Although, questions have been raised about whether the atomization devices based on the combination of two or three principles will lead to the new applications, the active flow control on stability during each stage is likely to overcome this.

The next stage in the atomizer design is likely to be the development towards independent control in various performance parameters. Independent control in droplet diameter is shown in Fig. (**9**), where the independent control is obtained over the SMD or the liquid flow rate without affecting each other. It can be seen in Fig. (**9**) that the droplet SMD can be changed over a range from 53 μm to 115 μm in the present invention.

ABBREVIATIONS

ALR	=	Air to Liquid mass ratio
SMD	=	Sauter mean diameter of droplets

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