Int. J. Multiphase Flow Vol. 9, No. 4, pp. 399–410, 1983
Printed in Great Britain.

0301-9322/83 $3.00 + .00
Pergamon/Elsevier

# FLOW PATTERN, VOID FRACTION AND PRESSURE DROP OF REFRIGERANT TWO-PHASE FLOW IN A HORIZONTAL PIPE—I

## EXPERIMENTAL DATA

KENICHI HASHIZUME
Energy Science & Technology Laboratory, R&D Center, Toshiba Corporation, Ukishimacho 4-1, Kawasaki, Japan

(*Received 2 March 1982; in revised form 5 December 1982*)

**Abstract**—Experiments with refrigerant two-phase flow in a horizontal pipe have been performed and data on flow pattern, void fraction and pressure drop have been obtained. Refrigerants used were R12 and R22, and the range of saturation pressure was from 5.7 to 19.6 bar.

In this paper, the experimental equipment and procedure are described in detail, and the data are both tabulated and presented graphically.

## 1. INTRODUCTION

Because of the complexity of the problem, theoretical treatment of gas/liquid two-phase flow is not easy. Therefore most investigations on two-phase flow have been carried out experimentally, and many empirical correlations to predict flow pattern, void fraction and pressure drop have been proposed. To clarify the range of applicability and the accuracy of these correlations, good experimental data are necessary. The purpose of this investigation was to produce good data on flow pattern, void fraction and pressure drop of refrigerants in such a pressure range as is encountered in practical situations.

## 2. RANGE OF EXPERIMENTAL CONDITIONS

A large amount of data has been obtained on gas/liquid two-phase flow. Much data are compiled in data banks, such as those of Dukler (1962) or HTFS. Most data, however, relate to air/water two-component systems, and only limited data are available for one-component systems of refrigerants in the higher pressure ranges.

Chawla (1967) performed experiments with refrigerant R11, and Bandel (1973) experimented with R11, R12 and R22, where only one of three parameters, i.e. saturation temperature (pressure), flowrate and quality, was changed systematically. In these experiments, however, due to limitations of the apparatus, the pressure range was relatively low (from 0.6 to 3.6 bar), and void fraction was not measured.

Taking this background into consideration, the pressure range in the presently expected experimental work was chosen to be from 5.7 to 19.6 bar; and the refrigerants chosen were R12 and R22, which are used in practical applications, such as refrigerators or Rankine-cycle engines. The data have not been published before.

The inner diameter of the horizontal measurement section was 10 mm. The range of experimental conditions are summarized in table 1, and the fluid property values after Hirschberg (1966) are shown in table 2.

## 3. EXPERIMENTAL EQUIPMENT

To produce controlled two-phase flow in the measurement section, a natural circulation loop, figure 1, was used. From the condenser, which was located on the laboratory roof at a point about 10 metres above the horizontal measurement section, the refrigerant in liquid phase flows via the downcomer, strainer, flowmeter and control valve into the pre-cooler. After the

Table 1. Experimental range and conditions

| Refrigerant | R12 | | | R22 | | |
|---|---|---|---|---|---|---|
| $T_s$ [ °C ] | 20 | 39 | 50 | 20 | 39 | 50 |
| $P_s$ [ bar] | 5.7 | 9.4 | 12.2 | 9.2 | 15.1 | 19.6 |
| W [kg/h] | 25, 35, 50, 70, 100 | | | | | |
| x [ - ] | 0.1, 0.3, 0.5, (0.7), 0.8, (0.9) | | | | | |

Table 2. Property values

| | $T_s$ [°C] | $P_s$ [bar] | $\rho_L$ [kg/m$^3$] | $\mu_L$ [cP] | $\rho_G$ [kg/m$^3$] | $\mu_G$ [uP] |
|---|---|---|---|---|---|---|
| R12 | 20 | 5.67 | 1329 | 0.264 | 31.5 | 124 |
| | 39 | 9.37 | 1260 | 0.241 | 52.0 | 129 |
| | 50 | 12.15 | 1213 | 0.230 | 68.6 | 132 |
| R22 | 20 | 9.17 | 1215. | 0.238 | 38.8 | 127 |
| | 39 | 15.13 | 1136 | 0.222 | 66.0 | 134 |
| | 50 | 19.64 | 1084 | 0.213 | 88.5 | 138 |

quality was settled in the pre-heater, refrigerant two-phase flow reaches the measurement section, which consists of the entrance region, the pressure drop measurement section, the void fraction measurement section, the flow pattern observation section and the exit region. When refrigerant two-phase flow leaves the measurement section, it is heated to superheated gas in the after-heater, and returns, via the riser, to the condenser.

Bypass opens only during void fraction measurement, when the shut-off valves close.

Loop piping consists of 3/8-in. Cu-pipe (9.53 mm OD × 0.8 mm thick) for the liquid phase and 5/8-in Cu-pipe (15.88 mm OD × 1.0 mm thick) for the gas phase. The inner diameter of the measurement section including the two shut-off valves was 10 ± 0.05 mm.

All piping and components of the loop were thermally insulated with 50 mm glass wool, except for some parts of the void fraction measurement section and the flow pattern observation section. Further, the loop, except for the condenser, was located in a room with an air

