# **MELT ATOMIZATION BY HEATED GASES**

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#### Abstract

Specific melt types as mineral melts have high viscosity and comparably low surface tension. Therefore, twin fluid atomization of these melts for powder production often results not in spherical particles but in a great amount of fibres. Within this investigation, mineral melts are atomized in a pilot plant by means of hot gases to produce spherical particles. Within the hot gas environment the melt solidifies slower, due to the lower heat transfer between melt and hot gas. Therefore, the melt element residence time at higher temperature levels with still low viscosity is increased. In this way spherical melt droplets are achieved. Atomization results show that for constant atomization pressure the mean diameter of the powder particles decreases with increasing atomization gas temperature. CFD-simulations support the description of the gas temperature and flow conditions have been realized. Comparing the experimental results with the results of the CFD-simulation, a shear process characterized by the Reynolds number can be determined as the main driving mechanism of the atomization process.

#### Introduction

Mineral melts, as glas melts or slags, have comparably high viscosity and low surface tension. Granulation and powder production of these melts by gas atomization result not in spherical particles but in fibres or at least in a product with a high fibre content. Within this investigation, a model melt containing  $Al_2O_3$ ,  $SiO_2$  and CaO (melt temperature about 1970K, viscosity about 1 Pas) has been atomized using specifically designed twin fluid atomizers in a pilot plant with hot gases. Because the lower temperature difference between hot gas and melt jet result in a lower heat transfer, the melt in the spray solidifies slower. So the mineral melt stays longer in a state of low viscosity and the melt elements spheroidize due to surface tension and solidify as globular particles.

A few approaches cited in literature are known using hot gas to atomize (metal resp. polymer) melts [1] [2] [3]. In these works an improvement of the atomization result was observed. On the other hand there are some works investigating heated free jets, which predict a deterioration of the atomization process, caused by the decreasing gas density and also decreasing gas momentum with increasing gas temperature [4] [5]. Therefore, the influence of gas temperature on the atomization process in twin fluid atomization is still somewhat controversial.

To investigate the influence of increased gas temperatures on the atomization process and to produce a powder containing a high amount of spherical particles, a pilot plant for hot gas atomization of viscous melts has been designed and set to work.

# Setup of the pilot plant

The setup of the pilot plant and the used gas atomizer are shown in fig.1. Main part of the plant is a spray tower app. 5.5m in height. On top of the spray tower the material is molten by an induction heating device. The melt flows out of the crucible due to gravity (melt-mass flow rates up to 500kg/h) and is atomized in a free fall-twin fluid atomizer by heated gases (air or nitrogen). Also atomization by means of superheated water steam is possible.

The melt jet is initially covered by a primary gas flow to suppres recirculation of melt droplets in the nozzle vicinity and prevent clogging of the crucible or the gas nozzles. Atomization of the melt jet is realized by the secondary gas flow (see enlarged sketch in fig. 1). Gas temperatures up to 1270K and gas pressures up to 0.6MPa can be realized.

The resulting melt droplets in the spray may be quenched and solidified about 2m below the atomization nozzle. Main parts of the resulting powder are collected at the bottom of the spray tower, the fine powder is deposited in a heated cyclone.

The heated gas is produced by a discontinuous heat exchanger, a so called cowper. A ceramic bulk material inside the cowper is heated by a propane burner up to 1670K. After this heating process compressed gas or steam

is blown into the cowper. The preset value of the atomization gas temperature is obtained by mixing the heated gas with gas at room temperature at the top of the cowper.



Figure 1. Experimental setup of the pilot plant and the atomization nozzle.

#### **Experimental Results**

Several atomization experiments for different gas temperatures, gas pressures and melt temperatures have been performed [6]. The results demonstrate, that an almost fibre free product with powder mass fractions up to 97% can be obtained by hot gas atomization of mineral melts. In fig. 2 a SEM-image of the powder fraction with a diameter  $d < 50 \mu m$  is shown. It can be seen that most of the particles of the powder produced by hot gas atomization got a spherical shape.



**Figure 2**. SEM image of hot gas atomized powder fraction  $d < 50 \mu m$ .

The influence of gas temperature  $T_{gas}$  (before the expansion through the nozzle) on the powder mass fraction and the resulting powder mass median diameter  $d_{50,3}$  is illustrated in fig. 2. The experiments shown in fig. 2 were performed at **constant** gas pressures  $p_1 = 0.3$ MPa and  $p_2 = 0.45$ MPa, so that **gas mass flow rate decreases** with increasing gas temperature  $T_{eas}$ .

The powder mass fraction (particles with a diameter  $d < 710\mu$ m) increases with increasing gas temperature. While melt atomization with gas at room temperature (T = 298K) results in a product containing only a small powder mass fraction (about 25%) and high fibre mass fraction, melt atomization with heated gas results in an almost fibre free powder. For constant atomization pressure, also the mass median diameter  $d_{50,3}$  of the powder particles **decreases** with increasing atomization gas temperature and consequently **decreasing gas mass flow rate**.



Figure 3. Influence of the gas temperature  $T_{gas}$  on the mass fraction of powder (left) and the powder mass median diameter  $d_{50,3}$  (right).

## **CFD-Simulation**

Theoretical investigations of the temperature- and flow profiles in the atomizer nozzle vicinity respectively the atomization area have been performed. Because of the extreme atomization conditions and the corresponding problems to install suitable measurement devices close to the atomization area, CFD-simulations support the proper description of the temperature and flow conditions during the atomization process. Numerical simulations for different nozzle designs and several operating conditions have been realized [7]. The computations were performed on a 2D-grid of app. 15000 cells resp. a 3D-grid of app. 505000 cells. A standard k- $\epsilon$ -model and a coupled implicit solver have been used. The geometry of the atomization nozzle used in the experiments described above was pictured using the circumferrential symmetry of the nozzle.

