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HEAT TRANSFER TO GAS–LIQUID MIXTURES IN A VERTICAL TUBE FITTED WITH TWISTED-TAPES

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NOMENCLATURE

D, i.d. of the tube [m];
h_L, single phase heat transfer coefficient for liquid flow [kcal/hm^2 °C];
h_{tp}, two-phase heat transfer coefficient [kcal/hm^2 °C];
N_{ReL}, liquid Reynolds number, $DV_L\rho/\mu$;
V_G, velocity of gas [m/h];
V_L, velocity of liquid [m/h];
ρ, density [kg/m^3];
μ, viscosity [kg/hm];
λ, number of pipe diameters per 360° tape rotation.

The introduction of twisted-tapes in the single-phase and two-phase gas–liquid streams were shown to have greatly increased the heat transfer rates and this enhancement was of the order of three times at critical heat flux and constant pumping power [1]. The aim of the present investigation is mainly to obtain data on heat transfer under swirl flow conditions employing tapes of different sizes and different flow rates of the fluid streams.

EXPERIMENTAL SET-UP

The test section was described in detail elsewhere [2]. Briefly, it consisted of a 20 cm high, 1·28 cm i.d. and 2·22 cm o.d. stainless steel tube, surrounded by a steam jacket. Fourteen 26-gauge copper–constantan thermocouples were attached to the tube at seven different levels to measure the wall temperature. The main test section was flanked by upstream and downstream calming sections of 1 m and 1·5 m lengths, respectively. Four different tape twist ratios ranging from 3·47 to infinity were investigated. The tape fitted in the test section was separated by a short distance from the tapes on each end of it to minimize the heat conduction along the tape. Steam, after passing through a water-separating tee, an entrainment separator and a distributor, was introduced into the assembly at the inlet section.

RESULTS AND DISCUSSIONS

In all the runs, the heat flux was calculated from the amount of condensate collected. The heat balance was checked and was found to be within ±10 per cent for most of the runs. The fitness of the experimental set up was tested by comparing single-phase data, with the values predicted by the well known Sieder–Tate equation. The agreement was within ±6 per cent, proving the worth of the set up.

TWO-PHASE SWIRL FLOW RESULTS

Heat transfer studies in the presence of twisted-tapes were carried out using air and water as the two-phase fluids at 5 different flow rates of liquid, varying the superficial liquid Reynolds number from 4060 to 27500. Figures 1–3 show some of the results obtained in this work with the variation of heat-transfer coefficient ratios plotted against the gas to liquid volumetric flow rate ratios (V_G/V_L). The plots show a general similarity in the variation of heat transfer results

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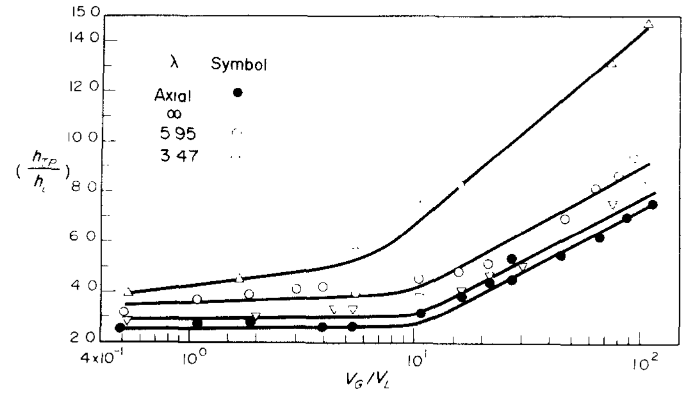

FIG. 1. Two phase heat transfer results at $N_{ReL} = 4060$.

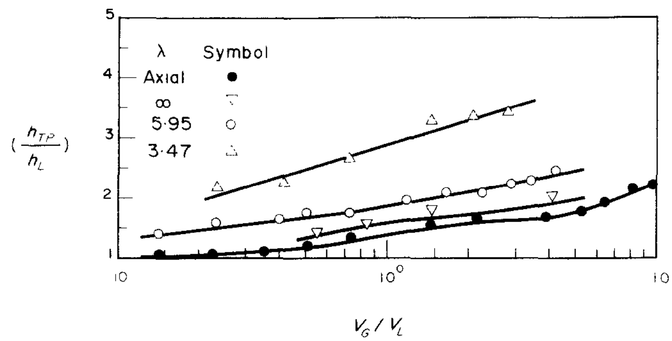

FIG. 2. Two phase heat transfer results at $N_{ReL} = 11700$.

