Int. J. Heat Mass Transfer. Vol. 27, No. 1, pp. 153–154, 1984
Pergamon Press Ltd. Printed in Great Britain

LETTERS TO THE EDITORS

COMMENTS ON 'A MECHANISTIC THEORY FOR HEAT TRANSFER BETWEEN FLUIDIZED BEDS OF LARGE PARTICLES AND IMMERSED SURFACES'

IN THE paper [1] the authors assume that in the absence of radiation the total heat transfer coefficient is the sum of conductive and convective components. Such use of heat transfer coefficients is not a good practice since heat transfer coefficients are meaningful only if the associated temperatures (or temperature differences) used in their definitions are known. If heat transfer coefficients are defined separately and temperature differences are not considered, summation can be confusing or even meaningless.

When several components of heat transfer are considered the preferred way is to sum up the heat fluxes. It can be then shown that the heat transfer coefficients and the associated dimensionless groups are only additive if the temperature differences used in their definitions are identical.

That mistakes can arise is apparent from the paper [1] where the temperature difference used in the definition of the conductive heat transfer coefficient is $T_s - T_{gp}$ but the temperature differences used in the definitions of the total and the convective heat transfer coefficients are most likely $T_s - T_b$. The latter temperature difference is not specified in the paper, but it is the temperature difference usually used and, furthermore, it is difficult to imagine that the former difference which contains one unknown parameter (τ_1, the particle residence time on the surface) would be employed.

The desire of the authors to eliminate the particle residence time from the calculations is the probable reason for using the temperature difference $T_s - T_{gp}$ in the definition of the conductive heat transfer coefficient. Since the particle residence time also appears in the conductive heat flux, their definition ensures that the particle residence time has a negligible influence on the conductive heat transfer coefficient.

The above manipulations and the whole level of the highly sophisticated mathematical treatment is incongruous compared with the relative crudity of the various assumptions used. Some clarifications are also required. For example, it is not clear if the conductive component is small as stated in the paper, or comparable with the convective component as stated elsewhere in the paper. Furthermore, the choice of the bed voidage is also confusing. Since the authors discuss in some detail the importance of the bed voidage variation in the vicinity of the surface, it seems inconsistent not to use the surface values in equations (3) and (38) which describe the behaviour near the surface.

Nevertheless, the paper does give very good agreement between the experimental results and the model. There are two possible reasons. First, the model contains an adjustable constant [C in equation (41)], and this constant was determined empirically. Secondly, and what is probably more important, the conductive contributions to heat transfer can be re-interpreted as follows:

The conductive heat flux, q_{cond}, can be written as:

$$q_{cond} = 1.06 \frac{k_g}{\delta}(T_s - T_b) f(\varepsilon),$$

where $f(\varepsilon)$ is a function of the bed voidage. This is equivalent to steady-state conduction across an approximately defined gas gap in the vicinity of the surface, with the outer gap temperature equal to the bulk bed temperature, T_b. (This would also imply that the first layer of particles does not heat up appreciably.)

Combination of such conductive mechanism with the authors' convective mechanism may give good agreement with experimental results, but it seems theoretically suspect.

J. KUBIE

CEGB HSD,
Nuclear Safety Branch,
Warwick Lane,
London, EC4P 4EB, U.K.

REFERENCE

1. V. L. Ganzha, S. N. Upadhyay and S. C. Saxena, A mechanistic theory for heat transfer between fluidized beds of large particles and immersed surfaces, *Int. J. Heat Mass Transfer* **25**, 1531–1540 (1982).

REPLY TO "COMMENTS ON 'A MECHANISTIC THEORY FOR HEAT TRANSFER BETWEEN FLUIDIZED BEDS OF LARGE PARTICLES AND IMMERSED SURFACES'"

IT IS well known that the linear addition of the heat transfer coefficient or fluxes due to conduction, convection and radiation to get the total heat transfer coefficient or total heat transfer flux is an approximate procedure and more so for an unsteady-state than for a steady-state heat transfer process. In the context of the process considered in our paper [1] this is reasonably valid. It may be pointed out that this assumption has been generally made by workers in the field of fluidization and has been invariably substantiated by the reasonable agreement found between experiments and calculations made on a realistic model.

