PREFILMING HYBRID ATOMIZATION

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ABSTRACT

The energy efficiency of an atomization process may be expressed in terms of the difference between the initial liquid surface energy (before atomization) and the total sum of the resulting atomized droplet surface energy. The larger the initial surface, the less energy is needed for disintegration. Thus to reduce the energy input within the fragmentation process or to increase the atomizer efficiency, the liquid feed stream may be properly treated and deformed before atomization. The control of the feed stream is of importance especially if viscous liquids are to be atomized. A prefilming hybrid atomizer is proposed here, where the liquid feed stream is transformed into a prefilm prior to twin-fluid atomization of the liquid. The generated prefilm is a free-flowing liquid stream that will be transported into the atomization zone just by utilizing the natural forces from the gas entrainment flow. Experiments show an enhancement of the atomizer performance compared to conventional prefilming atomizers.

INTRODUCTION

Airblast atomizers (e.g. systems of the "prefilming" type) have specific advantages, especially in applications within gas turbine engines of high pressure ratio. These atomizers require low liquid pressures to produce a relatively fine spray. Typically the liquid is first deformed into a thin, continuous sheet and then subjected to atomization by means of high velocity gas [1]. Prefilming atomization has been initially studied e.g. by Lefebvre, Dombrowki, Fraser and Eisenklam et al. [2], [3], [4]. Because of the advantage of fine powder production at low energy inputs, the prefilm design is also used for atomization of highly viscous liquids [5]. But for viscous liquids, investigations have shown that the produced droplets are just in the mm-range, which is too coarse e.g. for typical powder applications. The application of twin-fluid atomizers for fragmentation of highly viscous melts has been reported by Lohner [6].

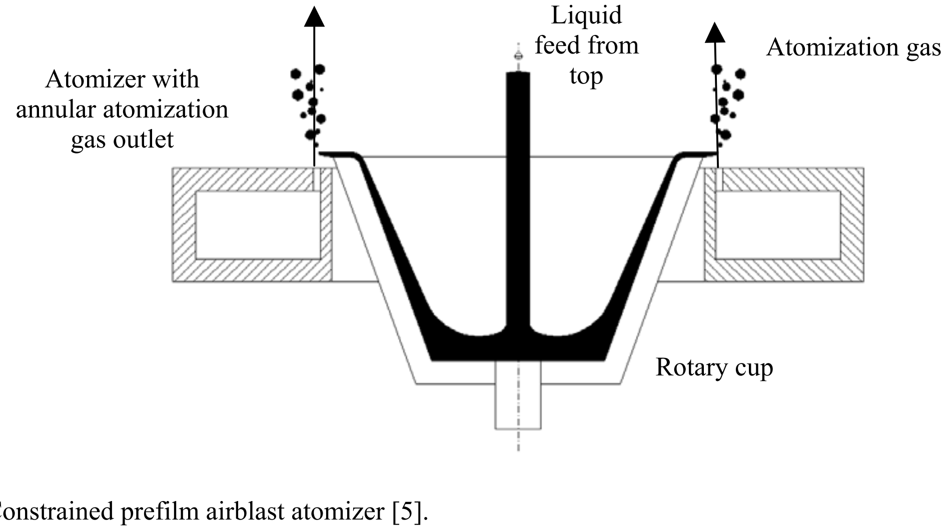

Figure 1 Constrained prefilm airblast atomizer [5].

Figure 1 shows the principle of a specific prefilming airblast atomizer for atomizing highly viscous melts [5]. The liquid is poured into a rotating cup whereby centrifugal forces generate a film along the cup inner wall. The film spreads out from the rim of the cup where the atomization gas is directed parallel to the cup axis and perpendicular onto the film. Thereby the film is atomized directly at the rim of the cup. Hence the generated prefilm is directly constrained into the atomization zone.