Two different configurations of free fall atomizer nozzles have been compared: the nozzle configuration with discrete jets (primary nozzle 12 bore holes; secondary nozzle 16 convergent-divergent bore holes) and a configuration with slit nozzles. The outlet area of the slit nozzle corresponds to the total area of the discrete bore holes. In fig. 4 the local gas velocity w on the center line of the atomizer jet near the nozzle exit and in the atomization area is shown for both nozzle configurations ( $T_{gas} = 298$ K, atomization pressure  $p_2 = 0.55$ MPa, primary pressure  $p_1 = 0.18$ MPa).

It is obvious, that the velocity distribution differs considerably especially in the vicinity of the primary nozzle. The slit nozzle generates an annular free jet in form of a hollow cone. Due to a depression inside the cone the primary jet kinks towards the center line and an area of strong recirculation (negative velocity) develops close to the primary nozzle. The maximum gas velocity is reached when the primary flow hits the center line.

In between the individual jets of the nozzle with discrete holes a pressure compensation may takes place. Therefore, the jets kink less than the annular jet of the slit nozzle. An area of recirculation is still developed close to the secondary nozzle with comparatively low gas velocity. The nozzle with discrete jets obtains higher gas velocities in the atomization area, therefore it has been used in the experiments and the following computations were performed for this nozzle configuration.



Figure 4. Local gas velocity w on the jet center line of a slit nozzle (2D) and a nozzle with discrete jets (3D)  $(T_{gas} = 298 \text{K}, p_1 = 0.18 \text{MPa}, p_2 = 0.55 \text{Mpa}).$ 

The local gas velocity w on the center line of the atomizer jet near the nozzle exit and in the atomization area increases with increasing gas temperature  $T_{gas}$  at constant pressure (atomization pressure  $p_2 = 0.55$ MPa, primary pressure  $p_1 = 0.18$ MPa) as illustrated in fig. 5.



Figure 5. Influence of gas temperature  $T_{gas}$  on gas velocity w (left) and specific gas momentum  $\rho w$  (right) on the jet center line at constant gas pressure,  $p_1 = 0.18$ MPa,  $p_2 = 0.55$ MPa.

The influence of the atomization temperature on the specific gas momentum  $\rho w$  and the kinetic energy of the gas  $\rho w^2$  in the atomization area was computed herefrom. The decreasing gas density  $\rho$  for increasing atomization gas temperature at constant gas pressure results in a decreasing gas mass flow rate and also decreasing specific gas momentum in the atomization area (see fig. 5).

In fig. 6 the results for the distribution of the kinetic energy of the gas in the atomizer vicinity and the atomization area are shown for different gas temperatures but at constant gas pressure. It is obvious that the kinetic energy changes along the symmetry axis but obtains identical values for all gas temperatures.



Figure 6. Results of 3D-CFD-computation: Kinetic energy  $\rho w^2$  of the gas on the center line of the atomizer jet,  $p_1 = 0.18$ MPa,  $p_2 = 0.55$ MPa.

# **Discussion of results**

The experimental investigation presented in this work show that an almost fibre free product can be received as result of hot gas atomization of viscous mineral melts. The mean diameter of the particles **decreases** for constant atomization pressure with increasing gas temperature and **decreasing** gas mass flow rate resp. **decreasing** specific gas momentum in the atomization area. Therefore, the slip velocity between gas and melt respectively a shear process can be assumed to be the main driving force of the atomization process and not the momentum exchange between gas flow and melt jet. This assumption is confirmed by the relevant non-dimensional characteristic numbers, the aerodynamic Weber number  $We_{gas}$  and the Reynolds number *Re*. As shown in fig. 6, the kinetic energy of the gas  $\rho w^2$  takes constant values for constant gas pressure with increasing gas temperatures. Assuming a constant surface tension  $\sigma$ , the aerodynamic Weber number is not a function of the gas temperature anymore. Therefore, the experimental results presented above cannot be sufficiently described by the aerodynamic Weber number (eq. 1).

$$We_{gas} = \frac{\rho_{gas} \cdot \Delta w^2 \cdot d_l}{\sigma} = const.$$
 (1)

The influence of the increasing shearing action between the melt jet and the gas flow with increasing gas temperature and constant gas pressure is formulated in the Reynolds number formed with the relative gas velocity between gas flow and melt jet  $\Delta w$ . In eq. 2 the Reynolds number is multiplied by  $\Delta w/\Delta w = 1$ .

$$Re = \frac{\rho_{gas} \cdot \Delta w^2}{\mu \frac{\Delta w}{d_l}}$$
(2)

The numerator of eq. 2 is constant for all gas temperatures as shown above. The denominator increases caused by the increase of  $\Delta w$  and  $\mu$  with increasing gas temperature and constant gas pressure.

#### Summary

In this paper a concept to atomize viscous mineral melts by heated gases has been presented. An almost fibre free product can be obtained. As main driving force of the atomization process the shearing action between gas flow and melt jet can be determined.

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Re	Revnolds	number

- $We_{gas}$  aerodynamic Weber number
- $d_l$  diameter of the melt jet
- $d_{50,3}$  mean diameter
- *p* pressure
- T temperature
- w velocity
- $\Delta w$  relative velocity between gas and melt jet
- z axial coordinate
- $\mu$  viscosity
- $\rho$  density
- $\sigma$  surface tension

#### Subscripts

- *l* primary nozzle
- 2 secondary nozzle
- gas gas
- *l* liquid

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