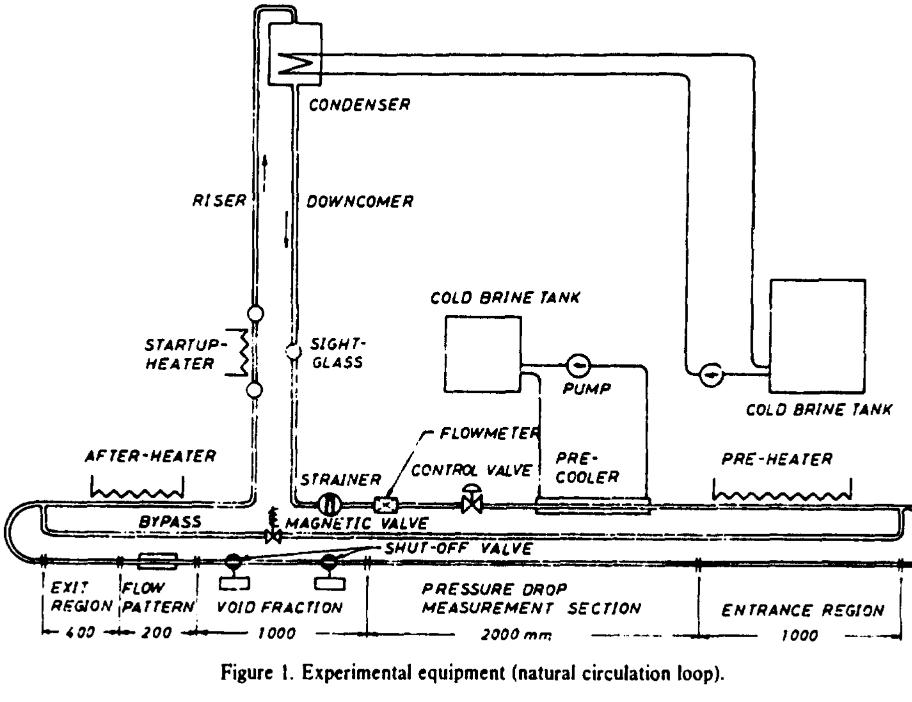


Figure 1. Experimental equipment (natural circulation loop).

conditioner, and the room temperature was held at a constant value, which was below 5–10 K than the saturation temperature in the measurement section.

For cooling the condenser and the pre-cooler, cold brine pumped from cold brine tanks were used. The three heaters, i.e. the pre-heater, the after-heater and the startup-heater, were heated electrically. The flowmeter was a Rotameter with electrical output.

## 4. CALIBRATION RUNS

The quality in the measurement section was calculated from the enthalpy rise based on the enthalpy at the inlet of the pre-heater, where the refrigerant flows in subcooled liquid phase. To calculate the quality accurately, calibration of the flowmeter was done and the heat loss from the pre-heater was measured. In the calibration runs, natural circulation was kept by heating of the after-heater and the startup-heater.

The refrigerant in liquid phase through the flowmeter was cooled in the pre-cooler and then again so heated in the pre-heater, that the refrigerant temperature at the outlet of the pre-heater recovered to the value in the inlet of the pre-cooler. From the heat removal in the pre-cooler, the heat input in the pre-heater, the temperatures at the inlet and the outlet of the pre-cooler and the pre-heater, calibration curves were obtained as shown in figures 2 and 3. The heat loss in figure 2 is shown against the temperature differences between the inner surface of the insulation layer and the ambient. In the following measurement, these figures were used to determine the flowrate and the quality.

## 5. FLOW PATTERN OBSERVATION AND RESULTS

The two-phase flow pattern was determined by visual observation after the sketches by Alves (1954). Flow pattern observed in this experiment were 5 types, i.e. stratified (*St*), wavy (*W*), slug (*Sl*), semi-annular (*SA*) and annular (*A*) flow. Semi-annular flow is a transient flow pattern to annular flow, where although a continuous liquid film flow can be observed, but the liquid film at the top of the pipe is too thinner than at the bottom to be determined as annular flow.

The flow patterns for various flowrates, quality and saturation temperature are shown in figure 4 and listed in tables 3 and 4.

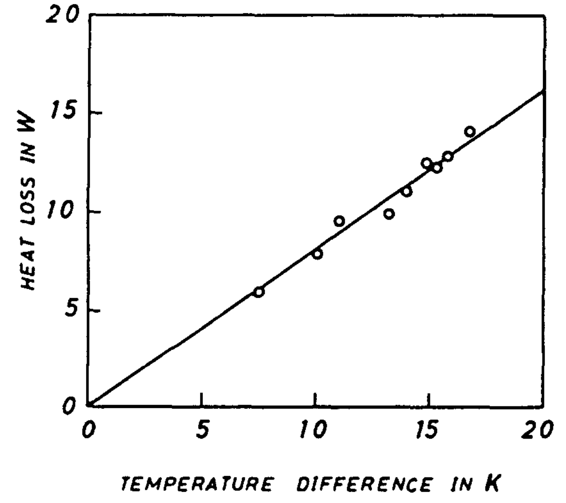


Figure 2. Heat loss in the pre-heater.

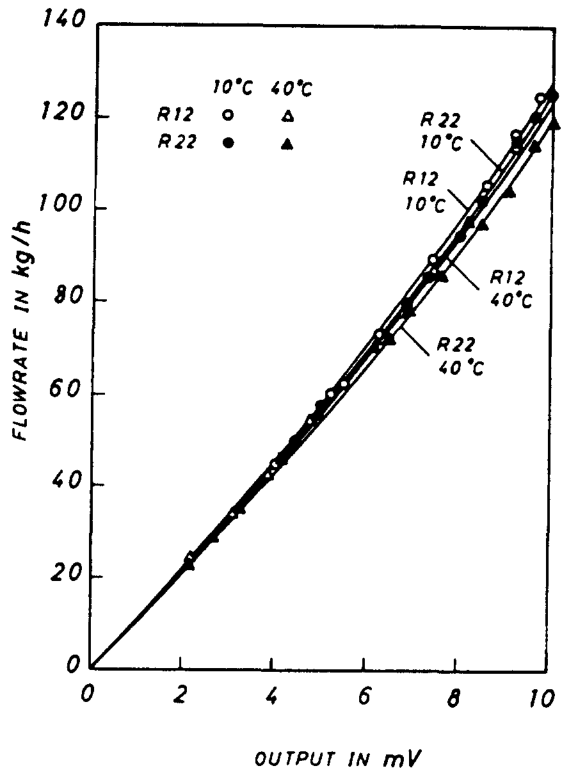


Figure 3. Calibration curve for the flowmeter.

