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HEAT TRANSFER IN SHALLOW CROSSFLOW FLUIDIZED BED HEAT EXCHANGERS—II. EXPERIMENTAL

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Abstract—A laboratory scale crossflow fluidized bed heat exchanger has been built and operated in order to investigate the generalized theory proposed for the system. Because available correlations for gas particle heat-transfer coefficients in fluidized beds were considered to be unsatisfactory, the equipment was used to develop the following new correlation:

$$\frac{hd}{k} = 0.353\left(\frac{\rho u d}{\mu}\right)^{0.9}\left(\frac{d}{Z_T}\right)^{0.47}\left(\frac{d}{P}\right)^{0.19}\left(\frac{d}{D}\right)^{-0.19}.$$

The application of this correlation in conjunction with the generalized analysis was verified experimentally.

NOMENCLATURE

A, particle surface area per unit base area of bed;
C_g, C_s, specific heats of gas and particles;
d, particle diameter;
D, distributor plate hole diameter;
$E(\theta)\,d\theta$, fraction of particles having reduced bed residence time between θ and $\theta + d\theta$;
h, gas–particle heat-transfer coefficient;
k, thermal conductivity of gas;
M_g, M_s, mass flow rates of gas and particles through bed;
Nu, Nusselt number;
P, distributor hole pitch;
Pr, Prandtl number;
Re, Reynolds number;
t_{si}, t_{gi}, temperature of inlet particles and gas to bed;
t_{som}, mean outlet particle temperature;
u, superficial gas velocity in bed;
Z_T, depth of fluidized bed.

Greek symbols

θ, reduced bed residence time;
μ, gas viscosity;
ρ, gas density.

1. INTRODUCTION

In Part I of this paper [1], a generalized theory was developed to describe the overall process of gas–particle heat transfer in a shallow rectangular section fluidized bed with a crossflow of particles. The analysis included the possibility of internal resistance to heat transfer, as well as a residence time distribution of particles through the bed, and a distribution of particle sizes. Important special cases involving the application of appropriate simplifying assumptions to the general analysis were also presented.

In the application of the described theory to design or to evaluate the performance of a particular piece of equipment, it is necessary to know the gas–particle heat-transfer coefficient under the proposed bed operating conditions. Gas–particle heat transfer in fluidized bed systems in general, has been extensively studied and many correlations for the heat-transfer coefficient have been developed over a wide range of operating conditions. Even though most of these investigations were carried out in circular section beds with no particle flow, it should theoretically be possible to apply an appropriate heat-transfer coefficient correlation obtained from previous work, provided that particle flow through the bed does not significantly modify the gas–particle contacting characteristics. Unfortunately, there are large differences between the many proposed correlations, as shown in the various reviews on the topic [2–9]. Some investigations of the possible reasons behind these differences are thus necessary.

An examination of the methods and techniques used by the various investigators in the determination of the gas–particle heat-transfer coefficient shows that the differences between the correlations could have been caused in a number of ways. These may be classified as follows: (a) Two different models have been used to describe the bulk contacting characteristics of particles and gas. The first model assumed that the fluidizing gas passed through the bed in plug flow while the particles were perfectly mixed. The second model assumed that both particles and gas were perfectly mixed within the bed. Gas temperature profiles measured [3] in the vertical direction above the distributor plate indicate that the first model is more realistic than the second, hence this model was used in the general analysis [1]. (b) Different techniques were used to measure the particle and gas temperatures in the bed. Particle temperatures were obtained from an overall heat balance, by inserting a thermocouple within a particle, by taking a thermocouple reading in a collapsed bed and by using an optical pyrometer. Gas temperatures were obtained by using either a bare thermocouple or a suction thermocouple within the bed. Since these measurements were taken in the active heat-transfer zone serious problems arose of interpreting the meaning of the readings. (c) The coefficient was based on different heat-transfer areas. Some investigators used the entire particle surface area to define their heat-transfer coefficients, even though equilibrium of heat transfer was reached in the bed. Other investigators correctly used the particle surface area associated with the active heat-transfer zone alone. (d) Many different types and designs of distributor plate were used in the various investigations, including perforated plates, porous plates and cloth distributors. Distributor plate design was, however, never included as a variable in any investigation and only one investigator [10] even mentioned its importance in heat transfer. He found a higher heat-transfer coefficient with a canvas distributor than with a porous plate. (e) Nearly all investigators assumed that bed depth was not a variable. Chang and Wen [11] however demonstrated its importance when they found a marked reduction in heat-transfer coefficient with increasing bed depth. Kato and Wen [8] in their review re-examined the results of selected investigators and attempted to introduce the bed depth as a variable when comparing the results of these investigators. In spite of this, however, the scatter of results was still high (i.e. $> \pm 50\%$).