Sattelmayer [6] also used a design where the liquid is constrained into the atomization zone and the fragmentation process is initialized at the rim. It was observed that directly at the rim a liquid reservoir will be formed frequently out of which liquid elements are released and atomized. Here due to the action of surface tension at the just atomized liquid sheet rim, the liquid is repelled towards the disc rim where it forms an increased liquid film thickness (reservoir). This result in an oscillating feed of liquid into the high velocity atomization gas [6]. A way to improve the efficiency of this atomization type may be to prevent the forming of the reservoir at the edge by generating a free (unconstrained) prefilm prior to atomization. For proper transport of the free prefilm into the atomization zone, the forces from the natural gas jet entrainment flow can be utilized.

THE HYBRID ATOMIZER

Aim of the development is an atomizer design for highly viscous liquids at high throughputs that produce a considerable droplet size. The prefilming hybrid atomizer to be introduced here is a combination of a single-fluid rotary atomizer and an external mixing twin-fluid atomizer. The advantage of that specific design is that the feed material is first spread out by a spinning disc due to centrifugal forces, thereby increasing the initial liquid surface prior to the gas atomization process. The rotary atomizer is operated in sheet formation mode so that in the vicinity of the rotary disc a free prefilm will be established. This prefilm subsequently is guided to the atomization zone of the external mixing atomizer by means of intrinsic aerodynamic forces in the gas flow field. To ensure a stable atomization, aerodynamic forces are also used to protect the atomizer body from coming into contact and being blocked by the liquid. Here a small gas mass flow rate from the inside of the atomizer protects the atomizer body. In figure 2 a sketch of this prefilming hybrid atomizer is shown.

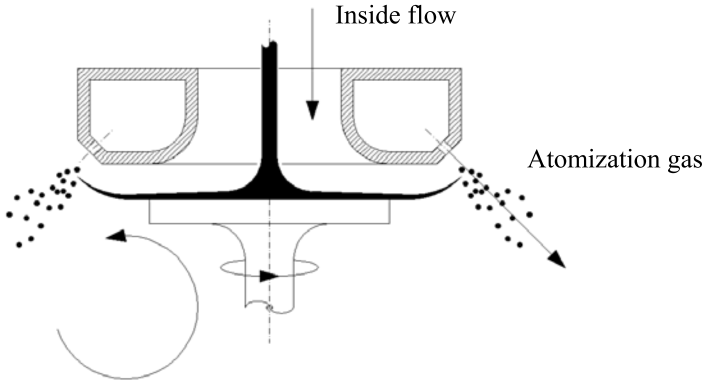

Figure 2 Sketch of the prefilming hybrid atomizer

PREFILM PRODUCTION

In case of the hybrid atomizer the prefilm is produced by a rotary disc that is operated in sheet formation mode [7], where the rotation disc speed, the liquid properties, the geometry of the disc, and the liquid mass flow rate have to be properly adjusted. The radial position of ligament break-up can be estimated by equation 1. The break-up radius for the hybrid atomizer should be greater than the diameter of the atomization gas outlet position:

$$r_z = D_0 \cdot \frac{1}{16} \cdot We \cdot \frac{v_0}{w(r_z)} \tag{1}$$

where r_z is the radial position of the lamella break-up, D_0 is the disc diameter, We is the Weber number, v_0 is the velocity at the rim of the disc and $w(r_z)$ is the radial velocity at the break-up position of the film.

The advantage of this kind of atomization of a free prefilm is that no reservoir (frequent swelling of the film at the rim of the disc) is formed. This principle also is assumed to prevent an oscillation liquid feed into the atomization zone as observed by Sattelmayer [6]. Furthermore, the thickness of the free prefilm will be reduced significantly with increasing distance from the rotary disc. Calculations of the film thickness on the disc may be adopted from Bär [8] and calculations of the free film from Theissing [9].

PREFILM TRANSPORT

One important design detail of the prefilming hybrid atomizer is the way of affecting the prefilm flow ones it is generated. Here the gas jet entrainment plays an important role. In figure 4 the entrainment of a simple free gas jet in a gaseous environment is shown. The high velocity gas jet leads to a local ambient gas entrainment, whereby the total pressure of the free jet is constant.

A prefilm which will be brought into this situation parallel to the axis of the free jet will be transported towards the free jet centre by aerodynamic forces of the entrainment flow. Assuming an inertia-free prefilm, the film will follow the entrainment flow directly. Thus if the prefilm enters the displayed situation in figure 3 at z = 0, the film will be transported directly to the jet exit and enters the atomization zone where the gas velocity is the highest.