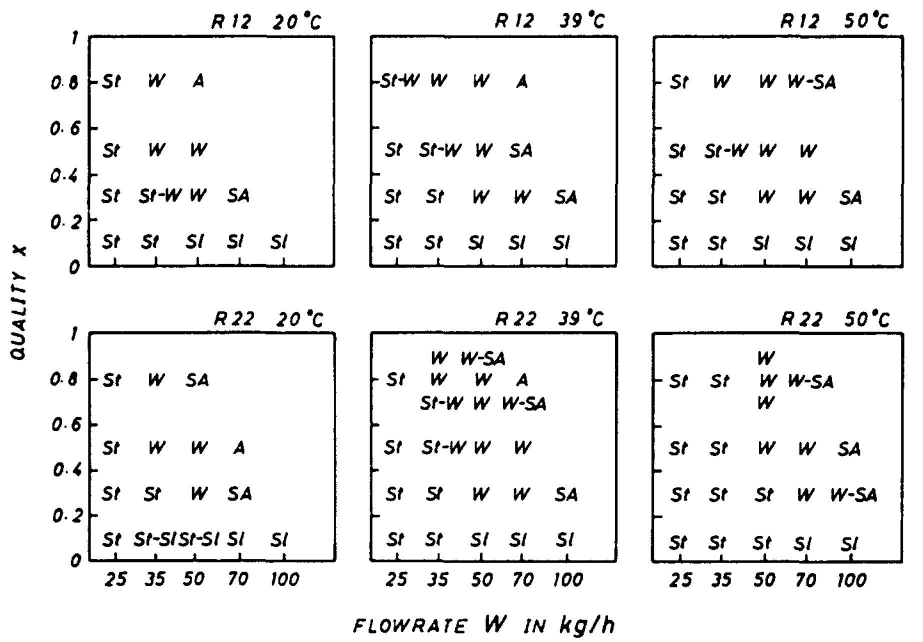


Figure 4. Results of flow pattern observation.

Table 3. Experimental results with R12

| $T_s$ [°C] | W [kg/h] | x [-] | α [-] | dP/dL [N/m³] | FP |
|---|---|---|---|---|---|
| 20 | 25 | 0.10 | 0.586 | - | St |
| | | 0.11 | 0.633 | - | St |
| | | 0.29 | 0.774 | - | St |
| | | 0.31 | 0.820 | - | St |
| | | 0.50 | 0.890 | 162 | St |
| | | 0.50 | 0.899 | 172 | St |
| | | 0.79 | 0.963 | 299 | St |
| | | 0.79 | 0.962 | 294 | St |
| | 35 | 0.09 | 0.576 | - | Sl |
| | | 0.10 | 0.662 | - | Sl |
| | | 0.31 | 0.803 | 184 | St-W |
| | | 0.31 | 0.807 | 184 | St-W |
| | | 0.50 | 0.863 | 358 | W |
| | | 0.51 | 0.940 | 343 | W |
| | | 0.80 | 0.965 | 564 | W |
| | | 0.81 | 0.970 | 576 | W |
| | 50 | 0.10 | 0.801 | - | Sl |
| | | 0.10 | 0.694 | - | Sl |
| | | 0.30 | 0.850 | 405 | W |
| | | 0.30 | 0.847 | 405 | W |
| | | 0.50 | 0.906 | 736 | W |
| | | 0.50 | 0.903 | 736 | W |
| | | 0.79 | 0.954 | 1350 | A |
| | | 0.81 | 0.961 | 1350 | A |
| | 70 | 0.10 | 0.474 | - | Sl |
| | | 0.10 | 0.743 | - | Sl |
| | | 0.30 | 0.803 | 809 | SA |
| | | 0.30 | 0.821 | 809 | SA |
| | 100 | 0.10 | 0.609 | 515 | Sl |
| | | 0.11 | 0.662 | 540 | Sl |
| 39 | 25 | 0.10 | 0.567 | 46.6 | St |
| | | 0.10 | 0.514 | 46.6 | St |
| | | 0.30 | 0.720 | 78.5 | St |
| | | 0.30 | 0.747 | 83.9 | St |
| | | 0.50 | 0.842 | 113 | St |
| | | 0.50 | 0.846 | 123 | St |
| | | 0.79 | 0.951 | 189 | St-W |
| | | 0.80 | 0.947 | 194 | St-W |
| | 35 | 0.10 | 0.552 | 66.2 | St |
| | | 0.11 | 0.521 | 68.7 | St |
| | | 0.30 | 0.740 | 132 | St |
| | | 0.31 | 0.708 | 132 | St |
| | | 0.50 | 0.864 | 196 | St-W |
| | | 0.50 | 0.872 | 196 | St-W |
| | | 0.79 | 0.945 | 343 | W |
| | | 0.79 | 0.940 | 343 | W |
| | 50 | 0.10 | 0.433 | - | Sl |
| | | 0.10 | 0.533 | - | Sl |
| | | 0.10 | 0.605 | 123 | Sl |
| | | 0.30 | 0.742 | 245 | W |
| | | 0.30 | 0.788 | 245 | W |
| | | 0.50 | 0.864 | - | W |
| | | 0.50 | 0.881 | 441 | W |
| | | 0.79 | 0.945 | 858 | W |
| | | 0.79 | 0.943 | 736 | W |
| | 70 | 0.10 | 0.691 | - | Sl |
| | | 0.10 | 0.622 | 206 | Sl |
| | | 0.11 | 0.729 | - | Sl |
| | | 0.30 | 0.760 | 491 | W |
| | | 0.31 | 0.786 | 515 | W |
| | | 0.50 | 0.876 | 858 | SA |
| | | 0.50 | 0.861 | 858 | SA |
| | | 0.80 | 0.950 | 1590 | A |
| | | 0.80 | 0.938 | 1620 | A |
| | 100 | 0.10 | 0.441 | - | Sl |
| | | 0.10 | 0.561 | 392 | Sl |
| | | 0.10 | 0.518 | 417 | Sl |
| | | 0.30 | 0.793 | 1030 | SA |
| 50 | 25 | 0.09 | 0.501 | 45.1 | St |
| | | 0.10 | 0.527 | 46.6 | St |
| | | 0.30 | 0.692 | - | St |
| | | 0.30 | 0.663 | 73.6 | St |
| | | 0.50 | 0.821 | 90.7 | St |
| | | 0.50 | 0.816 | 94.2 | St |
| | | 0.77 | 0.925 | 145 | St |
| | | 0.81 | 0.938 | 150 | St |

