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A DEVICE FOR MEASURING TEMPERATURE AND HUMIDITY IN A SPRAY DRYER CHAMBER

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The design of a device is discussed that can be used to separate small particles ($\sim 10\,\mu$m) from a gas stream. Computational fluid dynamics was used in the design process. The device proved to be very useful in measuring temperatures and humidities in a spray drying chamber.

Keywords: spray drying; computational fluid dynamics; particles; temperature measurement; humidity measurement

INTRODUCTION

To predict the quality of a spray dried product, one has to know what happens to the particles after they have been produced by the atomizer. It is necessary to know what air temperatures and humidities a particle 'experiences' on its way through the spray drying chamber. Therefore it is important to know the temperature and humidity patterns in the spray drying chamber.

Measuring the air temperature and humidity patterns is complicated by the presence of the particles being dried. Special measures have to be taken to eliminate the interfering effect of the disperse phase.

In this article a device is discussed with which temperatures and humidities in a spray drying chamber can be measured. This device is designed using computational fluid dynamics, which proved to be a simple and effective tool to predict the effectiveness of the device.

DEVICES DESCRIBED IN THE LITERATURE

Temperature measurements in spray drying chambers have been described in the literature a number of times. Many researchers have just neglected the influence of the spray (for instance Fieg *et al.*[1]). Other researchers have addressed the problem and have come up with two approaches. One is to take measurements with an unprotected probe until the probe is covered with liquid. The probe is then cleaned and another measurement cycle can begin. Another approach is to prevent the probe from being hit by droplets.

Periodical Removal of Liquid from the Probe

Most systems for the removal of liquid from the probe are based on heating the probe to evaporate the liquid. This limits its application to sprays of liquids without dissolved solid materials. The time span over which actual temperatures can be measured is limited by the temperature equilibration of the probe and the rate of particle deposition. This means that in most sprays the response time of the probe should be very short while the denseness of the spray should be low.

Avoiding Wetting of the Probe

Arrangements to shield the probe vary from simple shields to so called aspirated probes. A simple shield as used by Papadakis[2] (see Figure 1) protects the probe from being hit by droplets mainly from one direction only. It is clear that such an arrangement will not work in flow systems with circulations or large eddies. To protect the probe from particles coming from all directions, the shield can be extended[3]. In such arrangements the problem arises that the probe is measuring temperature in stagnant air, surrounded by the cooler walls of the shield. To avoid this, the probe should be aspirated. Such a system is described by Nijhawan *et al.*[4] and used in a spray drier by Goldberg. As can be seen in Figure 2, this is quite a large system and quite complex to build.

BASIC IDEA

Our approach to developing a temperature and humidity measurement device is based on protecting the temperature probe from being hit by particles by removing the particles from the gas stream. The cleaned gas stream can be led to a hygrometer outside the spray drying chamber.

The best way to separate the particles from the air is to utilize the difference in inertia, as in a cyclone. A cyclone cannot be used though, because of its large volume and of

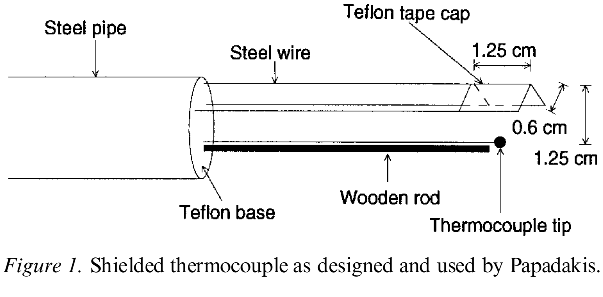

Figure 1. Shielded thermocouple as designed and used by Papadakis.

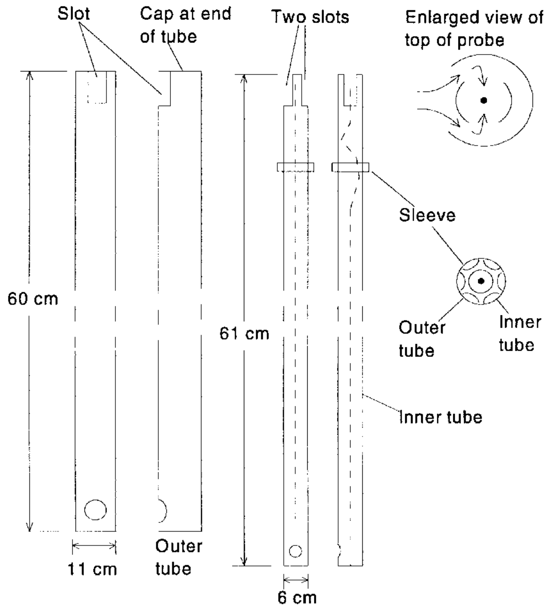

Figure 2. Shielded aspirated probe as used by Goldberg.

