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WALL HEAT TRANSFER COEFFICIENTS OF DOWTHERM – A IN FIXED BEDS

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An experimental investigation into the effect of packing diameter, fluid velocity and thermal conductivity upon the wall heat transfer coefficients of Dowtherm-A, flowing in closed loop through a packed-bed reactor heated radially at the wall, has been made. Spherical and cylindrical shaped particles are employed as the packing material.

A theoretical equation is developed which could predict the wall heat transfer coefficients of Dowtherm. The values of heat transfer coefficients so obtained are compared with the experimental data; an agreement is found within an accuracy of ± 9%.

INTRODUCTION

Sometimes it is not possible to use steam as the heat transfer medium in the process industry due to certain design difficulties. Under such conditions a search for an alternate heat transfer source becomes invetable. Dowtherm-A (diphenyl-diphenyl oxide) is one of those heat transfer fluids which have been reported during the last few years. Keeping in view its industrial importance, a few studies on the determination of film coefficients of Dowtherm-A have been made but none of these deal with the fluid flowing through fixed bed of granular solids [2, 3]. In order to meet this demand, an experimental investigation into the wall heat transfer coefficient of Dowtherm-A, flowing through beds packed with cylinders and spheres, has been undertaken.

THEORY

In order to design a packed bed reactor/heat exchanger, data on the wall heat transfer coefficient and thermal dispersion coefficient (both axial and radial) are needed. These parameters can be calculated from a knowledge of temperature profiles in the reactor. In the absence of these data, wall heat transfer coefficients alone can be calculated by measuring fluid temperature in the wall region.

The fluid temperature in the wall region can be measured by installing temperature probes in the region of the thermal boundary layer. The thickness of the thermal boundary layer for metallic and non-metallic particles have been reported else-where [1].

The steady state heat transfer coefficients can then be calculated by using the following two equations:

$$Q = h_w \, A_t \, (t_w - t_{r=R}) \qquad \text{Eq (1)}$$

$$Q = m \, C_p \, (t'_{bo} - t_{bi}) \qquad \text{Eq (2)}$$

EXPERIMENTAL ARRANGEMENT AND PROCEDURES

A line diagram of the experimental arrangement is shown in Fig. 1. The fluid (Dowtherm-A), emerging from an accurately insulated 35 litres' capacity constant-head steel tank, was pumped to a bank of rotameters by using a centrifugal pump (2700 rpm). The rotameter reading was fixed at a pre-determined fluid rate and the balance of

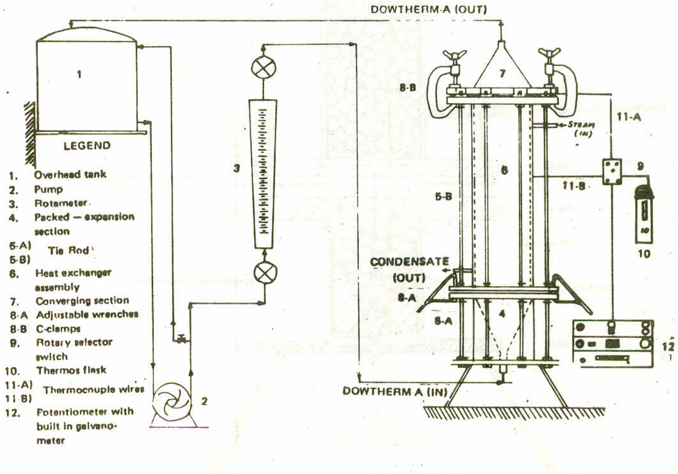

Fig. 1. Line diagram of the experimental set up.

Dowtherm-A passed through a flow distributor at the base of 0.15 cm thick aluminium cylinder containing the packing. The exit temperature of the fluid (Dowtherm-A) was measured by a network of calibrated thermocouples. The calibration was made by a precise thermometer.

Fig. 2 is a diagram of the packed bed showing the arrangement for heating. The packed bed 30.48 cm long and 8.89 cm in dia. was surrounded by a steel cylinder and fed by steam that had been reduced in pressure to a value slightly above the atmosphere. The steam temperature was measured by a thermocouple which throughout all of the experiments registered temperatures within 0.2° of 103.5°, while steam was passing through the equipment. A vent was fitted at the top of the annulus and during the experiment a slow flow of steam was maintained into the chest and out of the vent. The condensate was continuously purged from the steam chest.