The ideal approach in demonstrating the applicability of the proposed analysis would have been to carry out a suitable series of experiments over wide ranges of the system variables. Appropriate measurements would be taken in the experiments to enable the mean outlet particle temperature to be calculated from the combination of an appropriate existing heat-transfer coefficient correlation and the generalized analysis. This theoretically predicted temperature could then be compared to that measured experimentally in each case. Unfortunately, however, this approach was not possible since, for the reasons described in the previous paragraph, the existing heat-transfer coefficient correlations were unsatisfactory.

It was thus considered necessary to develop a new correlation between the gas–particle heat-transfer coefficient and the system variables. The new correlation must include, if applicable, the particle flow rate as well as the variables neglected in the previous work, i.e. bed depth and the variables associated with distributor plate design. The examination of previous work also showed that it was important that the temperature measurement techniques should be such that no problems of interpretation would arise, and the experiments must be operated under conditions such that thermal equilibrium between particles and gas is not approached.

In order to develop the required heat-transfer coefficient correlation and demonstrate its application in conjunction with the generalized analysis, the approach adopted was to carry out the experimental work in two phases. In the first phase, a programme of experiments was carried out on single sized particles over ranges of the operating variables, the gas particle heat-transfer coefficient being calculated in each experiment. The heat-transfer coefficient correlation in dimensionless form was developed from the experimental results in this phase. In the second phase a programme of experiments was carried out using mixed sizes of particles. In this phase the derived correlation was used in conjunction with the generalized analysis and the appropriate experimental measurements to calculate a theoretically predicted mean outlet particle temperature, this being compared to that measured experimentally.

2. EXPERIMENTAL

The experimental work was carried out in a laboratory scale system as depicted in Fig. 1, with a heat-transfer zone 29.4 cm long and 5.1 cm wide. The bed consisted basically of a rectangular box built of $\frac{1}{4}$ in thick perspex sheet, mounted on an interchangeable perforated plate. The fluidizing air was supplied to the underside of the perforated plate horizontally along a rectangular duct of reducing cross section. Suitable baffles, B_2, were placed in the inlet section in order to ensure an even air distribution under the plate.

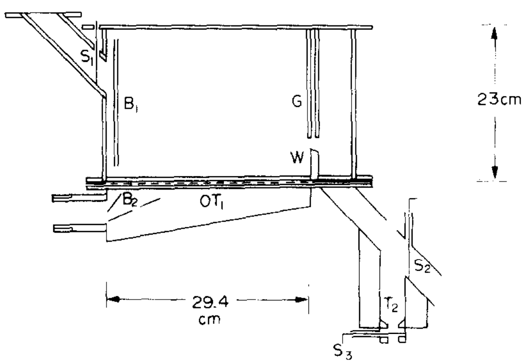

FIG. 1. Diagram of particle cooler. Normal materials. Above distributor plate: $\frac{1}{4}$ in Perspex sheet. Distributor plate and below: 14 swg mild steel. Scale $\frac{1}{10}$ full size.