the risk of being clogged with the sticky particles. Another way to use the difference in inertia is a system in which the pathway of the airstream to be cleaned follows a sharp curve, such that the particles cannot follow this curve. The sharpest curve is at complete flow reversal (curve 180°). Such a system is depicted in Figure 3. This system has been called a 'micro-separator'.

SIMULATION

Before building the system, it was necessary to know if the concept would be effective. Furthermore, the optimum airflows through the inner and outer tube had to be determined.

To answer these questions, the computational fluid dynamics (CFD) package Fluent V3.03 and V4.25 was used, which proved to be an effective and handy tool in the design process.

The goal of using CFD was to calculate the fraction of particles that would *not* be dragged into the clean air stream (the so-called separation quality). For this, particle trajectories had to be calculated for which in

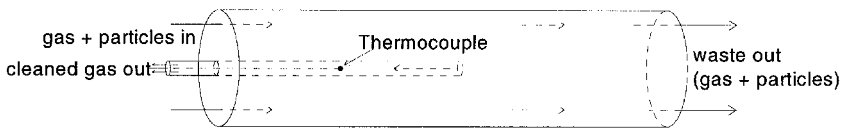

Figure 3. Concept of micro-separator.

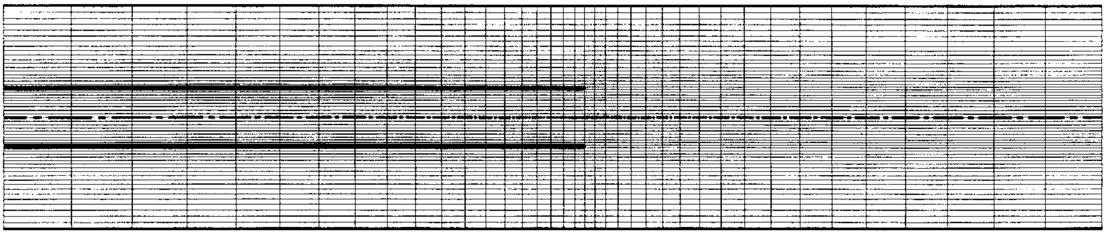

Figure 4. The grid used in the CFD modelling (standard geometry). The bold lines represent the geometry, the dash-dot line represents the symmetry axis. In this picture both halves of the domain are drawn. Only one half is calculated.

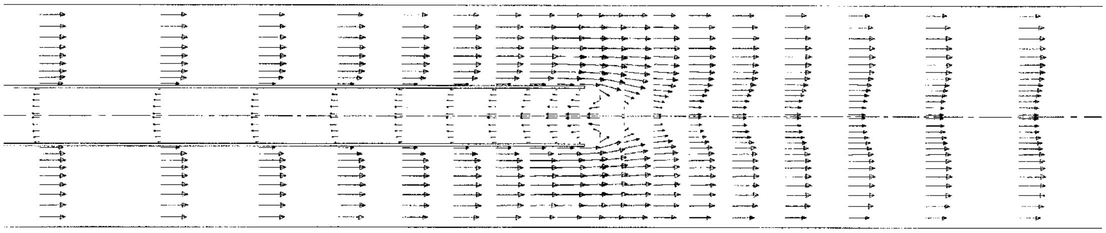

Figure 5. The calculated flow field. Normally each computational cell is represented with one vector. To avoid overcrowding of the picture, every other vector is plotted (in x and y direction so one quarter of the total number of vectors is plotted).

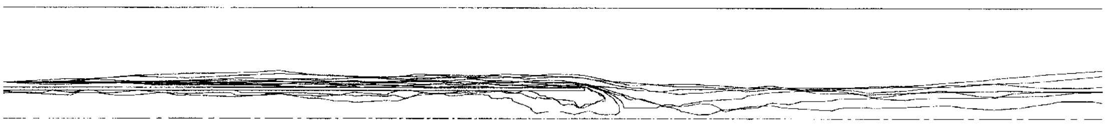

Figure 6. Ten particle tracks (2 micrometer). Due to turbulent dispersion every particle track is unique. The topmost horizontal line represents the wall of the outer tube, the dash-dot line represents the symmetry axis. Particles are 'injected' just along the wall because of the worst case scenario. The particles' initial speed equals that of the air.