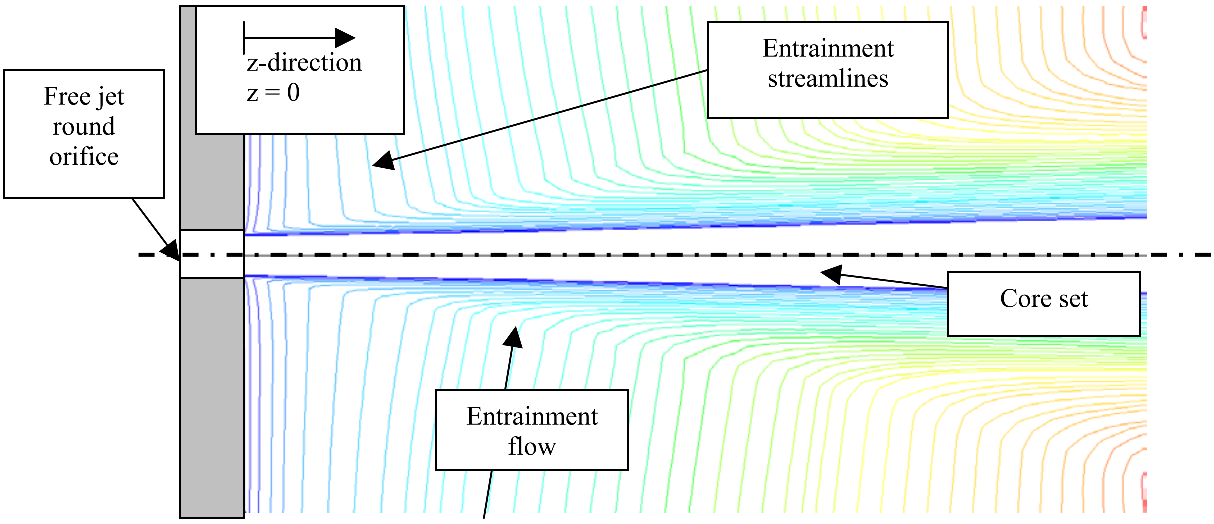

Figure 3 Entrainment flow of a circular single free gas jet

PROCESS CONTROL AND SAFETY

Atomization process control and safety is of great importance especially when atomizing viscous melts at high temperatures. Ones the melt comes in contact with the atomizer body or the atomization gas outlet, it will stick and may block the orifices. Hence the prefilm must be brought into the atomization zone at some distance away from the atomization gas outlet.

One way to prevent any contact of the liquid prefilm with the atomizer body is to increase the momentum of the film by increasing the entering velocity. The disadvantage of this operation is that with increasing the velocity of the film, the prefilm itself becomes more unstable and the velocity difference in z-direction decreases, causing decreasing atomization efficiency. As the film thickness is very low, the momentum change by the increasing prefilm velocity compared to the aerodynamic forces is marginal.

Preventing of contact of liquid or melt with the atomizer may also be achieved by positioning of the liquid prefilm source (e.g. the edge of the rotary disc) that the entrainment gas carries the prefilm into the high velocity atomization gas at some safety distance. Thereby it is assumed that the prefilm follows the entrainment gas streamlines. Hence the total entrainment can be distinguished into a process safety entrainment, which occurs between the atomizer and the prefilm and a prefilm transportation entrainment that carries the prefilm into the atomization zone.

The gas entrainment flow in this particular arrangement is influenced by the angle of the atomization gas and the arrangement of the atomization gas outlet [11]. Figure 4 shows numerical simulation results of the influence of the atomization gas jet inclination angle on the entrainment flow of an atomizer constructed with an annular slit atomization gas outlet. A suitable location of the prefilm origin is marked. Following the streamlines indicated by vectors from the prefilm origin and assuming that the prefilm flows along the streamlines, the prefilm is guided into the atomization gas flow, where for safety reasons a suitable distance to the atomizer body is maintained.