Table 3 (*Contd*)

| $T_s$ [°C] | W [kg/h] | x [-] | α [-] | dP/dL [N/m³] | FP |
|---|---|---|---|---|---|
| | 35 | 0.10 | 0.479 | - | St |
| | | 0.10 | 0.470 | 63.8 | St |
| | | 0.30 | 0.723 | - | St |
| | | 0.30 | 0.699 | 120 | St |
| | | 0.49 | 0.822 | 181 | St-W |
| | | 0.50 | 0.822 | 181 | St-W |
| | | 0.79 | 0.927 | 304 | W |
| | | 0.80 | 0.929 | 304 | W |
| | 50 | 0.10 | 0.520 | 98.1 | Sl |
| | | 0.11 | 0.571 | 108 | Sl |
| | | 0.30 | 0.710 | 221 | W |
| | | 0.30 | 0.726 | 216 | W |
| | | 0.50 | 0.827 | 353 | W |
| | | 0.50 | 0.830 | 353 | W |
| | | 0.80 | 0.922 | 579 | W |
| | | 0.80 | 0.925 | 559 | W |
| | 70 | 0.10 | 0.536 | 201 | Sl |
| | | 0.10 | 0.346 | 208 | Sl |
| | | 0.30 | 0.714 | 412 | W |
| | | 0.30 | 0.764 | 417 | W |
| | | 0.50 | 0.836 | 697 | W |
| | | 0.50 | 0.842 | 711 | W |
| | | 0.79 | 0.936 | 1100 | W-SA |
| | | 0.81 | 0.937 | 1120 | W-SA |
| | 100 | 0.10 | 0.610 | 358 | Sl |
| | | 0.10 | 0.509 | 358 | Sl |
| | | 0.30 | 0.766 | 760 | SA |
| | | 0.31 | 0.753 | 814 | SA |

Table 4. Experimental results with R22

| $T_s$ [°C] | W [kg/h] | x [-] | α [-] | dP/dL [N/m³] | FP |
|---|---|---|---|---|---|
| 20 | 25 | 0.10 | 0.620 | - | St |
| | | 0.10 | 0.615 | - | St |
| | | 0.10 | 0.588 | - | St |
| | | 0.29 | 0.727 | - | St |
| | | 0.30 | 0.762 | - | St |
| | | 0.30 | 0.772 | - | St |
| | | 0.49 | 0.880 | 123 | St |
| | | 0.51 | 0.883 | 123 | St |
| | | 0.80 | 0.972 | 213 | St |
| | | 0.80 | 0.963 | 221 | St |
| | 35 | 0.10 | 0.520 | - | St-Sl |
| | | 0.11 | 0.555 | - | St-Sl |
| | | 0.30 | 0.788 | 135 | St |
| | | 0.30 | 0.787 | 135 | St |
| | | 0.51 | 0.900 | 282 | W |
| | | 0.51 | 0.900 | 270 | W |
| | | 0.79 | 0.960 | 466 | W |
| | | 0.81 | 0.976 | 454 | W |
| | 50 | 0.10 | 0.530 | 123 | St |
| | | 0.11 | 0.723 | 123 | Sl |
| | | 0.30 | 0.788 | 319 | W |
| | | 0.31 | 0.805 | 294 | W |
| | | 0.49 | 0.884 | 515 | W |
| | | 0.50 | 0.900 | 491 | W |
| | | 0.79 | 0.957 | 981 | SA |
| | | 0.80 | 0.959 | 981 | SA |
| | 70 | 0.10 | 0.686 | - | Sl |
| | | 0.10 | 0.788 | 221 | Sl |
| | | 0.11 | 0.687 | - | Sl |
| | | 0.11 | 0.744 | 221 | Sl |
| | | 0.30 | 0.832 | 638 | SA |
| | | 0.30 | 0.800 | 638 | SA |
| | | 0.48 | 0.879 | 1180 | A |
| | | 0.49 | 0.889 | 1202 | A |
| | 100 | 0.10 | 0.752 | 491 | Sl |
| | | 0.10 | 0.624 | 491 | Sl |
| 39 | 25 | 0.09 | 0.507 | - | St |
| | | 0.10 | 0.547 | - | St |
| | | 0.10 | 0.517 | 44.1 | St |
| | | 0.29 | 0.707 | 73.6 | St |
| | | 0.30 | 0.720 | - | St |
| | | 0.30 | 0.703 | 68.7 | St |
| | | 0.49 | 0.819 | 95.6 | St |
| | | 0.50 | 0.828 | 98.1 | St |
| | | 0.50 | 0.846 | 98.1 | St |
| | | 0.79 | 0.939 | 147 | St |
| | | 0.80 | 0.944 | 147 | St |