Particles were fed on to the plate down a chute at one end of the bed, a baffle, B_1, being used to divert the particles on to the plate at that end. The depth of bed was controlled by the use of interchangeable weirs, W, and an outlet chute was provided to allow the particles to leave the bed. There was a simple slide value, S_1, in the inlet chute and another, S_2, in the outlet chute. Built into the outlet chute was a special sample point which was used for outlet particle temperature measurement, T_2. This sample point was simply a chamber into which particles could be passed, there being a slide valve, S_3, to hold the particles inside. Since it was used for particle temperature measurement it was well insulated by using a 2.5 cm air gap followed by a 2.5 cm thickness of polystyrene foam. This sample point was also used for diverting particles out of the system. During use for heat-transfer measurements, the bed was lagged with a 7.5 cm thickness of polystyrene foam. There was also provision for holding the fluidized particles within the bed by using a perspex plate which could be slid vertically down suitable guides, G, on to the top of the weir.

The experiments were carried out by cooling particles in the bed continuously from $> 100°C$ using ambient air. It was thus necessary to create a flow of particles through the bed as well as to heat up the particles before entering the bed. The particles were heated up in a bed of basically similar design to the cooler, the fluidizing air temperature being ~ 150°C. After leaving the particle heater the particles were passed into a lagged hopper. At the base of the hopper, directly before the fluidized bed cooler was a rotating table, which was used to control the particle flow rate in the system. After leaving the cooler, the particles were pneumatically conveyed back to the particle heater, so that the system as a whole was operated under steady state conditions during each experiment.

The particles used in the experimental programme were glass ballotini, being virtually spherical, easily obtainable and easy to handle. The size specifications and minimum fluidizing velocities of the ballotini used were:

Mean particle diameter (mm)	Range	Minimum fluidizing velocity (ms^{-1})
1.25	±15%	0.8
1.83	±10%	1.3
2.75	±10%	1.7
3.07	±10%	1.9
3.89	±10%	2.1

In order to apply the generalized theory to obtain a correlation for the heat-transfer coefficient and to verify the combination of both, the following experimental measurements were necessary: particle inlet and outlet temperatures, particle flow rate and residence time distribution, cooling air flow rate and temperature, bed depth and particle surface area in bed.

The particle inlet and outlet temperatures as well as inlet air temperature were measured with sensitive mercury in glass thermometers, these being calibrated against a standard thermometer with a National Physical Laboratory calibration. The inlet particle temperature thermometer was placed in the particle stream flowing down the well lagged hopper outlet pipe just above the rotating table. The inlet air thermometer was placed in the air stream directly underneath the perforated plate. The outlet particle temperature thermometer was placed in the special sampling device provided, T_2 in Fig. 1. The air flow rate was measured by an orifice plate, this being calibrated by pitot traverses. The residence time distribution was measured by a tracer technique using a sample of about 300 of the appropriate size ballotini, to which a very thin coating of enamel paint had been applied. The tracer particles were injected into the particle inlet stream at the beginning of the bed, and the residence time distribution measured using an electrically driven catchpot system situated directly underneath the sample point. The residence time distribution was determined as $E(\theta)\,d\theta$, the fraction passing in time $d\theta$, against θ dimensionless time. The catchpot system was also used to measure the particle flow rate. The particle surface area in the bed was calculated from a knowledge of the particle size, density and bed weight. The bed weight was obtained by isolating the material in the bed, during operation, using the inlet slide valve S_1, and the perspex plate slid on to the top of the weir. After this isolation of the bed it was removed from the system and weighed. Low bed depths were measured with a cathetometer, higher bed depths by photographic techniques.

A vertically traversing copper–constantan thermocouple was used to check that thermal equilibrium was not reached in the bed in any of the experiments. The thermocouple was mounted along the centre line of the bed about 7 cm from the particle inlet end and a vertical transverse in each experiment was carried out over the full depth of bed starting with the thermocouple just above the distributor plate. The outlet air temperature distribution was also measured occasionally using a series of rototherms suspended directly above the bed during operation.

