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A STUDY OF REFRIGERANT/OIL MIXTURES IN HORIZONTAL TUBE EVAPORATORS

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ABSTRACT

This paper examines the effects of refrigerant/oil mixtures on horizontal tube evaporators. Oil holdup and void fraction data have been collected for smooth, axially grooved, and 18° helically grooved tube evaporators at a variety of mass fluxes and qualities. This data will be discussed and compared to results of tests run with pure refrigerants to see how oil affects refrigerant charge.

INTRODUCTION

The primary goal of this project is to investigate the effect of oil holdup on refrigerant heat transfer, pressure drop, and void fraction during evaporation. Several different tube and flat plate geometries are being tested with different oil and refrigerant combinations. The data collected from these tests will be compared to models developed for pure refrigerants to show how different oil and refrigerant combinations, oil viscosities, and oil concentrations affect void fraction, heat transfer, and pressure drop in evaporators. Oil holdup and void fraction results from tests conducted in smooth and enhanced horizontal tubes using RL32S polyol ester (POE) oil in combination with R134a will be presented in this paper.

EXPERIMENTAL APPARATUS

Refrigerant Loop

The refrigerant loop allows the oil/refrigerant mixture to be circulated through the test section at the desired conditions, which includes mass flux, inlet temperature, and inlet quality, by first drawing subcooled liquid into a variable speed gear pump from a condenser (see Figure 1). A speed control connected to the pump and a series of bypass lines are used to adjust the mass flux. Mass flux is determined using a Micro-Motion® mass flow meter. After leaving the flow meter, the oil/refrigerant mixture enters a preheater where heat is added to the mixture to achieve the desired inlet quality. The preheater consists of a serpentine copper tube wrapped in electrical heater strips. Several switches and a 115 volt variac control the amount of heat added to the refrigerant by the heater strips. The oil/refrigerant mixture then enters the test section. After the test section, the mixture flows back into the condenser. A bypass line around the test section allows the mixture to circulate even when the test section is closed during a void fraction measurement. A chiller system is used to remove heat from the condenser and subcool the oil/refrigerant mixture. Details involving the refrigerant loop can be found by referring to Wilson, 1998.

Test Sections

Data has been collected using three horizontal tube test sections, including a smooth tube test section, an axially grooved test section, and an 18° helically grooved test section. All three tubes have an outside diameter of 9.53 mm (3/8"). Other dimensions are given in Wilson, 1998. A schematic of a test section is shown in Figure 1. Each test section is 1.52 m (5 ft) long, and has a shutoff (ball) valve on each end of the tube. Outside of the shutoff valves are spring lock quick disconnects. Inside of the shutoff valves are two pressure taps located 1.22 m (4 ft) apart. A void fraction tap is located next to the left pressure tap. A group of four thermocouples is soldered to the tube every 30.5 cm (12 in). In each group of four thermocouples, one is placed every 90°. Five electric heater strips of equal resistances are wrapped around the tube and thermocouples to allow a uniform heat flux to be applied to the test section.

Instrumentation and Data Acquisition

All temperature measurements are made with type T copper/constantan thermocouples. Three strain gage absolute pressure transducers are used to read the pump inlet pressure, the preheater inlet pressure, and the test section pressure. A differential pressure transducer is used to measure the pressure drop in the test section. Mass flow rate is read with a Micro-Motion® mass flow meter. Two power transducers are used to measure the heat input to the preheater. One additional power transducer is used to determine the heat flux into the test section. All of the instruments are monitored and logged using a Hewlett Packard data acquisition system.

EXPERIMENTAL PROCEDURE

Test Matrix

Void fraction and oil holdup data has been collected using ICI's EMKARATE® RL32S POE oil in combination with R134a. Testing was done at low (0.2-0.4%) and high (3-5%) loop oil concentrations. The evaporator test loop was operated with mass fluxes ranging from 75 to 500 kg/m^2s and test section inlet qualities from 10 to 70%. All tests were conducted with a test section inlet temperature of 5° C, while test section heat fluxes were varied from 0 to10 kW/m^2.

Oil Concentration Measurement

Before each void fraction data point is taken, the mass flux, test section inlet quality, and the test section inlet temperature are brought to test conditions and an oil concentration measurement is taken. In order to measure the oil concentration, a small sampling cylinder is evacuated and weighed. It is then cooled to below 0° C in dry ice/acetone slurry. Once the cylinder is colder than the subcooled liquid in the test loop, the cylinder is attached to a tap in between the flow meter and the preheater. Approximately 100 grams of subcooled oil/refrigerant mixture is drawn into the sampling cylinder and the cylinder is removed from the loop and weighed. The refrigerant is then allowed to boil off leaving pure oil. The oil concentration is determined by evacuating and weighing the cylinder, and dividing the mass of oil left in the cylinder by the refrigerant mass.