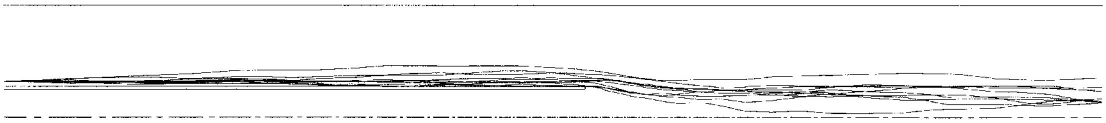

Figure 7. Tracks of 8 micrometer particles.

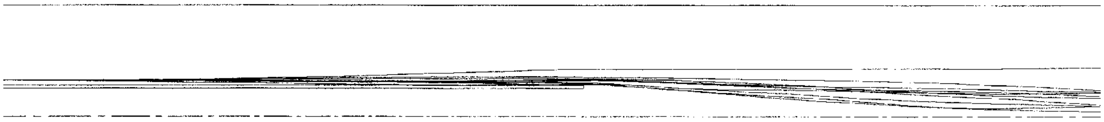

Figure 8. Tracks of 32 micrometer particles.

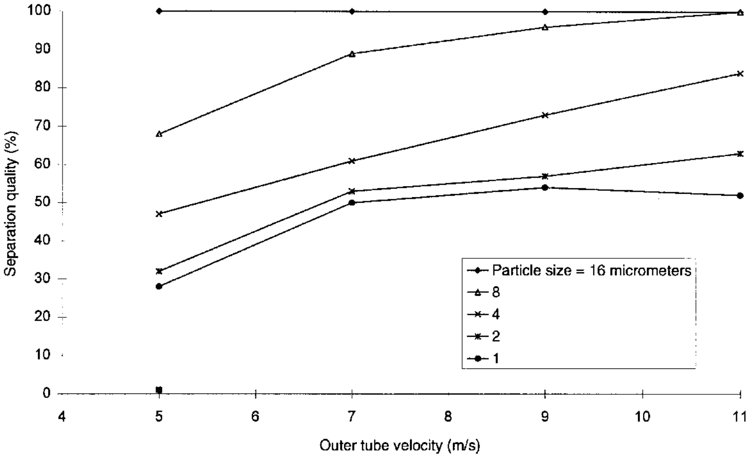

Figure 9. Separation quality as function of outer tube velocity for the standard geometry. The air flow in the inner pipe is fixed at 4 m s^{-1}. For every point in the chart 100 particle tracks were calculated (turbulent dispersion).

turn the airflow pattern had to be calculated. Assuming rotational symmetry, the flow domain was divided into small rectangles, the grid (see Figure 4). Using this grid and inlet boundary conditions, Fluent calculates an approximate solution of the conservation laws of mass and momentum. Turbulence is calculated using a standard $k - \varepsilon$ turbulence model. Thus a time-averaged air velocity and turbulence intensity pattern is obtained (see Figure 5). Using this airflow pattern, individual particle trajectories can be calculated by 'injecting' particles into the air-stream. The trajectory is calculated by integrating the equation of motion (i.e. a combination of the conservation of momentum and the drag the airflow exerts on the particle) over time. Obviously the dragforce depends on the airspeed, for which the time averaged airspeed can be used; in this case two identical particles will have identical trajectories.

In reality, the airspeed is not constant but fluctuates around an average due to turbulence; this causes two identical particles to have different trajectories. In Fluent this turbulent dispersion is calculated by adding a normal distributed random value to the time averaged velocity in each cell. The magnitude of this random value is related to the local turbulence intensity. Fluent calculates the trajectory by integrating over time during the lifetime of an eddy. After this time span or if the particle moves across the boundary of a grid cell, a new gas velocity is calculated using the random generator.

A number of these particle trajectories are depicted in Figures 6 to 8. Most particles are dragged by the waste air stream, only a few particles enter the inner tube.

RESULTS

Based on practical considerations, an outer tube of 250 mm and a diameter of 20 mm have been chosen. The inner tube was chosen to be 75 mm long and 5 mm in diameter. Using this geometry the simulations were carried out.

