Int. J. Heat Mass Transfer. Vol. 33, No. 12, pp. 2751–2752, 1990
Pergamon Press plc. Printed in Great Britain

LETTER TO THE EDITORS

Comments on "The effect of a magnetic field on the heat transfer characteristics of an air fluidized bed of ferromagnetic particles"

IN A TECHNICAL note Neff and Rubinsky [1] reported measurements of heat transfer between an electrically heated vertical flat surface to an air fluidized bed of ferromagnetic particles (iron chilled shots of average diameter 727 μm) as a function of air velocity at several values of the magnetic flux density. They [1] missed mentioning a similar earlier work of Syutkin and Bologa [2] who determined the heat transfer coefficient between an electrically heated textolite rod and beds of narrow size iron powders of different average diameters as a function of air velocity and magnitude of the externally applied magnetic field. The qualitative dependencies of the heat transfer coefficient on air velocity and magnetic field intensity in the two works are similar. The technique adopted by Neff and Rubinsky [1] to measure the heated surface temperature and the bed temperature by measuring the temperature of a single thermocouple on the surface with the electrical power on and off respectively leaves something to be desired. The single thermocouple neither gives the average nor the local heat transfer coefficients [3]. Additionally, the thermal field established by the heated probe in the prevailing environment must be accurately established to obtain the appropriate thermal driving force.

Neff and Rubinsky [1] like many other earlier workers [4–7] have confused the minimum bubbling velocity, U_{mb}, with the minimum fluidization velocity, U_{mf}. U_{mb} has been also referred to as the transition velocity in recent literature. As pointed out by Rosensweig [8] in a uniform magnetic field U_{mf} is independent of the value of the applied magnetic field while U_{mb} uniquely depends on the magnitude of the magnetic field for a given magnetizable particle system. Consequently the relation of equation (3) in ref. [1] is misleading. The procedures of determining U_{mf} and U_{mb} must be adopted carefully and defined clearly as elaborated by Shrivastava [9]. This could explain the variance which exists in the reported relationships between U_{mb} and the applied magnetic field.

Neff and Rubinsky [1] on the basis of their heat transfer data maps as a function of magnetic flux density at discrete air velocities proposed three distinct heat transfer regimes in terms of magnetic field strength namely, low, medium and high. In the first region, the interparticle forces are weak and the heat transfer coefficient exhibits a gradual monotonic and approximately linear decreasing dependence on increasing magnetic flux density. This is probably the region where bed particles in increasing number align themselves in the direction of magnetic lines of force as the externally applied magnetic field strength is increased. The solids convective flow continuously decreases for the same air flow velocity as the magnetic field strength is increased and as a result the heat transfer coefficient gradually decreases. This region of operation has been referred to as the magnetically stabilized fluidized bed region [8, 10].

The medium field region is characterized by much reduced particle motion and bubbling. Further, the heat transfer coefficient exhibits a steeper reduction in its value with increase in magnetic flux density than in the low field region. This trend is more pronounced at higher air velocities. The interparticle attractive forces are stronger here than in the low field region. In the high field region, the interparticle forces are still stronger, the bed particles cling together and the bed behaves similar to that as if in the fixed-bed mode. The heat transfer coefficient remains almost constant as the magnetic flux density is increased at a given air velocity.

These observations of Neff and Rubinsky [1], made on the basis of the heat transfer coefficient behavior of an immersed body in a bed of ferromagnetic particles as the externally applied magnetic field is increased at various air flow velocities through the bed, are parallel to those proposed by Shrivastava [9, 11] from his hydrodynamic studies. It was concluded on the basis of bed pressure drop and bed voidage measurements as a function of air velocity for beds of three different sizes of steel shots and bed heights at different values of applied magnetic field that the bed behavior falls in three distinct regimes [9, 11]. These have been referred to as weak, moderate and strong magnetic field regions. The basic property that distinguishes between these three regions is the magnitude of the induced magnetic moment or magnetization in the bed particles and resulting interparticle cohesive force.

Lee [12] measured the solids discharge rate from the bed and taking it as the measure of bed rheology has proposed three operational regimes as quiescent, gelled and solidified. There is an obvious parallelism between these proposed three bed regime classification schemes based on distinctly different behaviors namely, thermal, hydrodynamic and rheological. These independent works [1, 9, 12] have clearly indicated a need for a coordinated effort in carefully investigating the hydrodynamic, rheological and thermal behaviors of beds composed of magnetizable materials under the influence of external magnetic fields as a function of operating and system parameters to understand their basic characteristics and immensely useful varied applications in the field of particulate processing such as solids separation, gas stream cleanup and others.

S. C. SAXENA
Department of Chemical Engineering
The University of Illinois at Chicago
P.O. Box 4348
Chicago, IL 60680, U.S.A.

REFERENCES

1. J. J. Neff and B. Rubinsky, The effect of a magnetic field on the heat transfer characteristics of an air fluidized bed of ferromagnetic particles, *Int. J. Heat Mass Transfer* **26**, 1885 (1983).
2. S. V. Syutkin and M. K. Bologa, Effect of magnetic field on heat transfer in a fluidized bed, *Electron. Orab. Mater.* **6**, 61 (1976).
3. S. C. Saxena, N. S. Grewal, J. D. Gabor, S. S. Zabrodsky and D. M. Galershtein, Heat transfer between a gas fluidized bed and immersed tubes, *Adv. Heat Transfer* **14**, 149 (1978).
4. D. G. Ivanov and G. T. Grozev, Determining the critical rate of a fluidized bed of ferrochrome catalyst for conversion of carbon oxide with water vapour in a magnetic field. *C. r. Acad. Bulg. Sci.* **23**(7), 787 (1970).
5. E. J. Tuthill, Magnetically stabilized fluidized bed, U.S. Patent, No. 3440731 (1970).

6. R. L. Sonoliker, S. G. Ingle, J. R. Giradkar and P. S. Mene, Influence of magnetic field on fluidization of iron particles, *Indian J. Technol.* **10,** 377 (1972).
7. M. K. Bologa and S. V. Syutkin, The influence of an electromagnetic field on the structural-hydrodynamic properties of a fluidized bed, *Elektron. Orab. Mater.* **1,** 37 (1977).
8. R. E. Rosensweig, Fluidization: hydrodynamic stabilization with a magnetic field, *Science* **204,** 57 (1979).
9. S. Shrivastava, Hydrodynamic behavior of an air-fluidized bed of ferromagnetic particles in an imposed magnetic field, M.S. Thesis, The University of Illinois at Chicago, v + 100 pp. (1986).
10. R. E. Rosensweig, J. H. Siegell, W. K. Lee and T. Mikus, Magnetically stabilized fluidized solids, *A.I.Ch.E. Symp. Ser.* **77**(205), 8 (1981).
11. S. C. Saxena and S. Shrivastava, The influence of an external magnetic field on an air-fluidized bed of ferromagnetic particles, *Chem. Engng Sci.* **45,** 1125 (1990).
12. W. K. Lee, The flowability of magnetically stabilized fluidized solids: I. Solids discharge from a stationary M.S.B., AIChE Annual Meeting, San Francisco (1984).