A series of simulations has been done to point out the influence of the atomization gas angle and restrictions of the entrainment on the entrainment flow with respect to an atomizer with annular gas outlet. Thereby the arrangement of the hybrid atomizer has been derived that has been realized and tested in an experimental setup.

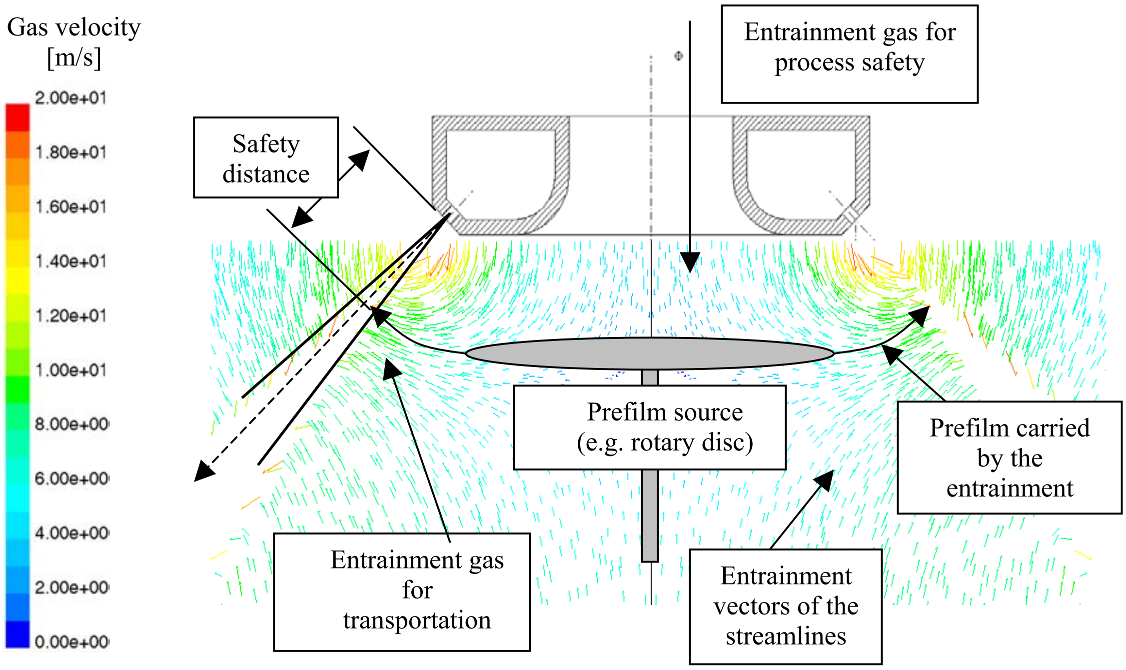

Figure 4 Simulation of the entrainment gas flow (streamlines) produced by a ring atomizer with 45 degree inclination angle.

EXPERIMENTAL SETUP

To investigate the influence of the constrained versus the free prefilm, the hybrid atomizer has been constructed with a horizontal slit atomization gas outlet (atomization angle 90 degrees). The prefilm is generated by a spinning disc that is operated in the sheet formation mode. Water is used as model liquid and air is used as atomization gas. The atomization gas pressure varied between 1 and 2 bar (rel.). The liquid mass flow rate is held constant at 1000 l/h. Two discs with different diameter are used to investigate the influence of the disc geometry on the atomization performance. The relative arrangement of the atomizer to the spinning disc is shown in figure 5. The distance z between the atomizer and the liquid film is varied from 5 to 10 mm. The droplet size distribution is measured by means of a laser diffraction technique (Malvern) downstream at a distance of 400 mm from the atomizer.