Dowtherm-A leaving the bed passed through a converging section for discharge to the storage tank. The average temperature of the fluid in the tank was measured by a precisely graduated thermometer. The fluid temperature in the wall region was measured by installing four chromel-Alumel thermocouples spaced at approximately equal intervals around the inner circumference of the upper bakelite flange of the heat transfer assembly and at a distance of 0.08 cm from the wall. The output of the thermocouples group was proportional to the average temperature of the fluid in the wall region; the output was measured by an accurate potentiometer. While installing the thermocouples, care was taken that the thermocouple junctions rest immediately above the packing during the flow of the fluid through the packed section. The cold junctions of the thermocouples were secured into the ice-filled thermos flask. All the heat exchange network was thickly lagged with glass wool; the heat exchanger assembly was further insulated with 2.54 cm thick foam quilt.

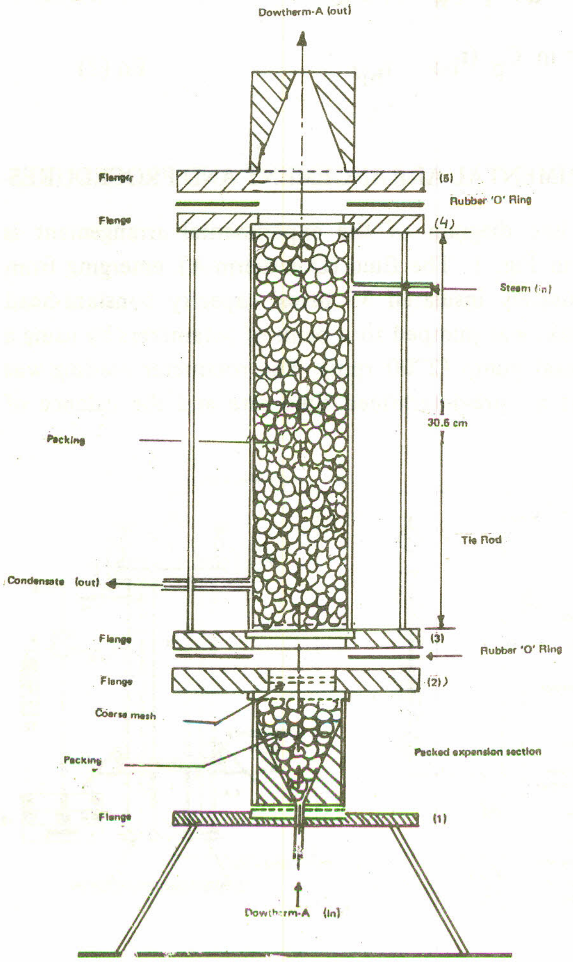

Fig. 2. Heat transfer assembly.

In the experimental procedure, the Dowtherm-A and steam flows were set and the thermocouples reading were monitored until a steady state was reached when all of the temperatures along with room temperature were recorded. The experimental set-up was allowed to cool down to the room temperature. The Dowtherm-A flow rate was then changed and the procedure repeated. A particle Reynolds number range from 15 to 200 was covered by changing the size of particles in the bed. Experiments were carried out for beds packed with two sizes of glass spheres and two sizes of brass cylinders.

The aluminium cylinder that formed the wall of the packed bed was 0.15 cm thick, and bearing in mind the high thermal conductivity of aluminium and large value of heat transfer coefficients for steam candensation, trial calculations showed that the inner wall of the pipe differed in temperature from the steam by less than 0.1°. Terefore the wall temperature was regarded as fixed at 103.5°.

Some replication experimnts were also performed during the course of the experimental programme without disturbing the orientation of the packing. The experiments showed high degree of reproducibility.

The heat transfer experiments were carried out for beds packed with 1.45 & 1.72 cm glass spheres and (0.62 x 0.62) and (1.91 x 1.91) cm brass cylinders. The experimental results on wall heat transfer coefficients were plotted as Nusselt (wall) group against particle Reynolds group in Fig. 3-6.

In order to confirm that the experimental data obtained from the study could be represented by a theoretical relationship, a curve-fitting technique was employed to develop the following equation such that the variance of the theoretical points about the experimental curve could be minimum:

$$Nu = \left(\frac{k_s}{k_f}\right)^{0.001}\left\{ e^{\epsilon_p} \left(\frac{d_p}{d_t}\right) + \eta^{-0.1}\right\}^{0.46}\left\{ (134.5 + \ln \eta^{-0.1}) \times R_{e_p}^{(\eta)^{-0.1}} + 2.07\, R_{e_p} - \frac{600}{\sqrt{Re_p}}\left(\frac{d_p}{d_t}\right)\right\} \qquad \text{Eq (3)}$$

DISCUSSION OF RESULTS

1. *Effect of particle reynolds number.* The overall trend of the experimental results on wall heat transfer coefficients, as shown by the figures, suggests that as the Reynolds number is increased, the Nusselt group also increases. This could be attributed to the fact that at the low Reynolds number, the resistance offered by the thermal boundary is large and it reduces, by the scouring action, as the Reynods group is increased.