Table 4 (*Contd*)

| $T_s$ [°C] | W [kg/h] | x [-] | α [-] | dP/dL [N/m³] | FP |
|---|---|---|---|---|---|
| 39 | 35 | 0.09 | 0.461 | - | St |
| | | 0.09 | 0.439 | - | St |
| | | 0.10 | 0.473 | 60.1 | St |
| | | 0.29 | 0.722 | - | St |
| | | 0.29 | 0.712 | - | St |
| | | 0.30 | 0.708 | 113 | St |
| | | 0.48 | 0.857 | - | St-W |
| | | 0.49 | 0.854 | - | St-W |
| | | 0.51 | - | 172 | St-W |
| | | 0.70 | 0.931 | - | St-W |
| | | 0.70 | 0.919 | - | St-W |
| | | 0.80 | - | 294 | W |
| | | 0.89 | 0.984 | - | W |
| | | 0.90 | 0.976 | - | W |
| | 50 | 0.11 | - | 98.1 | Sl |
| | | 0.11 | 0.464 | - | Sl |
| | 49 | 0.11 | 0.541 | - | Sl |
| | 50.5 | 0.15 | 0.595 | - | W-Sl |
| | | 0.16 | 0.670 | - | W-Sl |
| | | 0.16 | 0.562 | - | W-Sl |
| | | 0.16 | 0.647 | - | W-Sl |
| | | 0.16 | 0.619 | - | W-Sl |
| | | 0.16 | 0.644 | - | W-Sl |
| | | 0.17 | 0.598 | - | W-Sl |
| | | 0.17 | 0.572 | - | W-Sl |
| | | 0.17 | 0.660 | - | W-Sl |
| | 50 | 0.27 | 0.739 | - | W |
| | | 0.28 | 0.747 | - | W |
| | | 0.30 | - | 245 | W |
| | 51.5 | 0.41 | 0.820 | - | - |
| | 50.5 | 0.41 | 0.816 | - | - |
| | | 0.42 | 0.803 | - | - |
| | | 0.42 | 0.810 | - | - |
| | | 0.43 | 0.837 | - | - |
| | 50 | 0.43 | 0.803 | - | - |
| | | 0.43 | 0.815 | - | - |
| | | 0.43 | 0.816 | - | - |
| | 49 | 0.44 | 0.817 | - | - |
| | 47 | 0.46 | 0.821 | - | - |
| | 50 | 0.50 | - | 319 | W |
| | | 0.67 | 0.915 | - | W |
| | | 0.68 | 0.892 | - | W |
| | | 0.68 | 0.907 | - | W |
| | | 0.68 | 0.911 | - | W |
| | | 0.68 | 0.916 | - | W |
| | | 0.69 | 0.922 | - | W |
| | | 0.80 | - | 540 | W |
| | | 0.87 | 0.968 | - | W-SA |
| | | 0.89 | 0.972 | - | W-SA |
| | 70 | 0.10 | 0.555 | - | Sl |
| | | 0.10 | 0.383 | - | Sl |
| | | 0.11 | - | 172 | Sl |
| | | 0.29 | 0.770 | - | W |
| | | 0.29 | 0.760 | - | W |
| | | 0.30 | - | 392 | W |
| | | 0.49 | 0.843 | - | W |
| | | 0.50 | 0.858 | - | W |
| | | 0.50 | - | 638 | W |
| | | 0.70 | 0.923 | - | W-SA |
| | | 0.70 | 0.922 | - | W-SA |
| | | 0.80 | 0.934 | 1130 | A |
| | | 0.80 | 0.940 | 1130 | A |
| | 100 | 0.10 | 0.565 | - | Sl |
| | | 0.10 | 0.483 | - | Sl |
| | | 0.10 | - | 343 | Sl |
| | | 0.27 | - | 736 | SA |
| | | 0.28 | 0.774 | - | SA |
| | | 0.29 | 0.736 | - | SA |
| | | 0.29 | - | 785 | SA |
| 50 | 25 | 0.08 | 0.437 | 38.0 | St |
| | | 0.09 | 0.425 | 39.2 | St |
| | | 0.10 | 0.468 | 40.7 | St |
| | | 0.30 | 0.630 | - | St |
| | | 0.30 | 0.654 | 58.9 | St |
| | | 0.32 | 0.629 | 54.0 | St |
| | | 0.50 | 0.780 | 71.1 | St |
| | | 0.51 | 0.803 | 71.1 | St |
| | | 0.79 | 0.923 | 108 | St |
| | | 0.80 | 0.925 | 108 | St |

Table 4 (*Contd*)

| $T_s$ [°C] | W [kg/h] | x [-] | α [-] | dP/dL [N/m³] | FP |
|---|---|---|---|---|---|
| 50 | 35 | 0.09 | 0.381 | - | St |
| | | 0.10 | 0.440 | 52.7 | St |
| | | 0.12 | 0.425 | - | St |
| | | 0..30 | 0.679 | - | St |
| | | 0.30 | 0.681 | 94.4 | St |
| | | 0.31 | 0.672 | - | St |
| | | 0.48 | 0.798 | 122 | St |
| | | 0.52 | 0.820 | 122 | St |
| | | 0.78 | 0.920 | - | St |
| | | 0.80 | 0.923 | 196 | St |
| | 50 | 0.10 | 0.451 | - | St |
| | | 0.10 | - | 80.9 | St |
| | | 0.11 | 0.481 | - | St |
| | | 0.29 | - | 167 | St |
| | | 0.30 | 0.718 | - | St |
| | | 0.31 | 0.709 | - | St |
| | | 0.50 | 0.820 | - | W |
| | | 0.50 | 0.802 | - | W |
| | | 0.50 | - | 270 | W |
| | | 0.69 | 0.909 | - | W |
| | | 0.70 | 0.899 | - | W |
| | | 0.79 | 0.929 | 412 | W |
| | | 0.81 | 0.927 | 417 | W |
| | | 0.89 | 0.969 | - | W |
| | | 0.91 | 0.976 | - | W |
| | 70 | 0.10 | 0.465 | 172 | Sl |
| | | 0.10 | 0.488 | 157 | Sl |
| | | 0.11 | - | 162 | Sl |
| | | 0.11 | 0.540 | - | Sl |
| | | 0.30 | 0.723 | - | W |
| | | 0.30 | 0.717 | - | W |
| | | 0.30 | - | 314 | W |
| | | 0.50 | 0.829 | 466 | W |
| | | 0.50 | 0.818 | 540 | W |
| | | 0.73 | 0.907 | 711 | W-SA |
| | | 0.80 | 0.936 | 760 | W-SA |
| | | 0.80 | 0.926 | 760 | W-SA |
| | 100 | 0.09 | 0.500 | 319 | Sl |
| | | 0.10 | 0.514 | 319 | Sl |
| | | 0.10 | 0.404 | 319 | Sl |
| | | 0.12 | - | 343 | Sl |
| | | 0.30 | - | 613 | W-SA |
| | | 0.30 | 0.703 | - | W-SA |
| | | 0.31 | 0.691 | - | W-SA |
| | 98.5 | 0.49 | 0.812 | 971 | SA |
| | 100 | 0.50 | 0.853 | 961 | SA |