Void Fraction Measurement

After a test section is built, it is evacuated and weighed to find its base mass, and its volume is determined. The volume is determined by charging the test section with different gases such as nitrogen, R134a vapor, and R22 vapor. By knowing the pressure, temperature, and mass of the gas in the test section, the ideal gas law can be used to find the volume. Once the test loop has been brought to the proper conditions and the oil concentration sample has been taken, a void fraction measurement is performed. First, the valves on the two pressure taps are closed. The ball valves on the ends of the test section are then shut simultaneously and the bypass line is opened to allow the mixture to continue to circulate throughout the test loop. All insulation is then removed from the test section and the thermocouples and heater strips are disconnected. The spring lock quick disconnects are then undone and the test section is removed. Before weighing, the test section is wiped down to ensure that there is no water condensation on the outside of the test section. The test section is then weighed to determine the total charge in the evaporator. After the test section is weighed, the refrigerant is bled off and the section is evacuated and re-weighed to measure the oil holdup. The void fraction can then be calculated as follows. The specific volume of the test section (v_{ts}) based on refrigerant mass can be determined by:

$$v_{ts} = \frac{V_{ts}}{m_{ts}} \tag{1}$$

where V_{ts} is the volume of the test section and m_{ref} is the mass of refrigerant in the test section. The specific volume of saturated vapor (v_g) and the specific volume of saturated liquid (v_l) at T_{inlet}=5° C are found and used to calculate the static quality (x_s) in the test section.

$$x_s = \frac{v_{ts} - v_l}{v_{lg}} \qquad (2)$$

Once the static quality is known, the void fraction (α) can be determined from the following relation:

$$\alpha = \left[\left(\frac{1 - x_s}{x_s}\right)\frac{v_l}{v_g} = 1\right]^{-1} \qquad (3)$$

RESULTS

The oil holdup results for low and high oil concentrations at adiabatic and heat flux conditions are presented in Figures 2-9. At low loop oil concentrations, the oil holdup decreases as quality increases (Figures 2-4). This is probably because the oil is dissolved in the liquid refrigerant and there is less liquid moving through the tube at higher qualities. This same trend is not necessarily true at higher oil concentrations as shown in Figures 5 and 6. The oil holdup appears to dip at mid qualities. One possible explanation for this is that at low qualities the flow is stratified and the liquid has trouble wetting the top of the tube, allowing oil to collect there. The flow at mid qualities is annular and washes the oil off the tube surfaces. At high qualities the flow is still annular but may be more viscous and oily, leaving a higher oil holdup. A higher oil holdup at high qualities occurs in the high oil concentration heat flux data, as seen in Figure 8, but the mid quality dip is not as apparent. Still, in the high concentration adiabatic case, it is hard to tell if the trend seen in Figure 7 is due to the differing loop oil concentrations between points. Higher loop oil concentration does appear to give a higher oil holdup, as in Figure 9, while mass flux and tube geometry do not seem to significantly affect oil holdup.

Refrigerant void fraction measurements for all three tube types at high and low test loop oil concentrations with and without heat flux have been compared to void fraction results for pure refrigerants (Graham, 1999) in Figure 10. The oil has little effect on void fraction even at high oil concentrations, where there is significant oil holdup.

Conclusions

The results found thus far in this project tend to show that mass flux and tube geometry have little effect on oil holdup and oil holdup does not significantly affect void fraction. There seem to be differing trends occurring between low and high loop oil concentrations, and between adiabatic and heat flux conditions at high oil concentrations. More data is needed to further analyze these differences. As this project continues, data will be collected with different refrigerant/oil mixtures in horizontal tubes and flat plate evaporators to help show the effect of different viscosity oils in evaporators.

