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Investigation on the influence of the atomization gas in coating processes

Dr. Oliver Tiedje, Dr.-Ing. Qiaoyan Ye*, Bo Shen**
** Fraunhofer-Institute for Manufacturing Engineering and Automation IPA, Stuttgart*

Atomization plays a crucial role in spray coating processes. The liquid paint is broken up to small droplets and accelerated to the work piece. A conflict of goals is appearing here: A high quality of the layer requires usually a fine atomization, but small droplets can lead to enhanced overspray. Discussions regarding the use of other atomization gases than air shall be focused to a systematic base in this article.

Research project glaze-forming

A research project, in which Fraunhofer IPA transfers methods and processes from painting to glazing of ceramics, aims for significant savings of energy. Ceramics production is one of the most energy consuming industries that is characterized by approx. 25 % of electrical energy consumption leading to high CO_2 emissions.
A fundamental goal of the project is to minimize overspray and compressed air. For that reason atomizing with water steam (an approach of the project partner Krautzberger) is investigated in the painting lab of Fraunhofer IPA. This lab is built on an industrial level, but can additionally include highly sophisticated optical measurements and numerical simulations. Using these methods, the effect of exchanging the usual compressed air by overheated steam for atomizing the glaze is investigated.

Goal of a perfect atomization

The atomization breaks up the liquid paint into small droplets (depending on application and material between 10 and 100 µm). In the same moment the droplets are accelerated to the object and deposited. Generally the transfer efficiency shall be high to save material and avoid contamination. Overspray leads to a high demand on conditioned air and expensive facilities (e.g. wet or dry scrubbing) to be removed. Coarser atomizing will minimize the overspray, but worsens the structure of the film, the colour or the homogeneity.
The central factor in creating overspray is the impact pressure generated by the air accumulated in front of the object. This could be atomizing air and horn air at pneumatic guns, shaping air at high rotation bells or air sucked in the paint stream in airless applications [1].

To minimize the impact pressure, a fine atomization has to be achieved with a small amount of air. One approach is to separate the atomization process from the droplet transport – for example in high rotation bells, in ultrasonic atomization, or in the recently presented overspray free paint application [2]. However, the pneumatic guns are widely spread, so it is reasonable to look for adjustment here.

Influence of atomizing gas

Due to theoretical consideration (e.g. theory of von Lefebvre [3]), we learn that the air velocity is of quadratic influence, but the momentum is only linear. So a fine atomization is achieved with a high air speed in that region where the atomizing air stream hits the paint. In contrast, the air amount is of minor importance. In consequence, a gas with low density and high speed of sound should show interesting potentials:

	Speed of sound [m/s] at 25 °C	**Speed of sound [m/s] at 100 °C**	**Density [kg/m³] at 25 °C; 1 bar**	**Density [kg/m³] at 100 °C; 1 bar**
Air	346	390	1,18	0,95
CO_2	266	298	1,78	1,4
Nitrogen	334	378	1,13	0,9
Water steam	---	477	---	0,6

Tab. 1: Properties of different gases

According to tab. 1 a mean could be the warming of the compressed air or using other gases. The example of overheated steam is investigated in the mentioned project by using scientific methods, like laser measurements or numerical simulations under industrial circumstances (fig. 1).

Fig. 1: Experimental setup with Krautzberger steam atomization in IPA-lab

Methods for simulation and measurement

The simulations base upon *computational fluid dynamics* (CFD), using adaptations to paint topic within the framework of the finite volume method ANSYS FLUENT. The gas phase was modelled using the Eulerian conservation equations for mass, momentum and energy. The three-dimensional compressible airflow was calculated with the segregated solver. The turbulent transport was modelled using the sst k-ω model. Species transport, namely water vapour and air, was calculated. An unstructured mesh with 6.2 million cells for the computational domain with a size of 1.6×0.4×0.8 m³ was used and mesh refinement was carried out [4,5].

