SIMULATION OF DRYING OF SLURRIES IN A HOT GAS STREAM

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Abstract

Heat, mass and momentum transfer between a slurry droplet and a gas flow are investigated numerically. The developed model can be applied to assess drying and combustion properties of slurries inside spray dryers or combustors and to estimate the time needed to reach ignition of the solid component in slurry fuels. The model was applied to coal water droplet slurries the properties of which are available in the litterature but can also be used for study of drying of any other slurry such as that encountered in flue gas desulfurization systems or in food industry. The parametric study revealed that the most important factor in slurry drying is the ambient temperature and that the injection velocity, the ambient pressure of the flowing medium or the particle initial temperature affect very little the drying rate.

Keywords: Slurry drying; mass transfer; first stage of drying; second stage of drying; Stefan diffusion.

1. Introduction :

The drying of slurries has various engineering applications (see Sirignano [1]): Food and pharmaceutical industries, spray pyrolisis, bioengineering, combustion, etc. . It is carried out for many reasons: among others for ease of handling, transporting, storing.

The drying often takes place in spray dryers (Fig.1) where the gas and slurry streams are brought into contact. At the initial period of drying (first phase of drying), a free liquid interface exists between the gas stream and the solution being dried(Fig.3), and evaporation proceeds as for a pure solvent- for example water drops for aqueous droplets (solutions). When the solution is concentrated beyond saturation, a crust forms to separate the gas and liquid interface, and a particle with a core of saturated solution results. This marks the end of the first phase of drying. During the second phase the heat for drying is supplied to the drop of slurry by convection from the hot gases to the droplet surface, and by conduction into the droplet. The liquid evaporated passes by diffusion through pores in the crust formed on the droplet(Fig.4), and then by convection into the gas stream.

Nikas et al [2] present a slurry evaporation model in which the evaporation rate of the second stage of drying could be deduced assuming a decaying exponential law of water content reduction when the second stage drying period was empirically specified.

In the present work, this empirical input is withdrawn by solving the temperature and vapour transient transport equations within the slurry droplet. Also, in order to increase the accuracy of the predictions, effective heat and mass transfer coefficients are used in the second phase of drying when the heat and vapour diffuse through a porous medium.Typical parametric results are presented on the effects on drying time and size distribution of various initial flow field or slurry conditions.

2. Mathematical Model

The equations governing the incompressible turbulent flow of a gas are the continuity equation, the momentum equations, the turbulence kinetic energy equation and the dissipation rate equation[3]. These have been solved in the coordinate system of fig. 2 using a finite volume method. The convective terms in these equations have been approximated using the VONOS scheme which has been developed recently by Varonos and Bergeles[4]. The scheme is a combination of the QUICK and BSOU schemes which are both second- order upwind schemes. The scheme is bounded, does not have an oscillatory behaviour and is less time-consuming than currently used higher order schemes.

Also, in order to obtain a high rate of convergence of the numerical method, a multigrid method is used. This was based on a V-cycling algorithm. The V-cycle can use k grids, k varying between 1(corresponding to the finest grid) and M(representing the coarsest mesh). To pass from a fine grid k to a coarse grid k-1 the mesh increments are doubled. The method is well explained by Kadja et al [5].

The flow equations are solved along with the equations governing the evaporation of the slurry droplet and its motion in the ambient gas.

3.Results and Conclusions

Applications of the model were made using coal-water slurry droplets for which properties are available in the literature. A coal slurry is conceived as being composed of a suspension of small solid(coal) particles in a spherical liquid droplet. The water contained in coal can be either unbound or weakly bound or chemically bound. Unbound water evolves at a temperature corresponding to the saturation temperature under the prevailing pressure(95~100 °C at ~1 atm). Weekly bound water is held by adsorption, Van der Waal's forces and capillarity and separates at temperatures somewhat higher than the saturation temperature. Chemically bound water which resembles water of hydration for crystals evolves at much higher temperatures, typically 200-400°C. Coals contain up to 40% w/w water the largest proportion of which is of the unbound type. Predictions were performed with different values of ambient humidity, different initial droplet diameters, different initial temperatures of slurry droplets, different ambient pressures and different injection velocities.