It is true that in the calculation of h_{cond} the temperature difference employed is $(T_w - T_{gp})$ on the basis of the stated assumption of our model [1] that for large particles all the resistance to heat transfer is confined to the first row of particles and the gas film thickness at the heat transfer surface. However, the detailed calculations revealed that the use of T_{gp} (instead of T_b) makes only a small difference, see equation (24) of ref. [1], and the gas film thickness plays a very significant role and is primarily responsible for the heat transfer resistance. It is, therefore, not quite inconsistent with the definitions of heat transfer coefficients based on $(T_w - T_b)$. Further, the choice of temperature is not critical to the calculation of Nu according to equation (40) of ref. [1] in this particular case where it appears only through the dimensionless parameters.

The use of the temperature difference, $T_w - T_{gp}$, in evaluating the average conduction flux, equation (21) of ref. [1], is considered an appropriate procedure and is not intended to eliminate the appearance of particle residence time in the formulation. The final result of our calculation reveals that h_{cond} is composed of two parts, namely, a steady-state component and an unsteady-state component involving particle residence time through Fourier number. Fortunately, the contribution of unsteady-state heat transfer to the total heat transfer for such large particle systems is small and can be ignored completely if one can tolerate a small uncertainty in the estimation of h_{cond} as detailed in our paper [1].

We also find it difficult to reconcile with the expressed concern of the sophistication of our mathematical treatment in relation to the well-defined assumptions of the proposed model for the heat transfer process. In fact our rigorous formulation has brought to light the contributions made by various mechanistic aspects of the heat transfer model by highlighting their contributions. In some cases the approach has also provided a rationale for the assumptions implicit in our model.

The comment made about the relative magnitudes of conductive and convective components is inappropriate. The paper rightly asserts that for small particles (Geldart Groups A and B powders) the h_{cond} is significantly greater than h_{conv} and the latter may be regarded even as negligible in certain cases. For large particles (Geldart Group D powders) the case is opposite in as much as h_{cond} is now either comparable or much smaller than h_{conv}.

We agree that in equations (3) and (38), it is more appropriate to use ε_w instead of ε, and indeed this is accomplished by replacing ε with ε_w in our final calculations of Nu_{cond} and Nu_{conv}. Therefore, our approach and numerical results are consistent with the suggestion made in the comments on our paper [1].

The comment made about the very good agreement between the experimental results and the predictions of the heat transfer model is not to be interpreted as a fortuitous coincidence. In fact in our later work where this theory has been checked against new data on heat transfer from vertical and horizontal tube bundles in pressurized fluidized beds of large particles equally good agreement is found. The comment about the adjustable constant C in equation (41) of our paper as being the reason for good agreement between theory and experiment is improper. It may be pointed out that C is determined by the experimental data on a restricted bed of large particles (3.1 mm glass beads) at high gas velocities. The agreement of proposed theory with this value of C for experimental data generated by different workers in fluidized beds is a reflection of the adequacy of the explicit assumptions and details of the mechanistic heat transfer process employed to develop this model. The interpretation of the heat transfer process as a steady-state conduction process for such a system and according to the equation written in the comments is an outcome of the intricate heat transfer process analysis presented in our paper and the validity of the assumptions. The manipulation of our equations (21) and (24)–(27) results in the general equation given by Dr Kubie. We also thank him for the patience with which he has tried to study our paper.

Luikov Institute of Heat and Mass Transfer
B.S.S.R. Academy of Sciences
Minsk, B.S.S.R., U.S.S.R.
V. L. GANZHA

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

REFERENCE

1. V. L. Ganzha, S. N. Upadhyay and S. C. Saxena, A mechanistic theory for heat transfer between fluidized beds of large particles and immersed surfaces, *Int. J. Heat Mass Transfer* **25**, 1531–1540 (1982).