3. USE OF ANALYSIS IN EXPERIMENTAL WORK

In the first experimental phase, the experimental measurements were used in conjunction with the general analysis to calculate values of the heat-transfer coefficient over as wide ranges of the variables as the apparatus could accommodate. These experiments were all carried out using single size particles. It was necessary to use the general analysis, as internal particle resistance to heat transfer was found to be important with the ballotini, and the particle flow conditions were such that plug flow was never approached. Since the residence time distribution of particles was measured in numerical terms using the catchpot system, the numerical form of equation (24) in [1] for the mean outlet particle temperature t_{som} was used:

$$t_{som} = \sum_{\theta=0}^{\theta=\infty} \begin{bmatrix} \text{Temperature} \\ \text{corresponding to bed} \\ \text{residence time } \theta \end{bmatrix} \times \begin{bmatrix} \text{Fraction consisting} \\ \text{of bed residence} \\ \text{time between } \theta \text{ and} \\ \theta + d\theta \end{bmatrix}. \quad (1)$$

In the experimental work, however, t_{som}, was a measured quantity and the form of the analysis was such that it was necessary to use a gas–particle heat-transfer coefficient in the successive heat balance calculations in order to calculate the first term in equation (1). A trial and error solution for the heat-transfer coefficient was thus necessary, based on a comparison of the calculated and measured values of the mean outlet particle temperature t_{som}. The starting point for the heat-transfer coefficient iteration was based on the value of the heat-transfer coefficient calculated using equation (31) in [1], the derived formula for the special case assuming no internal particle resistance to heat transfer

$$t_{som} = t_{gi} + (t_{si} - t_{gi}) \int_0^\infty \left[\exp\left\{ -\frac{M_g C_g \theta}{M_s C_s} \times \left[1 - \exp\left(-\frac{hA}{\rho u C_g} \right) \right] \right\} \right] E(\theta)\,d\theta. \quad (2)$$

In the use of the general analysis, it was assumed that the air was evenly distributed under the plate, and that the inlet air temperature distribution was uniform.

Before the general analysis could be used, it was necessary to obtain a suitable value for the number of elements N, in the analysis. In order to determine this, a value of the heat-transfer coefficient was first obtained, using a set of experimental results, in conjunction with equation (2), corresponding to the special case of no internal resistance to heat transfer. This calculated coefficient, together with an artificially high value of the thermal diffusivity (2000 times the true value) was fed into the general analysis for increasing values of the number of elements. The number of elements chosen for use in the analysis of the experimental results, was that where the calculated value of the mean outlet particle temperature, t_{som}, obtained from the general analysis, closely approached the measured value.

Even though the vertically traversing thermocouple was used as a check on thermal equilibrium, a further check was made by use of the relationship derived for thermal equilibrium conditions, i.e. equation (2) modified such that $\exp(-hA/\rho uC_g) \to 0$. In order to ensure that there were no dead areas or static zones in the bed for each experiment, the bed residence time as calculated from the hold up and throughput, was compared to that calculated from the residence time distribution results.

The values of the gas particle heat-transfer coefficient in the first experimental phase were related to the system variables by the use of dimensional analysis in the following way:

$$\frac{hd}{k} = f\left[\left(\frac{\rho ud}{\mu}\right), \left(\frac{M_s}{M_g}\right), \left(\frac{d}{Z_T}\right), \left(\frac{d}{D}\right), \left(\frac{d}{P}\right)\right]. \quad (3)$$