It is obvious that large particles are separated better than small particles. Particle sizes in pilot plant or commercial spray driers are expected to range from 25 to 250 micrometers. In the simulations a worst-case scenario was assumed: the particles in the simulation were considerably smaller than the particles expected to be present in the actual spray dryer chamber. Furthermore, the particles were injected near the wall of the inner pipe which is the location from which most particles will be trapped in the clean air stream. The following simulations were done:

Influence of the Waste Gas Flowrate

While the clean air flowrate was kept constant at –4 m s^{-1}, the waste gas flowrate was varied. The separation quality increased when the waste air flowrate increased (as

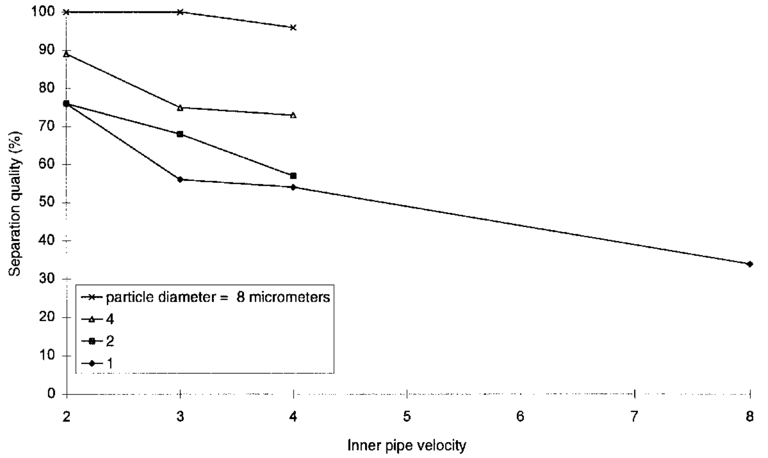

Figure 10. Separation quality as a function of the inner pipe velocity. The outer tube velocity was fixed at 9 m s^{-1}.

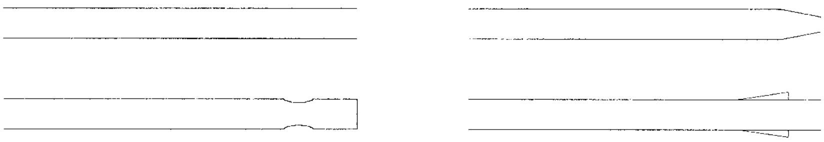

Figure 11. Various geometries: plain, sharp tip, holes in pipe and 'jumping ramp'.

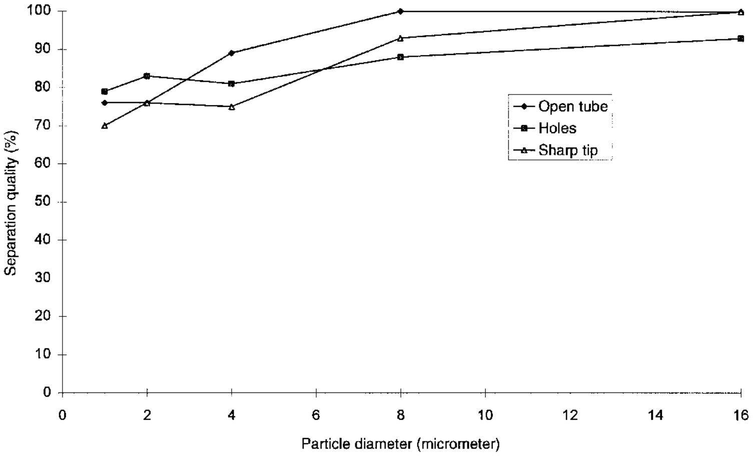

Figure 12. Performances of various geometries.

was to be expected). The results for a number of particle diameters are depicted in Figure 9.

Influence of the Clean Gas Flowrate

While the waste gas flowrate was kept constant at 9 m s^{-1}, the clean gas flowrate was varied. As expected, the separation quality decreases at increasing clean gas flowrates. The results for a number of particle diameters are depicted in Figure 10.

Geometry of the Inner Pipe

In the simulations described above, a plain inner pipe was used. In this simulation what would happen to the separation quality if the inner pipe inlet geometry was modified was investigated. The following geometries were considered (see Figure 11): sharp tip, holes in pipe and 'jumping ramp'. Surprisingly none of the modifications improved the separation quality significantly (see Figure 12).

The geometry with the holes in the wall collected an increased number of particles in the dead volume at the tip. The sharp tip caused a slightly deteriorated separation quality because the particles get a radial velocity because of the ramp and tend to penetrate further to the central axis.