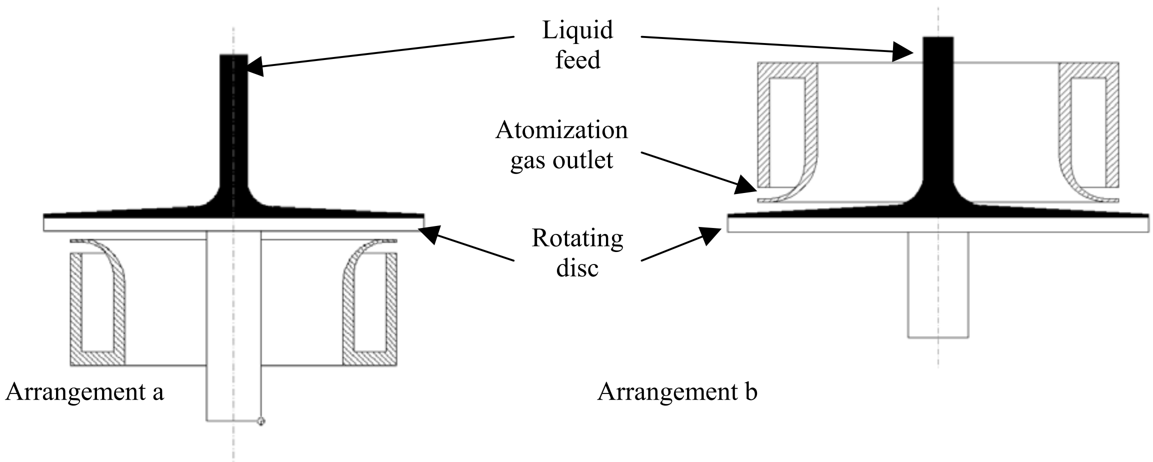

Figure 5a/b Atomizer to rotary disc arrangement

To investigate the influence of the constrained prefilm, the atomizer/disc arrangement 5a is investigated. The prefilm is produced and transported by centrifugal forces to the rim of the disc without being influenced by the atomization gas. The atomization in this case occurs directly at the edge of the disc where the liquid comes in contact with the high velocity atomization gas. Within the experiments the distance z between the disc and the outlet of the atomization gas is adjusted to 5mm, the atomization pressure and the diameter of the disc varied.

In the second set of experiments the atomizer to disc arrangement 5b is investigated. Again the prefilm was generated by centrifugal forces and transported to the edge of the rotary disc. The disc diameter and the atomization gas pressure vary, the distance from the disc to the outlet of the atomization is held constant. In the case where the larger disc is used, the liquid stream is conducted into the atomization zone, but the atomization process occurred not directly at the edge of the disc, but the liquid was detaching from the disc before the edge and is then atomized. When the smaller disc is investigated, a free flowing prefilm is generated first, which than is carried by the entrainment gas flow into the atomization zone.

RESULTS

In figure 6 some experimental results are shown. It can be seen that the arrangement 5b (A-5b) produces much finer particles compared to the arrangement 5a (A-5a). In the arrangement 5a the larger disc (l-disc) produces finer particles compared to the smaller disc (s-disc). This can be explained by the reduced thickness of the film on the disc in case of the larger disc. The arrangement 5b with the larger disc produces coarser particles compared to the free prefilming arrangement setup with the smaller disc. It is assumed that the oscillating liquid feed and the forming of a reservoir at the rim of the disc is suppressed and the prefilm thickness is decreased.