## 6. VOID FRACTION MEASUREMENT AND RESULTS

Void fraction measurement was performed by the shut-off method, the apparatus being shown in figure 5. A signal from the electrical circuit causes 3-way air solenoid-valves to move, and so allows air at about 5 bar from the compressed air tank to actuate the shut-off valves. The shut-off time, i.e. the time from the beginning to the end of shut-off, could be controlled from 0.05 to 2 sec by speed controllers. The time was measured with photocouplers and discs on the rotating axis of the shut-off valves. The signals from the photocouplers were recorded on photocorder via an electrical circuit. After the two shut-off valves have closed, the magnetic valve opens, allowing refrigerant to flow through the bypass.

The gas/liquid mixture of refrigerant, which was isolated between the two shut-off valves, was expanded to the ambient pressure through a needle valve. Then, in a heat exchanger, it was heated to the room temperature, and its volume measured by a gas meter. Void fraction $\alpha$ was calculated from the measured total volume of refrigerant under ambient conditions (i.e. superheated gas phase). The mass of refrigerant $M$ before measurement is

$$M = M_1 + M_2 \qquad [1]$$

$$M_1 = [\alpha\rho_G + (1-\alpha)\rho_L]V_1 + \rho_L V_2 \qquad [2]$$

$$M_2 = \rho_{SH} V_3. \qquad [3]$$

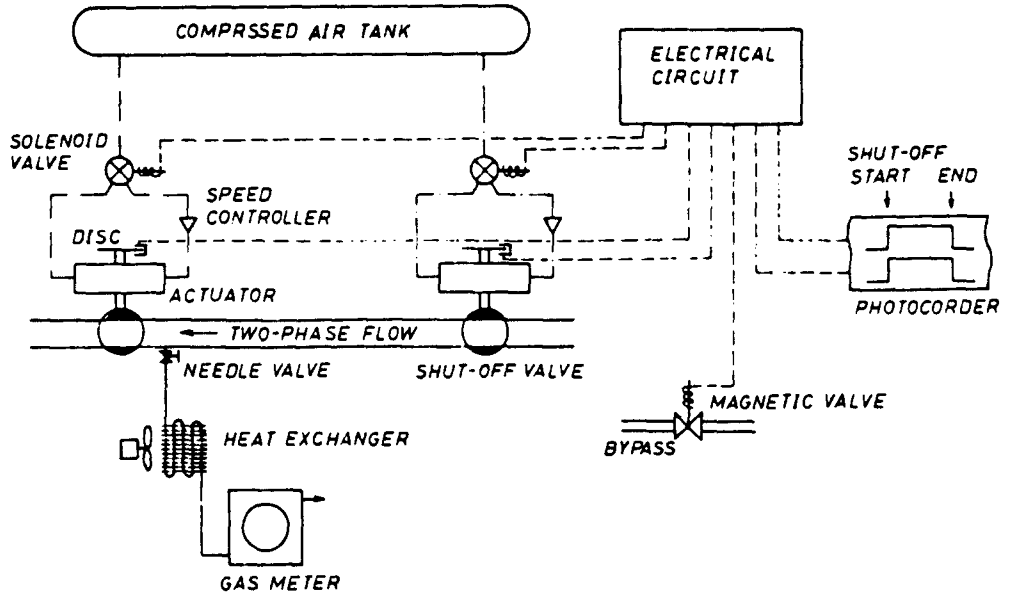


Figure 5. Measurement of void fraction.

Here, $\rho_{SH}$ is the density of refrigerant in superheated gas phase under ambient conditions. $V_1$, $V_2$ and $V_3$ are the volume of the measurement section between two shut-off valves, the volume between the measurement section and the needle valve, and the volume between the needle valve and the exit of the gas meter, respectively. Because the room temperature was held below the saturation temperature in the measurement section, the refrigerant in $V_2$ must be in liquid phase, whose density is nearly equal to $\rho_L$ in $V_1$. The refrigerant density in $V_3$ is $\rho_{SH}$, because the exit of the gas meter was so sealed, that the air could not enter into the gas meter. The refrigerant mass after measurement must be also $M$, which can be described as:

$$M = M_1' + M_2' + M_0 \qquad [4]$$

$$M_1' = \rho_{SH}(V_1 + V_2) \qquad [5]$$

$$M_2' = \rho_{SH} V_3 \qquad [6]$$

$$M_0 = \rho_{SH} V_0. \qquad [7]$$

Here, $V_0$ is the volume displacement of the gas meter. $M_1'$ and $M_2'$ are the mass remained in $V_1$, $V_2$ and $V_3$. $M_0$ is the mass calculated by the gas meter displacement. From [1]–[7] we obtain the following equations for void fraction.

$$\alpha = \frac{\rho_L - \dfrac{\rho_{SH}(V_1 + V_2 + V_0) - \rho_L V_2}{V_1}}{\rho_L - \rho_G}. \qquad [8]$$

The gas meter used was a wet type gas meter with a 0.5 l. rotating drum, and its accuracy was ±0.5 ml after the specification of manufacturer.