The tasks in the painting lab are to validate the simulations and to create reliable numbers about the atomizer, e.g.:

- Determination of the transfer efficiency according to DIN EN ISO 13 966
- Visualization of the air flow by laser light section
- Measurement of the droplet size distribution by laser diffraction
- Measurement of the droplet velocity by laser Doppler anemometry
- Determination of the temperature distribution by thermography
- Visualisation of the atomization by high speed camera

Results

In the investigated technology, provided by the company Krautzberger, the atomizing and horn air is replaced by water steam with a temperature between 150 °C and 200 °C. The focus is drawn to impact on atomization and droplet transport. The first step is to analyse the temperature in and in front of the atomizer (fig. 2). Consistently in theory and measurement, the steam cools down to approx. 100 °C in the region of atomizing. The painted object (steel) warms up to 40 °C at a painting distance of 20 cm, and to 37 °C at a distance of 25 cm. The simulations are in a good agreement with 36 °C in this case.

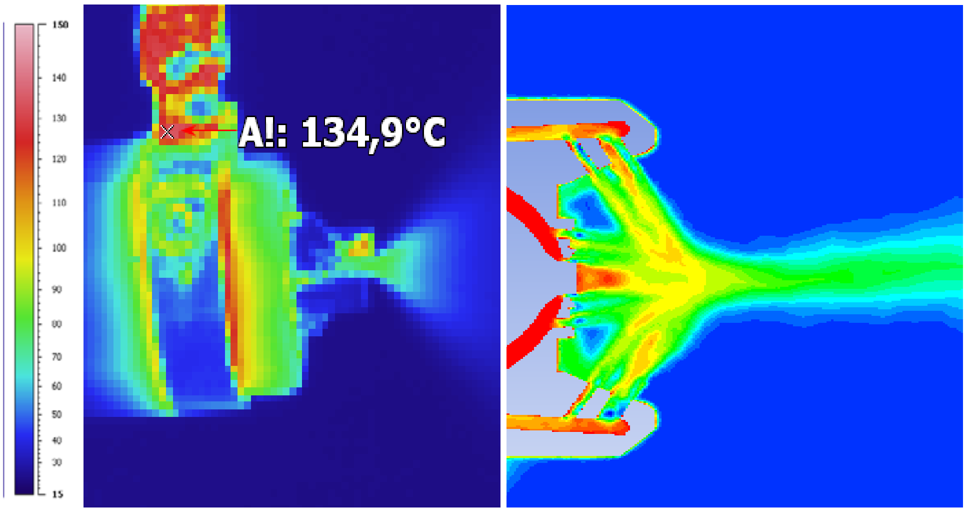

Fig. 2: Temperature in the vicinity of the air cap (steam atomization; left measurement with infrared camera; right: numerical simulation)

The important gas velocity in the crossing point (fig. 3) is calculated to 260 m/s at air (24 °C) and 470 m/s at steam vapour, and nearly doubling the gas speed for the same mass flow rate of 20 kg/s. Additionally the degree of turbulence (fig. 4) is higher, helping the atomization. Consequently the finer atomization is measured to be 40 µm instead of 100 µm. Simultaneously, the air stream relaxes stronger with steam, leading to no significant difference at the painting distance. A high transfer efficiency of 95 % is measured.