The second experimental phase was carried out using mixed sizes of particles to demonstrate the applicability of the experimental heat-transfer correlation in conjunction with the general analysis and the proposed method for dealing with both a particle size and residence time distribution, i.e. equation (25) in [1]. The relationship was used in summation form since both distributions were measured numerically:

$$t_{som} = \sum_{p=0}^{p=\infty} \sum_{\theta=0}^{\theta=\infty} \times \begin{bmatrix} \text{Outlet particle temperature} \\ \text{from bed particles of} \\ \text{size } p \text{ having bed residence} \\ \text{time } \theta \end{bmatrix} \times \begin{bmatrix} \text{Fraction of total flow of} \\ \text{particles having size } p \\ \text{and bed residence time} \\ \text{between } \theta \text{ and } \theta + d\theta \end{bmatrix} \quad (4)$$

In this phase of the work, the heat-transfer coefficient was obtained from the experimentally obtained correlation, i.e. equation (3), and the results were used in conjunction with the general analysis and equation (4) to calculate the outlet particle temperature. This was then compared to that measured experimentally.

4. EXPERIMENTAL RESULTS

All experiments were carried out in cooling glass ballotini from somewhere in the range 100–130°C to at least 5°C above the inlet air temperature, which was ~35°C. Operating air velocities were always such as to provide satisfactory particle transport through the bed. Thermal equilibrium between particles and gas was not reached in any experiment used in this work.

In the first phase of experiments, the effects of each dimensionless group on the gas–particle heat-transfer coefficient was examined. Eleven series of experiments were carried out in examining the five dimensionless groups. The details of each of these series is given in Table 1. The only type of distributor plate investigated was the perforated plate, an equilateral triangle pattern of holes being used. In the reference to the plate design in Table 1, the first figure refers to the hole diameter in millimetres and the second figure, after the slash, to the hole pitch, also in millimetres. The experimentally obtained power of the group examined in each series is given in column 8.

Examination of Table 1 shows that the flow ratio group had no effect on the heat-transfer coefficient and so was excluded from the correlation. The full experimental results are shown in Fig. 2, the point notation for which is given in Table 1. The final correlation obtained by averaging out the powers of the series within a given group was:

$$Nu = 0.353\left(\frac{\rho ud}{\mu}\right)^{0.9}\left(\frac{d}{Z_T}\right)^{0.47}\left(\frac{d}{P}\right)^{0.19}\left(\frac{d}{D}\right)^{-0.19}. \quad (5)$$

The function of the second phase of experiments was to demonstrate the validity of the use of the correlation, i.e. equation (5), in conjunction with the general analysis and the proposed method of dealing with a particle size and residence time distribution, i.e. equation (4). Two series of experiments were carried out in this phase using mixed sizes of particles. In the

Table 1. Series of experiments in first phase

Series	d (mm)	Z_T (cm)	u (ms^{-1})	M_s (kgh^{-1})	Plate —	Group examined —	Power of group —	Point notation —
1	1.25	0.7	2.0	$46 \to 114$	1/4	(M_s/M_g)	0	⊙
2	3.07	3.2	3.7	$88 \to 124$	2/5	(M_s/M_g)	0	⊗
3	1.83	$0.8 \to 3.2$	2.6	~90	1/4	(d/Z_T)	+0.53	◒
4	3.07	$2.1 \to 6.3$	3.7	~110	2/5	(d/Z_T)	+0.45	⊕
5	3.89	$2.5 \to 5.8$	3.6	~115	2/5	(d/Z_T)	+0.42	◓
6	1.25	0.7	$1.3 \to 2.3$	~90	1/4	$(\rho ud/\mu)$	+0.88	◑
7	1.83	0.9	$1.6 \to 3{\cdot}1$	~90	1/4	$(\rho ud/\mu)$	+0.85	◕
8	1.83	3.3	$2.4 \to 3.1$	~95	1/4	$(\rho ud/\mu)$	+0.93	◕
9	3.07	1.3	$2.2 \to 2.8$	~95	1/4	$(\rho ud/\mu)$	+0.94	◐
10	1.83	3.1	2.6	~95	$2/4 \to 2/9$	(d/P)	+0.19	◕
11	1.83	3.1	2.6	~95	$2/7.5 \to 3.7/7.5$	(d/D)	−0.19	◔