The influence of shut-off time on void fraction measurement was investigated in this experiment, because this has not been discussed in publications. Figure 6 shows the results. It is evident, that the influence of shut-off time is negligible. During the experiments, which

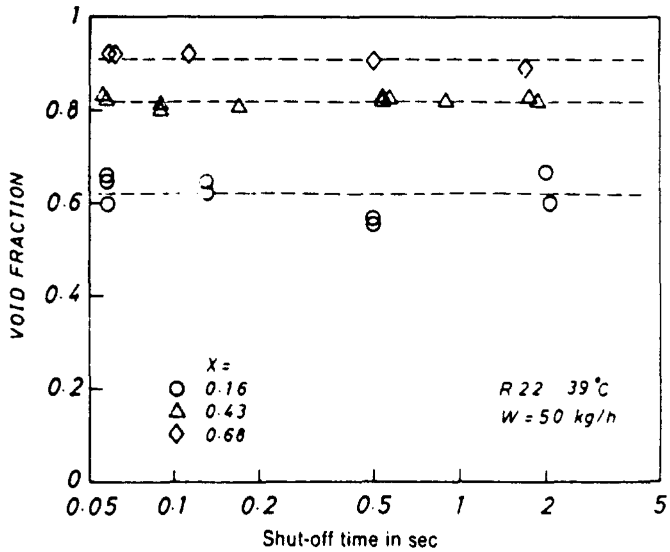


Figure 6. Influence of shut-off time on void fraction measurement.

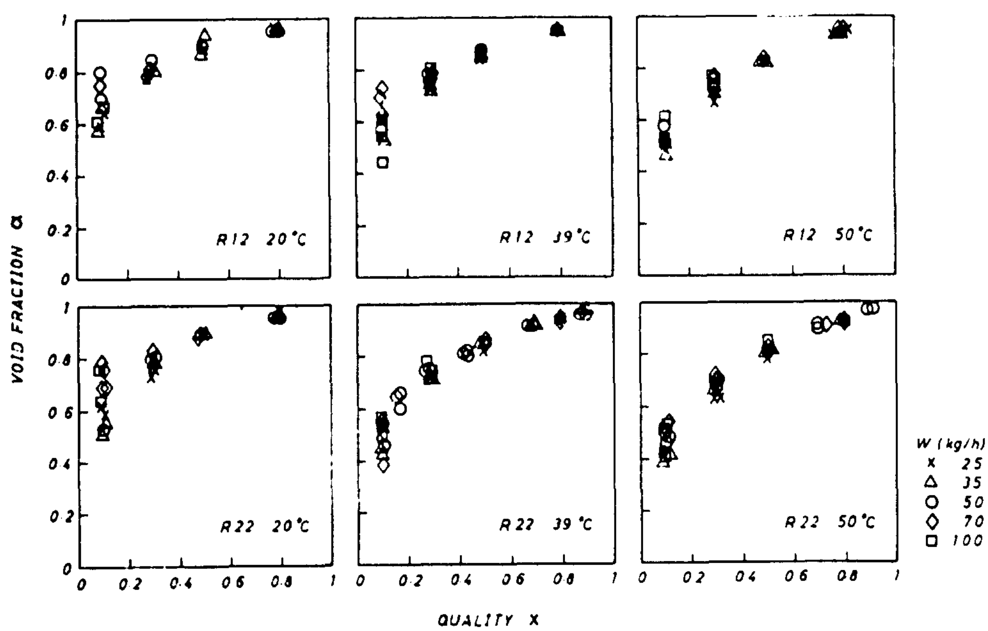


Figure 7. Results of void fraction measurement.

produced the data, shut-off time was kept at about 0.1 sec, and the shut-off simultaneity of the two shut-off valves was always within ±0.5% of the shut-off time.

Experimental results are shown in figure 7 and listed in tables 3 and 4.

## 7. PRESSURE DROP MEASUREMENT AND RESULTS

Pressure drop was measured as shown in figure 8. For the pressure drop measurement, a differential transducer with lineariser and amplifier was used. A pressure balancing valve between capillary tubes was closed only during the pressure drop measurement, to protect the transducer.

To fill the capillary tubes with refrigerant in subcooled liquid phase, the room temperature

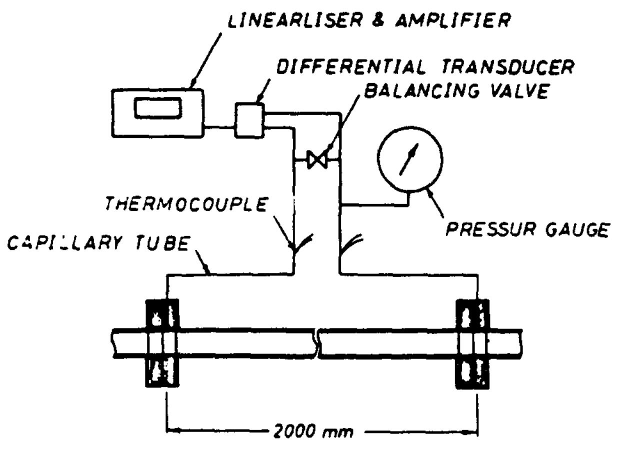


Figure 8. Measurement of pressure drop.

was held below the saturation temperature of refrigerant in the measurement section. The temperature of capillary tubes was watched during the measurement.

Experimental results are shown in figures 9 and 10, and listed in tables 3 and 4.

