PHASE DISTRIBUTION AND HEAT TRANSFER IN N-HEPTANE-WATER MIXTURES FLOWING IN VERTICAL, HORIZONTAL AND CURVED TUBES

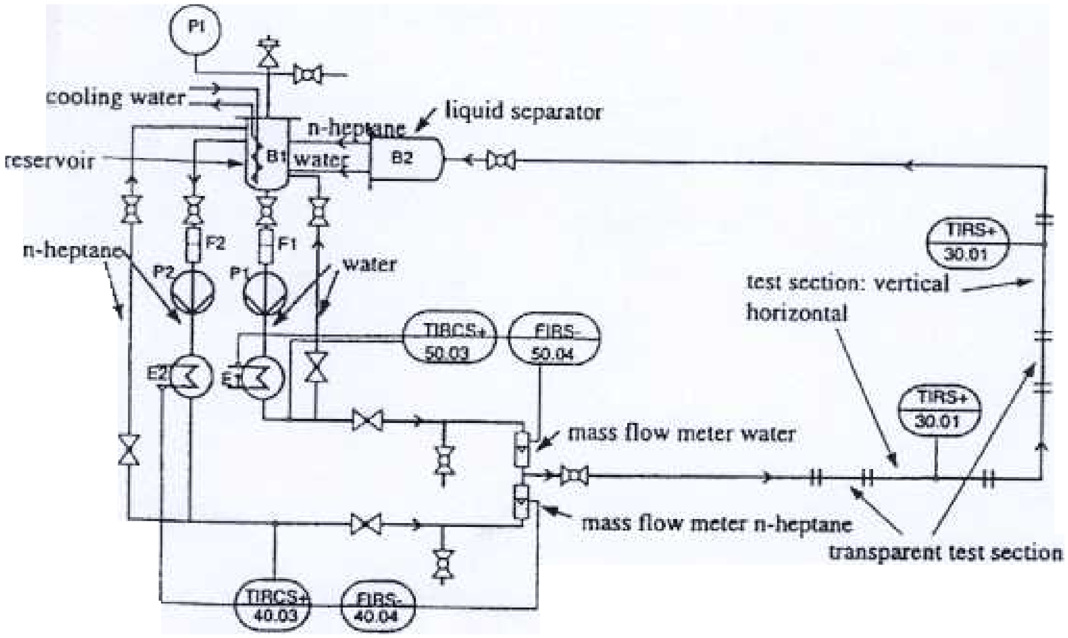
Hein Auracher* and Peter Lang**

*Institut für Energietechnik, Sekr. KT1, TU-Berlin, Marchstr.18, 10587 Berlin, Germany
** Robert Bosch GmbH, R.Bosch Str. 2, 71701 Schwieberdingen, Germany

Phase distribution and heat transfer measurements are carried out in a stainless steel tube of 16 mm inner diameter and 1 mm wall thickness. Figure 1 presents a schematic of the test loop. The test section is mounted either horizontally or vertically. In addition, heat transfer measurements are carried out in a bend between the horizontal and the vertical part.

After the test section the mixture is separated in a large vessel (B2; 80 x 10^{-3} m^3). From the reservoir B1, which has water in the lower part and n-heptane in the upper part, the liquids flow separately via filters F, pumps P, electric heaters E, and mass flow meters (Coriolis-type, Micro Motion D25, M_{max} = 0.6 kg/s, relative accuracy ±0.4% at M > 0.015 kg/s) and are mixed again in a T-junction 1.6 m before entering a transparent tube. Bypasses in the flow lines enable the liquid mass flow ratio to be varied in the test section.

Fig. 1 Test loop. TIRCS+ : temperature indication, registration, control, alarm. FIRS- : flow indication, registration, minimum alarm. TIRS+ : temperature indication, registration, maximum alarm. PI, pressure indication; F, filter; P, pump; E, electric heater.



The test section is directly DC-heated. In the horizontal and vertical case the total heated length is 850 mm. After 700 mm, eight thermocouples (metal-sheathed, 0.5 mm diameter, chromel-alumel) are soldered onto the outer surface of the tube, equally distributed around the perimeter. The same arrangement of thermocouples is used in section 1, 2 and 3 along the bend, as shown in Fig. 2. DC-heating starts in section 0. The inner wall temperature distribution is calculated by solving numerically the two-dimensional heat conduction equation.

For the phase distribution measurements in the vertical and horizontal tube arrangement very high frequency (300-500 MHz) impedance probes are used with a tip diameter of 0.58 mm. The radial distribution of the local phase fraction $\varepsilon(r)$ of n-heptane in the mixture is measured by stepwise moving the probes through a cross section of the tube by means of a computer-controlled stepping motor. $\varepsilon(r)$ represents a local time-averaged value obtained by electronic integration of the local phase sequences. To have an indication of the phase distribution in contact with the wall an additional probe is flush mounted in the tube wall. The radial distribution of local phase velocities $v(r)$ is also measured by cross-correlating the signals of two subsequently mounted probes with a tip-to-tip distance of 40 mm. Both probes are simultaneously moved through the cross section of the tube. Due to the nonsymmetric phase distribution in the horizontal test section, the probe measurements are carried out in vertical-, horizontal- and 45°-direction through the cross-section.

Fig. 2 The curved test section

The volumetric phase fraction of n-heptane is varied between 0 and 1, the mixture velocities between 0.5 and 2.3 m/s, and the temperature between 30 and 80°C.

Heat transfer to the liquid-liquid mixture depends on the phase distribution in the boundary layer at the wall. It was found that the change from water-dominated heat transfer to n-heptane-dominated heat transfer occurs nearly abruptly at n-heptane volumetric phase fractions between 0.6 and 0.7. In vertical flow an estimate of the heat transfer coefficient as a function of the mean volumetric fraction ε by a linear interpolation between the heat transfer coefficients at $\varepsilon = 0$ and $\varepsilon = 1$ would therefore lead to significant errors. The few correlations available in the literature are also not suitable to predict heat transfer to water-n-heptane mixtures. Therefore a preliminary prediction method is proposed based on the experimental data for phase distribution near the heated wall.

In horizontal flow the phase distribution is nonsymmetric with the higher water concentration in the lower part of the tube. At higher phase velocities the flow pattern approaches the annular flow regime. The heat transfer coefficient is nonuniform along the perimeter. Since in practical application mostly a perimeter-averaged heat transfer coefficient α_m is required, a simple correlation is presented which predicts α_m within ±25% for all system conditions of the experiments.

The heat transfer in the bend is characterised by a drastic increase of α_m in section 2 and, somewhat reduced, also in section 3 with respect to section 1 (see Fig. 2), especially at volumetric flow fractions of n-heptane between 20 and 90%. Secondary flows after the bend are most likely responsible for this increase. The average heat transfer coefficient can reasonably be predicted based on standard methods for the heat transfer improvement in bends. In our experiments the average heat transfer coefficient is about 45 % better than in vertical tubes.