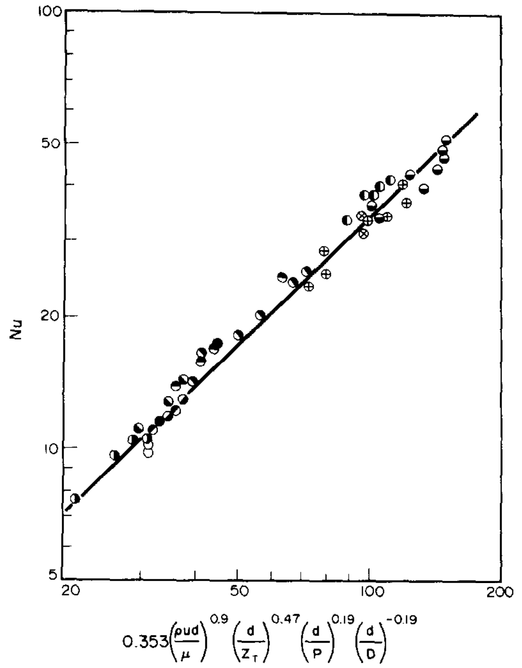

FIG. 2. Heat-transfer coefficient correlation.

first series, experiments were carried out using mixtures of 3.89, 3.07 and 2.75 mm dia ballotini over a range of bed depths varying from 2.0 to 6.5 cm at a fixed air velocity. In the second series of experiments mixtures of 3.07, 2.75 and 1.83 mm dia ballotini were used over a range of air velocities ranging from 2.9 to 3.9 ms^{-1} at a fixed bed depth. The results from these experiments were used to predict an outlet particle temperature which was compared to that measured experimentally. The results of the experiments are given in Table 2 where it is seen that the theoretically predicted temperature agreed with the measured temperature to within ± 0.4°C, which is within experimental error.

5. DISCUSSION

In order to avoid some of the problems of previously published work, great care was taken to ensure that the experimental measurements could not be misinterpreted and that all experiments were carried out under non-thermal equilibrium conditions with no dead areas in the bed. The applicability of the full analysis, in conjunction with the heat-transfer coefficient correlation, equation (5) and the method of dealing with both a particle size and residence time distribution was demonstrated in the second phase of experiments detailed in Table 2. As a further check on the validity of the general analysis, the outlet air temperature distribution as measured in some of the experiments in the first phase of experiments was compared to that predicted by the analysis in conjunction with the calculated heat-transfer coefficient. A typical comparison is shown in Fig. 3 where the line represents the theoretically predicted outlet air temperature profile and the points are experimental measurements. The outlet air temperature profile was an independent measurement which was not used in the determination of the heat-transfer coefficient.

It was not experimentally possible to include the

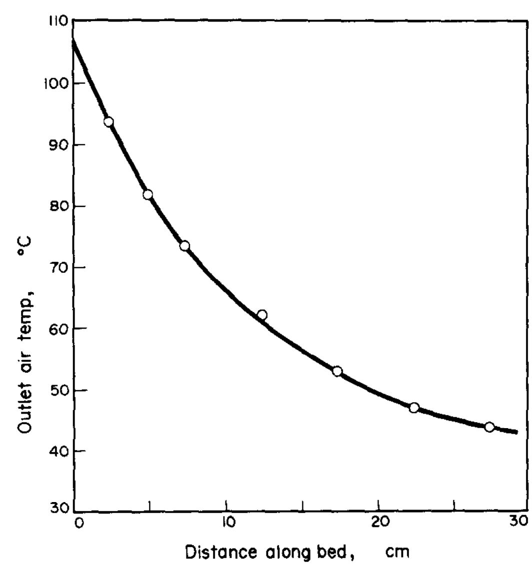

FIG. 3. Comparison of predicted outlet air temperature profile with that measured. The line represents the theoretically predicted profile. The points are experimental measurements.