## 8. CONCLUDING REMARKS

Experiments with refrigerant two-phase flow in a horizontal pipe were performed to determine flow pattern, void fraction and pressure drop. Systematically produced experimental data, especially on void fraction, in this range have not been published previously, although they would be useful in practical applications. The experimental data will also help to clarify

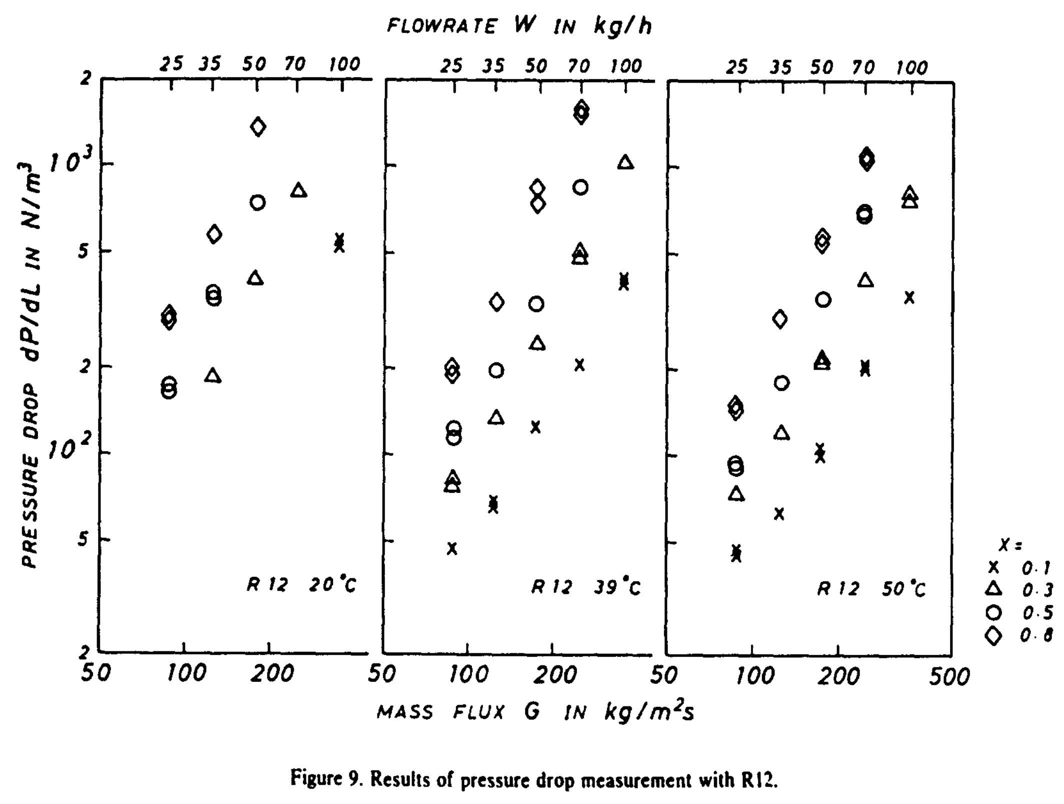


Figure 9. Results of pressure drop measurement with R12.

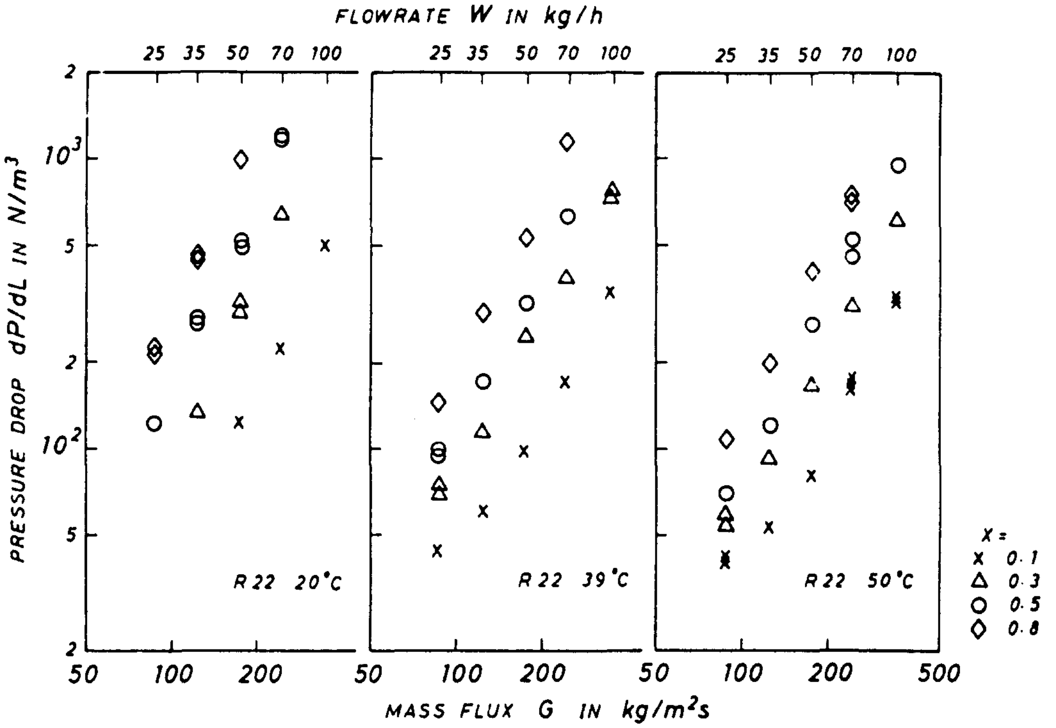


Figure 10. Results of pressure drop measurement with R22.

the applicability of the available correlations and their accuracy, and to develop theoretical models of two-phase flow.

## REFERENCES

Alves, G. E. 1954 Concurrent liquid/gas flow in a pipe-line contactor. *Chem. Engng Prog.* 59, 449–456.

Bandel, J. 1973 Druckverlust and Wärmeübergang bei der Verdampfung siedener Kältemittel im durchströmten waagerechten Rohr. Dissertation der Universität Karlsruhe.

Chawla, J. M. 1967 Wärmeübergang und Druckabfall in waagerechten Rohren bei der Stömung von verdampfenden Kältemitteln. VDI-Forsch.-H. 523.

Dukler, A. E. 1962 *Two-Phase Flow Data Analysis and Correlation Studies.* University of Houston.

Hirschberg, H. G. 1966 *Kältermittel.* Verlag C. F. Müller, Karlssruhe.