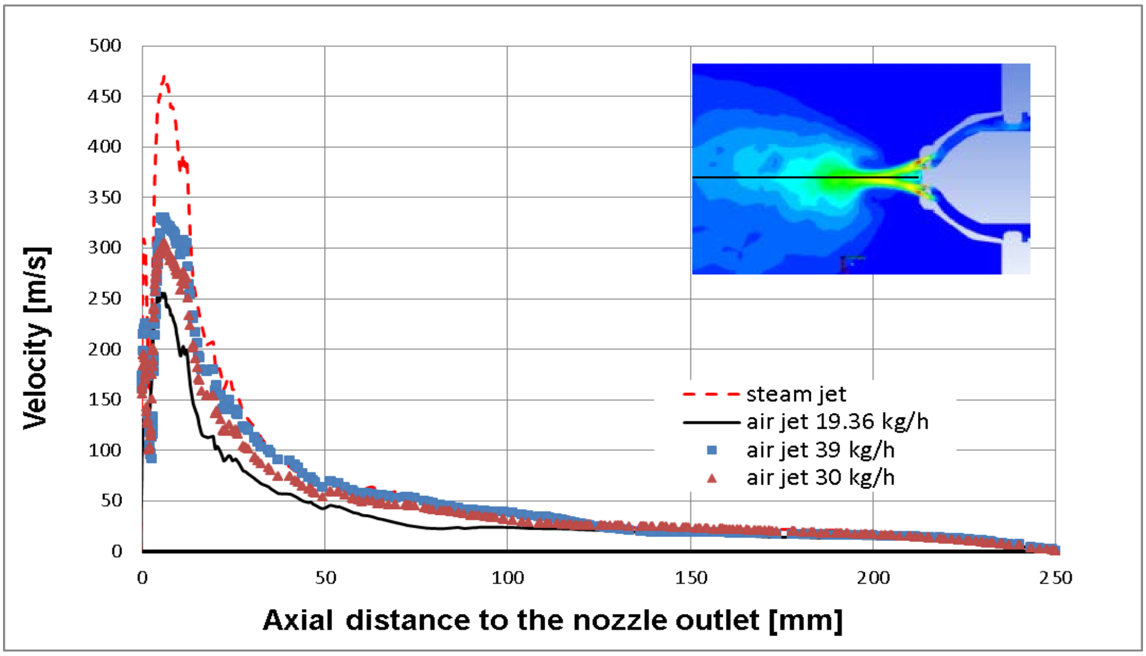

Fig. 3: Velocity magnitude along the jet axis

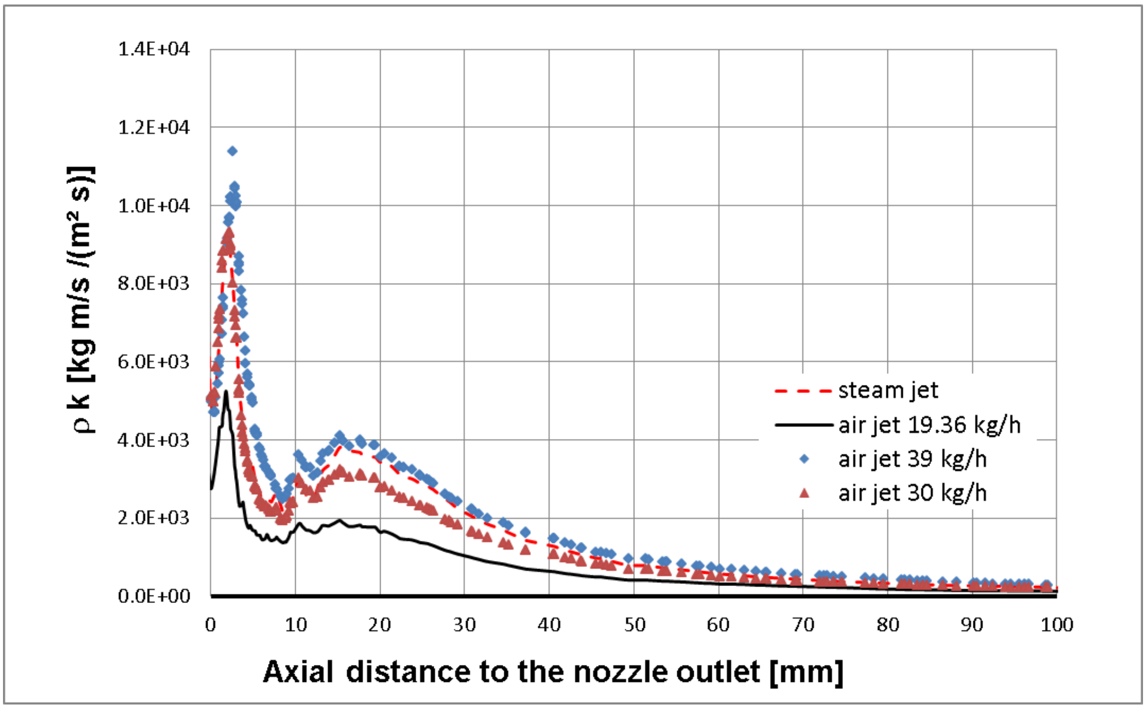

Fig. 4: Turbulent stress along the jet axis

In order to study the effect of droplet evaporation and condensation to clarify whether the liquid film on the target is too wet using steam atomizing, droplet trajectories in the steam jet were calculated. During the droplet trajectory, heat and mass transfer between droplet and the bulk flow was calculated. Information of sample droplets with original diameter from 1 µm to 300 µm was recorded in different cross-sections downstream during their trajectories. Mean values of solid component mass fraction in the record-section for every droplet class were calculated and shown in fig. 5, in which the legend shows the original droplet diameters. Bearing in mind, that the original solid mass fraction of the liquid is 0.675, values larger than 0.675 means dryer droplets. Clearly, vapour condensed on droplets when they were located near the atomizer. Smaller droplets evaporated more quickly. Far away from the nozzle, e.g. further away than 100 mm, the solid fractions of all droplets were larger than its original value, which means, that dryer droplets will deposit on the substrate.