Table 2. Results of experiments using mixed particle sizes

Exp. No.	Weir Ht. (cm)	M_g (kgh^{-1})	M_s (kgh^{-1})	Z_T (cm)	t_{si} (°C)	t_{gi} (°C)	t_{som} measured (°C)	t_{som} calculated (°C)
			Experiments at varying bed depth					
M2	—	222	91.7	2.0	115.5	36.7	45.7	45.8
M4	2.6	222	94.8	3.2	111.6	35.0	41.5	41.9
M5	2.6	222	110.2	3.2	113.6	36.8	45.1	44.9
M3	5.2	222	88.5	5.2	110.8	32.4	39.1	38.7
M1	7.0	222	107.3	6.5	109.0	34.9	44.8	44.6
			Experiments at varying air flow rate					
M7	2.6	180	108.1	3.0	111.0	33.4	43.0	43.0
M8	2.6	193	98.5	3.0	110.6	34.4	41.8	41.7
M9	2.6	208	115.9	3.0	111.0	36.8	45.7	45.7
M10	2.6	222	120.5	3.1	111.0	36.7	45.8	45.9
M6	2.6	238	108.7	3.2	112.3	34.0	41.3	41.3

Prandtl number in the correlation but it had previously been suggested [8] that the one third power be used. Modifying equation (5) appropriately to include this gives the following relation:

$$Nu = 0.4\,Re^{0.9}Pr^{1/3}\left(\frac{d}{Z_T}\right)^{0.47}\left(\frac{d}{P}\right)^{0.19}\left(\frac{d}{D}\right)^{-0.19}. \quad (6)$$

The heat-transfer coefficient correlation derived in this work shows the Nusselt number to be proportional to the 0.9 power of the Reynolds number. The range of Reynolds numbers investigated was 100–850. The majority of previously published work, however, was carried out at lower Reynolds numbers. Combining the results of five investigators who also used the same model for particle gas contacting as used in the general analysis, Kothari [7] obtained a relationship which showed the Nusselt number to be proportional to the 1.3 power of the Reynolds number over a range of Reynolds numbers varying from 0.1 to 100. For much larger particles Chang and Wen [11] found the Nusselt number to be proportional to the 0.55 power of the Reynolds number over a range of Reynolds numbers varying from 300 to 5000. Thus the power of the Reynolds number in the dimensionless correlation obtained in this work shows some agreement with the trends in previous work.

The effect of bed depth on the heat-transfer coefficient has generally been neglected to date. Kato and Wen [8], however, analysed the work of a number of investigators and suggested that the Nusselt number may be proportional to $(d/Z_T)^{0.6}$, at least for values of $Re(d/Z_T)^{0.6}$ less than about 20. Chang and Wen [11] demonstrated its importance for their much larger 4.8 mm dia particles, but did not include it in their correlation, since their work was mainly concerned with screen baffled fluidized beds. However an analysis of their quoted results in experiments where the screens were removed, seemed to indicate a much lower power than 0.6, something nearer 0.3 on the basis of the limited results quoted. This seems to show that there is a relationship between the power of the group and the particle size. The work described in this paper suggests an overall value for the power of the group of 0.47 for particles between 1.83 and 3.89 mm dia. Closer examination of the results quoted in Table 1, however, indicates that the suggested trend may be correct, since the powers of the groups for particle sizes 1.83, 3.07 and 3.89 mm dia were 0.53, 0.45 and 0.42 respectively.

The effect of distributor plate design on the heat-transfer coefficient has been virtually ignored in previous work. The work described in this paper was confined to perforated plates because they are the most important type of industrial gas distribution device for the particular system under consideration. The results showed that the heat-transfer coefficient was increased to a similar extent by increasing the hole diameter or decreasing the hole pitch. This seems to indicate that the lower the gas velocity through the holes in the distributor plate, the higher will be the system heat-transfer coefficient.