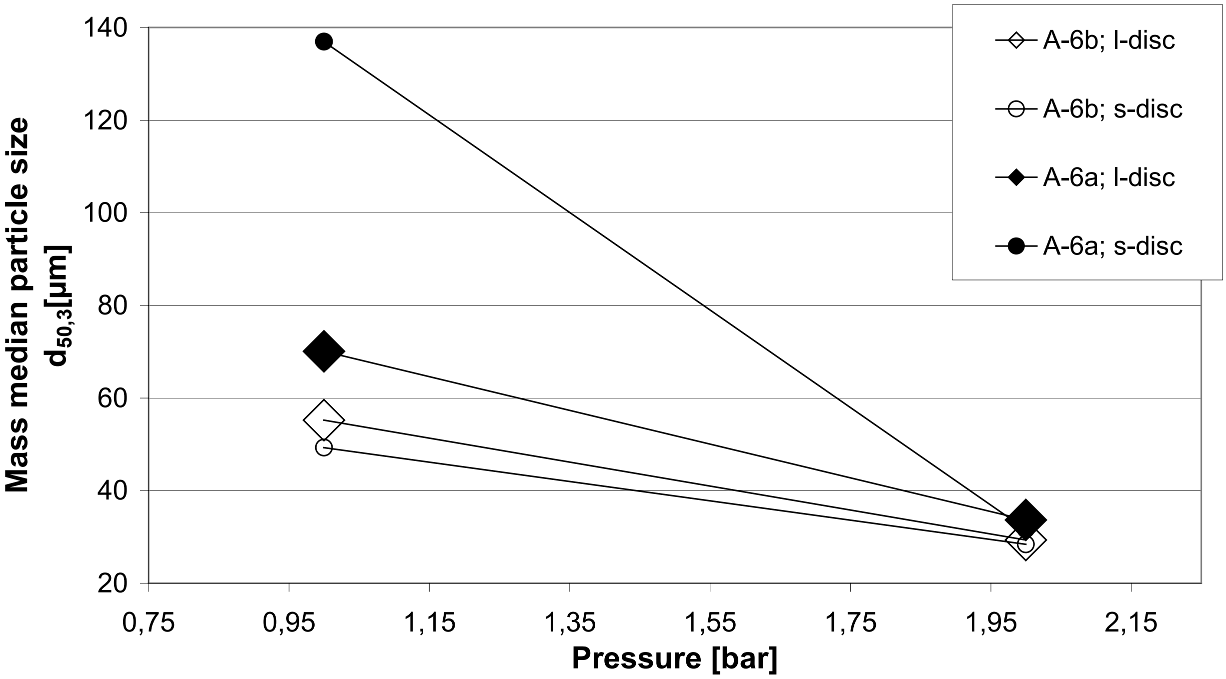

Figure 6 Experimental results: drop size distribution

CONCLUSIONS

A hybrid prefilming atomizer has been derived and set up for model experiments. Experimental results show that an unconstrained prefilm flow has some advantages for atomization. The particle size of the spray is reduced and the efficiency of the hybrid atomizer is increased especially for highly viscous liquids at low atomization gas pressure.

REFERENCES

[1] Lefebvre, A.H., *Atomization and Sprays*, pp. 201-267, Hemisphere Publishing Corporation, New York, 1989.

[2] Lefebvre, A.H., Airblast Atomization, *Prog. Energy Combust. Sci.*, vol. 6, pp. 233 – 261, 1980.

[3] Fraser, R.P.; Dombrowski, N.; Routley, J.H., The production of uniform liquid sheets from spinning cups, *Chemical Engineering Science*, vol. 18, pp. 315 – 321, 1963.

[4] Fraser, R.P.; Dombrowski, N.; Routley, J.H., The atomization of a liquid sheet by impinging air stream, *Chemical Engineering Science*, vol. 18, pp. 339 – 353, 1963.

[5] Roylance, T.F.; Pickering, S.J.; Hay, N.; Thomas, G.H., A rotary cup air blast atomizer for molten slag – an investigation of particle size and spray trajectory, *Proc. ICLASS-1985*, LP/VB/2/1-16, 1985.

[6] Lohner, H., Zerstäubung von Mineralschmelzen mit Heißgas, Ph.D. thesis, University Bremen, VDI Verlag, Düsseldorf, 2003.

[7] Sattelmayer T., Zum Einfluss der ausgebildeten, turbulenten Luft-Flüssigkeits-Strömung auf den Filmzerfall und die Tropfenbildung am Austritt von Spalten geringer Höhe, Ph.D. thesis, University Karlsruhe, 1985.

[8] Hinze, J.O.; Milborn, H., Atomization of liquids by means of a rotating cup, *Journal of Applied Mechanics,* vol. 17, pp. 145 – 153, 1950.

[9] Bär, P., Über die physikalischen Grundlagen der Zerstäubungstrocknung, Ph.D. thesis, University Karlsruhe, 1935.

[10] Theissing, P., *Erzeugung von Flüssigkeitsfilmen, Flüssigkeitslamellen und Tropfen durch rotierende Scheiben*, VDI – Forschungsheft 574, VDI Verlag, Düsseldorf, 1976.

[11] Czisch, C., Lohner, H., Fritsching, U., Impact of the gas nozzle arrangement on the flow field of a twin fluid atomizer with external mixing, *Proc. ICLASS-2003*, Sorrento, 2003.