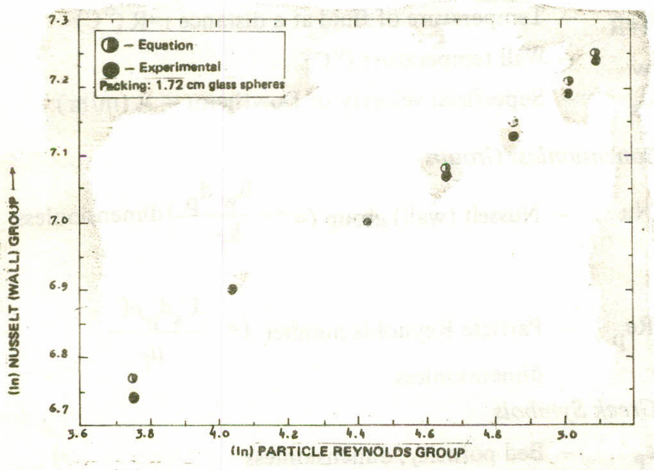

Fig. 3. Dependence of Nusselt (wall) group upon particle Reynolds group.

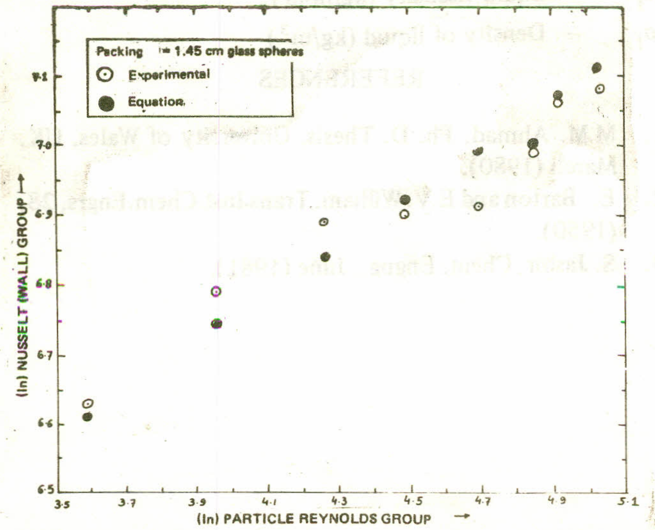

Fig. 4. Dependence of Nusselt (wall) group upon particle Reynolds group.

2. *Effect of packing size.* By comparing Fig. 3-6, the effect of packing size upon the wall heat transfer coefficient can be seen. At the same Reynolds number, beds packed with particles of the same thermal conductivity, the Nusselt group varies inversely with the packing size, the reason being that small size particles induce increased turbulence whereas large size packing results in reduced agitation; high turbulence enhances heat transfer at the wall, whereas reduced turbulence results in lower values of Nusselt (wall) group.

3. *Effect of thermal conductivity of packing material.* The effect of thermal conductivity of packing material can