The order of magnitude of the transfer coefficients calculated from the experimental work fit in well with previously reported work. The results fit generally into Fig. 3 of Kato and Wen's [8] comparison of previous work, filling in the gap between values of $Re(d/Z_T)^{0.6}$ of 35 to 200. Thus the correlation fits in quite well with the trends shown in some of the previously published work since the calculated coefficient was not affected by particle flow rate the correlation may thus be used for fluidized bed systems in general using perforated distributor plates, subject to the limits of the variables investigated.

6. CONCLUSIONS

The derived correlation for the heat-transfer coefficient may be used in conjunction with the generalized analysis to describe the overall process of heat-transfer in a shallow crossflow fluidized bed. The combination may be used in the design of new exchangers or in evaluating the performance of existing exchangers.

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TRANSFERT THERMIQUE DANS LES ECHANGEURS DE CHALEUR A LIT FLUIDISE PEU PROFOND—II. ASPECT EXPERIMENTAL

Résumé—Une maquette d'échangeur de chaleur à lit fluidisé a été réalisée et une expérimentation effectuée afin de vérifier la théorie généralisée proposée pour le système. Les formules connues qui donnent les coefficients de transfert thermique entre gaz et particules dans les lits fluidisés n'ayant pas fourni des résultats satisfaisants, le dispositif a été utilisé afin de développer une nouvelle loi empirique:

$$\frac{hd}{k} = 0{,}353\left(\frac{\rho ud}{\mu}\right)^{0,9}\left(\frac{d}{z_T}\right)^{0,47}\left(\frac{d}{p}\right)^{0,19}\left(\frac{d}{D}\right)^{-0,19}.$$

Cette formule, appliquée en relation avec la théorie généralisée, correspond bien aux expériences.

DER WÄRMEÜBERGANG IN KREUZSTROM-FLIESSBETT-WÄRMEÜBERTRAGERN MIT GERINGER SCHICHTHÖHE—II. EXPERIMENTELLE UNTERSUCHUNG

Zusammenfassung—Die verallgemeinerte Theorie für einen Kreuzstrom–Fließbett-Wärmeübertrager wurde an einem Laboratoriumsmodell überprüft. Da vorhandene Korrelationsformeln für den Wärmeübergangskoeffizienten in Fließbetten als unzureichend angesehen werden können, wurde durch Versuche an dieser Anlage die folgende neue Korrelationsgleichung aufgestellt:

$$\frac{hd}{k} = 0{,}353\left(\frac{\rho ud}{\mu}\right)^{0,9}\left(\frac{d}{z_T}\right)^{0,47}\left(\frac{d}{p}\right)^{0,19}\left(\frac{d}{D}\right)^{-0,19}.$$

Die experimentelle Untersuchung zeigte eine Übereinstimmung mit der verallgemeinerten Theorie.

ИССЛЕДОВАНИЕ ТЕПЛООБМЕНА В ТЕПЛООБМЕННИКАХ С ТОНКИМИ ПЕРЕКРЕСТНЫМИ КИПЯЩИМИ СЛОЯМИ. II. ЭКСПЕРИМЕНТ

Аннотация — Для проверки предложенной обобщенной теории сконструирован и опробован в лабораторных условиях теплообменник с тонкими перекрестными кипящими слоями. Так как имеющиеся обобщенные соотношения для коэффициента теплообмена между газом и частицами в кипящих слоях считаются неудовлетворительными, использовалась специальная установка для получения следующего нового соотношения:

$$\frac{hd}{K} = 0{,}353\,\frac{(\rho ud)^{0,9}}{(\mu)}\,\frac{(d)^{0,47}}{(Z_T)}\,\frac{(d)^{0,19}}{(P)}\,\frac{(d)^{-0,19}}{(D)}.$$

Экспериментально проверена возможность использования этого соотношения совместно с обобщенной теорией.