The results obtained can be considered qualitatively and physically correct. They show smaller total evaporation times for droplets with high solid content and indicate that higher rates of evaporation can be obtained when the injected slurry is atomized into very small droplets. Very little effect is however obtained when the relative motion between the droplet and the surrounding gas is increased at the point of injection, because this difference fades away as evaporation proceeds, due to opposing frictional forces. The results have also given information on the heat up time and the effects of other drying medium parameters(ambient pressure, ambient humidity, ….).

The results for varied initial slurry droplet size also indicated that the larger resistance to mass transfer is in the gas film.

The model can be improved in the future when experimental data become available.

References

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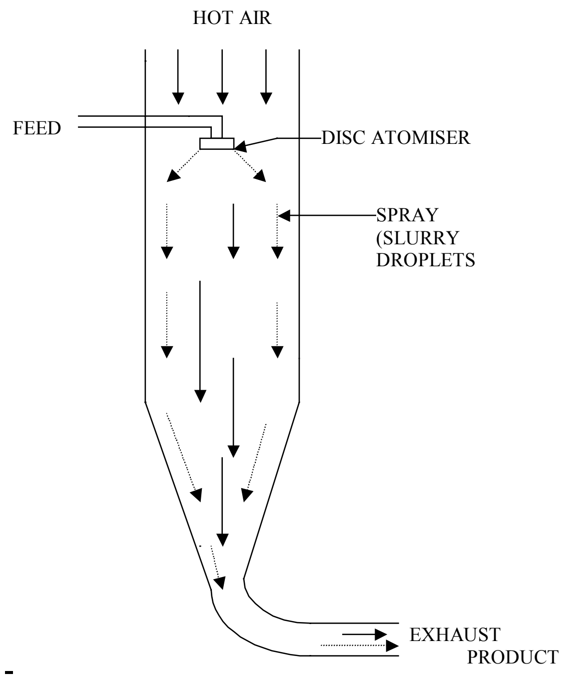

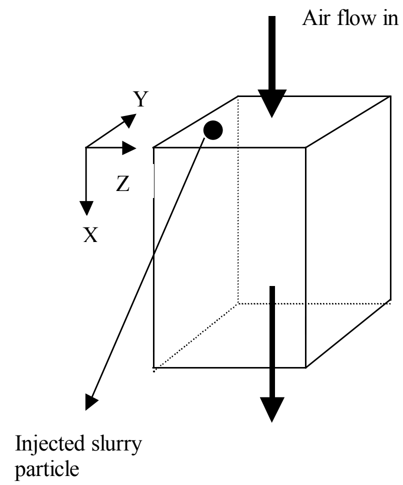

Fig. 1: A parallel-Flow spray drier

Fig.2 Coordinate system

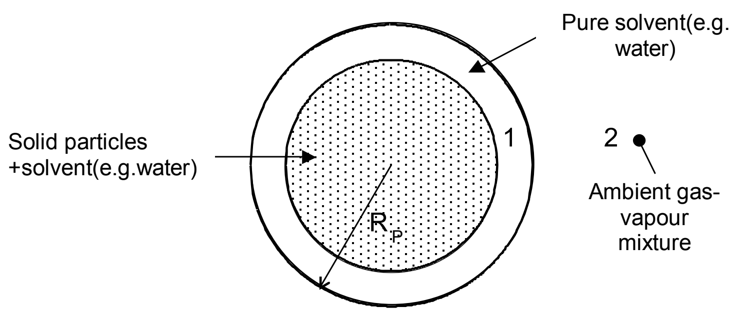

Fig. 3 Model of drying of a slurry droplet during first stage of drying

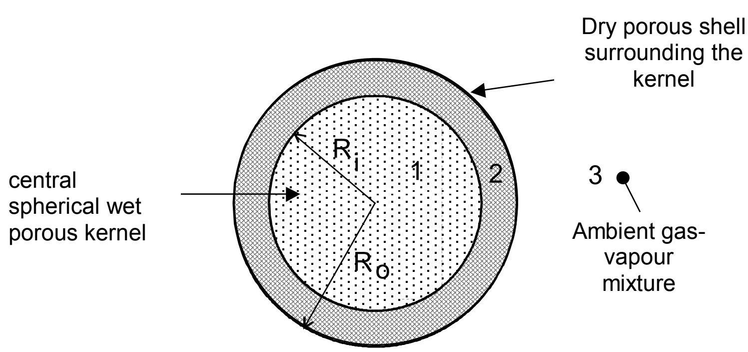

Fig. 4 Model of drying of a slurry droplet during second stage of drying