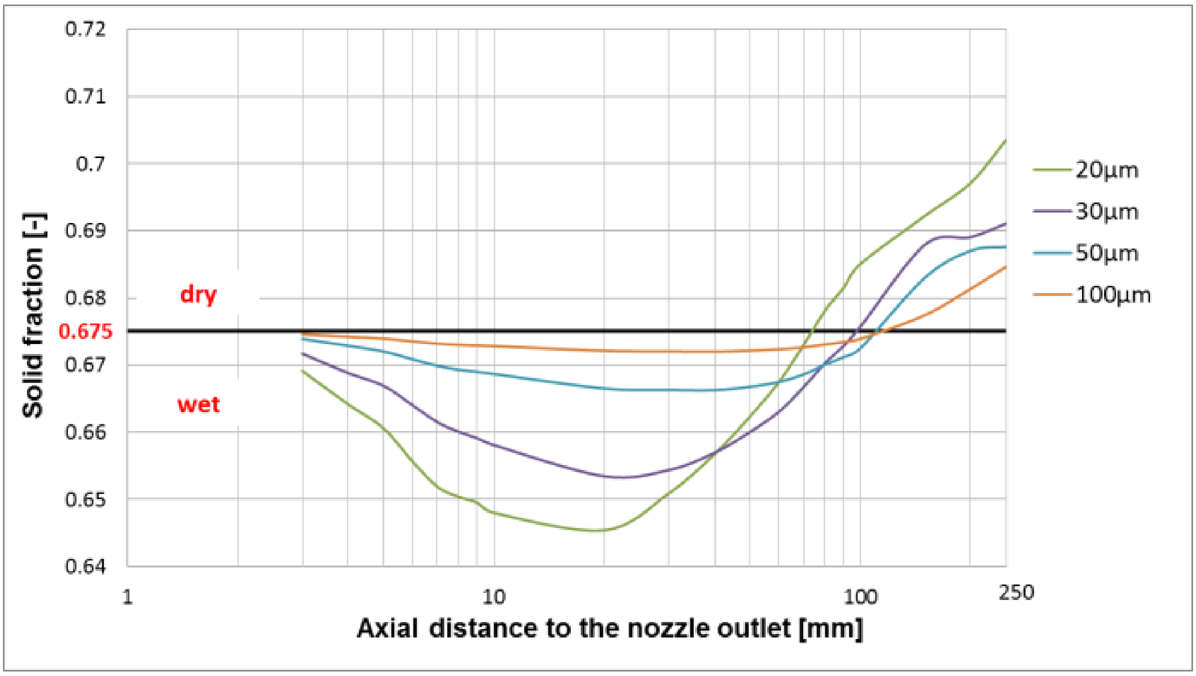

Fig. 5: Change in solid fraction of the coating material in droplets during their flight to the substrate

Summary

Numerical simulation is an adequate method to understand and optimize atomization, when it is accompanied by measurement techniques in a practically oriented lab. So it could be shown, that gases with low density like vapour steam, yield high velocities, good atomization and high transfer efficiencies.

The companies Villeroy & Boch, Krautzberger, massform, Geyer & Hamberger and Fraunhofer IPA collaborate in the research project *glaze-forming (ending in September 2015)*, to develop new methods for glazing. They aim for a new energy efficient process to produce glazed ceramics in order to reduce the CO_2 emissions. The project is supported by the German federal ministry of education and research (BMBF) within the framework „KMU-innovativ: Ressourcen- und Energieeffizienz“ (code 01LY1105E) and supervised by “Projektträger im Deutschen Zentrum für Luft- und Raumfahrt”. The authors of the publication are responsible for the content.

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