The geometry with the 'jumping ramp' had about the same performance as the plain open pipe.

DESIGN AND CONSTRUCTION

Based on practical considerations and the CFD modelling work, the micro-separator probe was designed and built. It consists of an aluminium outer tube (see Figure 13). At the outlet end of the tube, a screw-thread was installed so that it can be mounted on another tube (support), while dismantling remains easy. At the inlet end, a groove with a length

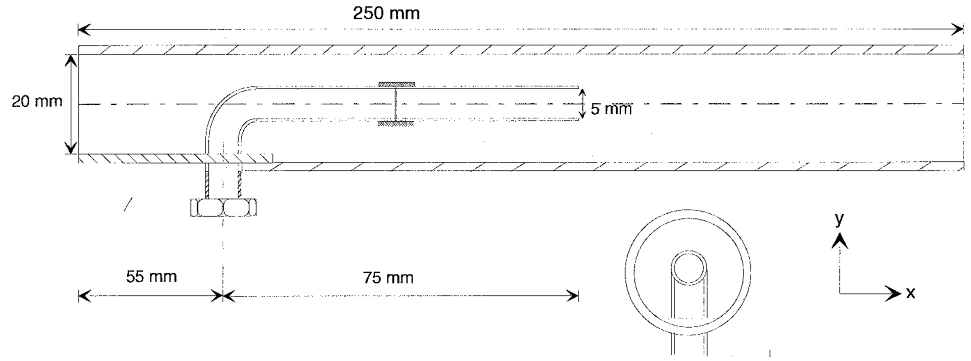

Figure 13. The micro-separator probe in detail. Please note: x scale and y scale are not equal!

of 5 cm was sawn. The inner pipe can be slid through this groove.

The inner pipe consists of an aluminium pipe that is bent 90°. The part parallel to the outer tube consists of two parts to enable easy installation and inspection of the thermocouple.

The groove in the outer tube is covered by a small plate that is fixed to the inner pipe. This plate, plus a nut at the other side, gives the inner pipe its mechanical stability. To avoid particles sticking to the outer tube and the inner pipe, the aluminium is coated with Teflon (Eriflon).

In the inner pipe a thermocouple is installed. The flow is led to a dewpoint meter. After the dewpoint meter a vacuum pump is installed. The airflow is measured using a rotameter and is fixed at $0.029\,l\,s^{-1}$ (equivalent to $1.5\,m\,s^{-1}$). To avoid condensation in the tubing to the dewpoint meter, electrical heating wire and insulation is wrapped around this tubing.

The airflow rate in the outer tube is set to $2.8\,l\,s^{-1}$ (equivalent to $9\,m\,s^{-1}$) using a blower and a rotameter. It proved to be necessary to install a small cyclone to avoid clogging of the rotameter and the blower.

MEASUREMENTS

To check if the micro-separator could indeed be used in an operational spray drying chamber, the micro-separator was held in a spray of maltodextrin solution for two hours. Maltodextrin is a non volatile solid material consisting of carbohydrates of high molecular weight. The solution, 42% by weight, is a sticky viscous wallpaper-glue-like liquid. The spray was produced using a pressure nozzle yielding a mean droplet size of $31\,\mu m$ which was determined by measuring a few thousand droplets under a microscope. The droplets were collected in silicon oil.

The micro-separator was positioned horizontally in the spray, 50 cm under the vertically positioned nozzle. After two hours in the spray, the micro-separator was disassembled and the inner pipe was inspected for the presence of maltodextrin. No maltodextrin was found, neither on the inside of the pipe nor on the thermocouple. The rotameter used to measure the flowrate in the inner pipe was clean too. This proves that the micro-separator functions well.

Eventually, the micro-separator was used to measure temperatures and humidities in a commercial spray dryer chamber. For this the micro-separator was installed horizontally, normal to the main flow direction. The set-up functioned without great difficulty, although measuring in the spray close to the hot air inlet (195°C) caused a built-up of a dry crust of maltodextrin of several centimetres thick on the outer tube. This shortened the maximum measuring period at that location to a few minutes.

The measurement data and CFD simulation of the conditions in the spray drying chamber will be published in a future article.

CONCLUSION

The design and construction of a device for the measurement of temperature and humidity in a spray drying chamber is described. This device was designed using a CFD package, which proved to be a useful tool. The device was tested and proved to function properly. Measurements in an actual spray drying chamber did not disclose great difficulties.

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ADDRESS

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