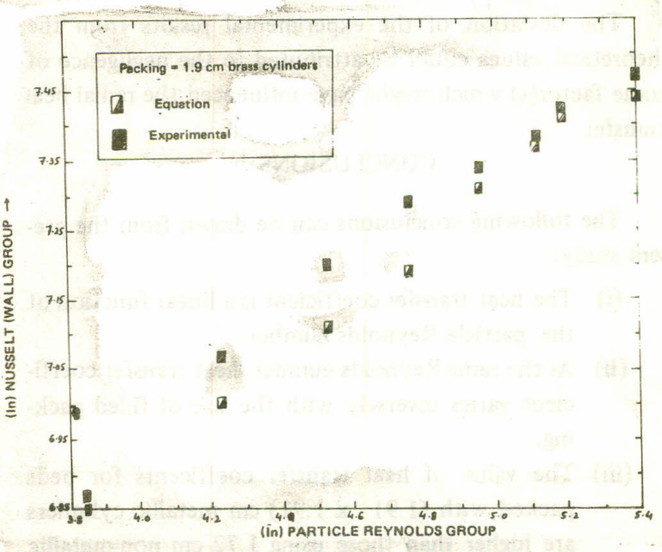

Fig. 5. Dependence on Nusselt (wall) upon particle Reynolds grou

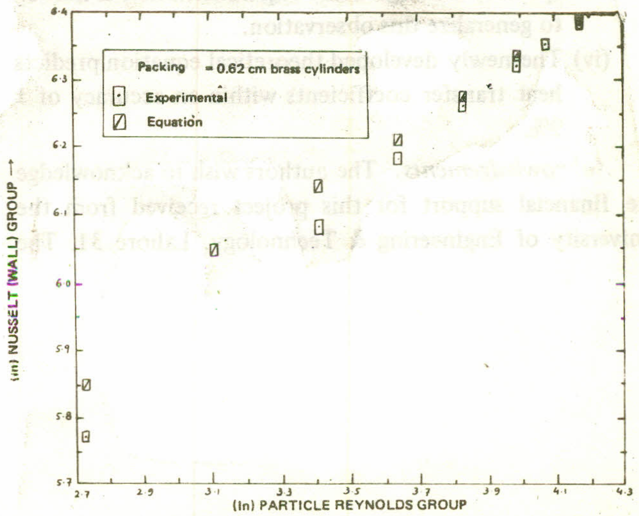

Fig. 6. Dependence of Nusselt (wall) upon particle Reynolds group

be seen from the comparison of results given in Fig. 3-6. It is evident that the level of Nusselt (wall) group for metallic particles is higher than those of non-metallic. Thus at the same particle Reynolds number, Nusselt group for (1.91 x 1.91) cm brass cylinders is higher than that of 1.72 cm glass spheres. The improvement in the values of heat transfer coefficient with an increment in thermal conductivity of the packing material is probably due to the enhancement of conduction through the solid phase at the wall boundary. The values of the Nusselt (wall) group given by equation (3) are also plotted in Fig. 3-6 for comparison. From the figures, a close agreement between the experimental and theoretical Nusselt (wall) groups for beds packed with glass spheres can be observed. But for beds packed with brass cylinders, a relatively large difference between the two values exists; the discrepancy is more pronounced at lower particle Reynolds numbers.

The deviation of the experimental results from the theoretical values could be attributed to the negligence of some factor(s) which might have influenced the radial heat transfer.

CONCLUSIONS

The following conclusions can be drawn from the present study:

(i) The heat transfer coefficient is a linear function of the particle Reynolds number.

(ii) At the same Reynolds number, heat transfer coefficient varies inversely with the size of fixed packing.

(iii) The value of heat transfer coefficents for beds packed with (1.91 x 1.91) cm metallic cylinders are higher than those using 1.72 cm non-metallic spheres, although more experimentation is needed to generalize this observation.

(iv) The newly developed theoretical equation predicts heat transfer coefficients within an accuracy of ± 9%.

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NOMENCLATURE

A_t – Effective heat transfer area (m^2)
C_p – Specific heat of Dowtherm – A (k Cal/kg–°C)
d_p – Packing size (m)
d_t – Inside diameter of column (m)
h_w – Wall heat transfer coefficient (K Cal/m^2 -hr-°C)
K_s, K_f – Thermal conductivity of packing material & fluid, respectively (K Cal/m-hr-°C)
m – Fluid mass flow rate (kg/hr)
Q – Heat transfer rate (k Cal/hr)
t_{bi} – Initial (bulk) temperature of fluid (°C)
t_{bo} – Final (bulk) temperature of fluid (°C)
$t_{r=R}$ – Temperature of fluid at a distance r=R (°C)
t_w – Wall temperature (°C)
U_s – Superficial velocity of Dowtherm – A (m/hr)

Dimensionless Groups

Nu – Nusselt (wall) group ($=\frac{h_w d_p}{k_f}$) dimensionless

Re_p – Particle Reynolds number ($=\frac{U_s d_p \rho_f}{\mu_f}$ dimensionless.

Greek Symbols

ϵ_p – Bed porosity, dimensionless
η – Fluid loading factor ($\frac{m}{d_p f}$) dimensionless
μ_f – liquid viscosity (kg/m-hr)
ρ_f – Density of liquid (kg/m^3)

REFERENCES

1. M.M. Ahmad, Ph. D. Thesis, University of Wales, UK, March (1980).
2. E. Barton and E.V. William, Trans.Inst.Chem.Engrs, **28**, (1950).
3. S. Jasbir, Chem. Engng., June (1981).