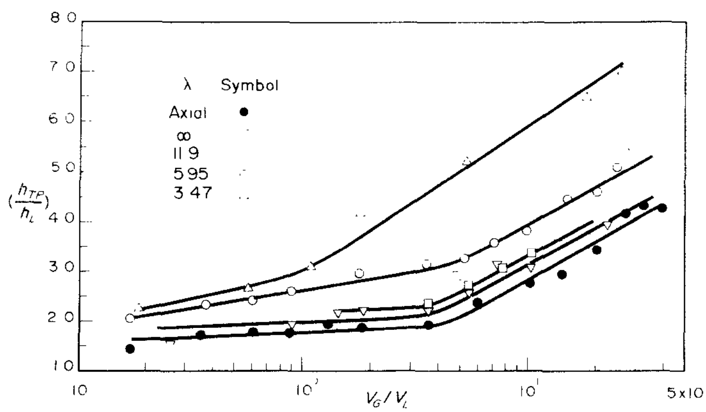

FIG. 3. Two phase heat transfer results at $N_{ReL} = 27500$.

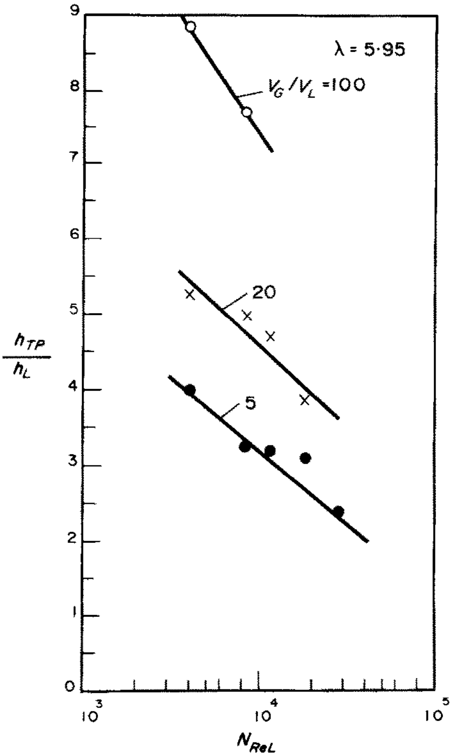

FIG. 4. Variation of h_{TP}/h_L with N_{ReL} for λ 5·95.

between axial and swirl flow studies. Higher heat transfer rates were obtained with tapes of low pitches. The ratio of heat transfer coefficient was found to decrease with increasing liquid rates as shown in a typical plot Fig. 4. The two-phase heat transfer coefficients were found to be a strong function of tape-twist ratios, smaller twists producing higher improvement in the heat transfer rates; thus at N_{ReL} = 4060, the tape of twist ratio = 5·95 increases the heat transfer by 47 per cent at V_G/V_L = 10 and this improvement goes up to 140 per cent with the tape of twist ratio = 3·47.

Two distinct heat transfer regimes were observed in both axial and swirl flow. A similar trend of data is noticeable in the results reported by Verchoor and Stemerding [3] and Groothuis and Hendal [4] under axial flow conditions. The first regime mostly occurred in the visually observed slug flow region which is characterised by alternate liquid and gas slugs. The interaction of phases in this regime generates circulatory currents within the liquid slugs, which cause improved heat transfer. The circulation assumes particular importance at small slug lengths. Higher gas rate increases the velocity of the liquid, but simultaneously reduces the effective heat transfer area and consequently retards the increase in the heat transfer rate. This retardation is partly compensated by an increase in the heat transfer rate across the gas slugs. Some or all of these factors account for the behavior shown in the first regime. The major portion of the second regime consists of annular flow and heat transfer continues to increase with the gas rate till the dry wall condition is reached. It may be noted that the inflections occurred at lower volumetric ratios under swirl flow conditions. For instance, at N_{ReL} = 11700 the inflection has occurred at V_G/V_L = 4·3 in the axial flow regime, whereas it occurred at VV_G/V_L = 1·0 in the presence of tape of twist ratio (pitch to diameter ratio) = 3·47. The inflection at N_{ReL} = 4060 has similarly shifted from 10 to 5 by the introduction of the same tape. The decrease in the point of inflection with the introduction of tapes must have been due to the change of flow pattern from slug to annular. The flow pattern studies [2] indicated that the annular flow was established at much lower volumetric flow-rate ratios by the introduction of the tape.

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