ACKNOWLEDGEMENTS

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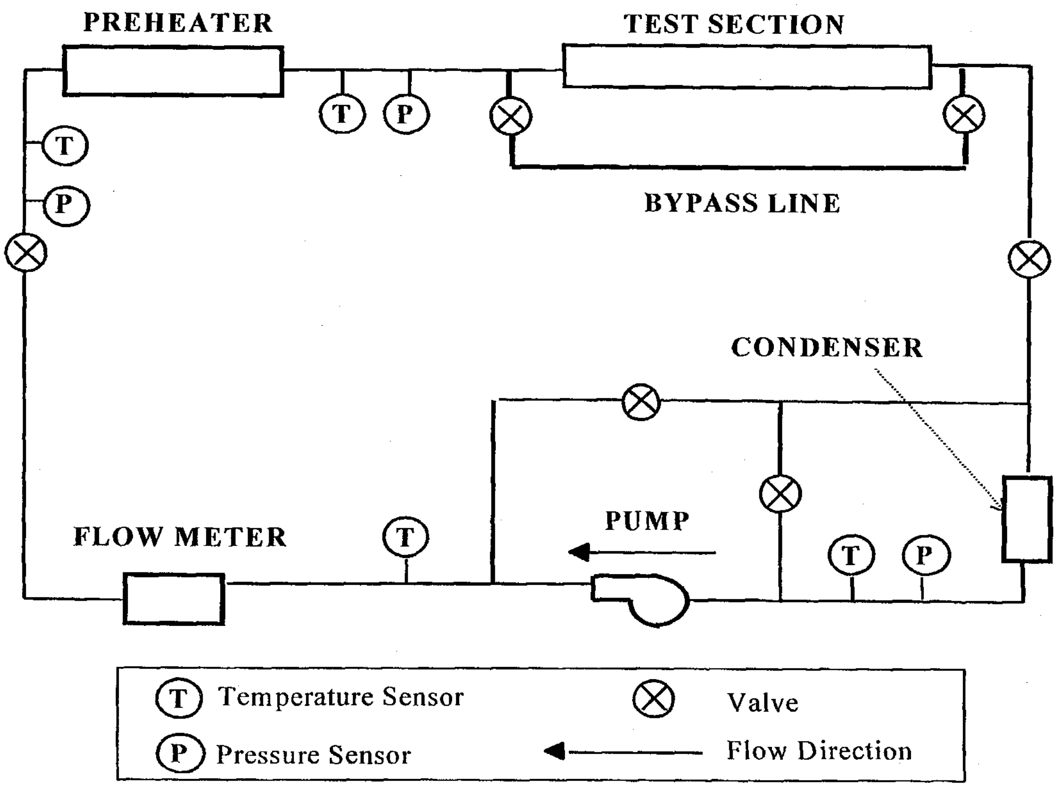

Figure 1: Schematic of Refrigerant Loop

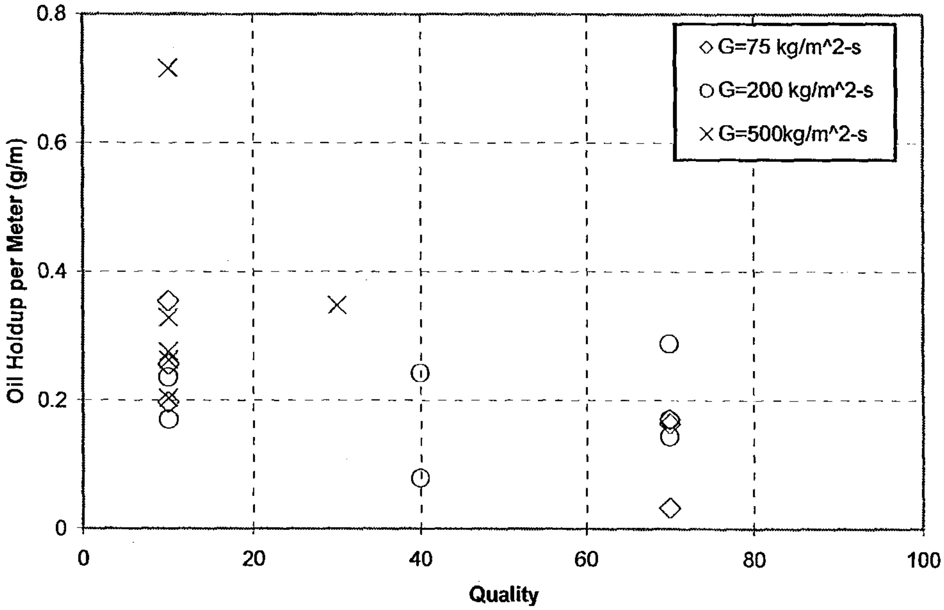

Figure 2: Oil Holdup per Meter vs. Quality at Adiabatic and Low Oil Concentrations - Separated by Mass Flux

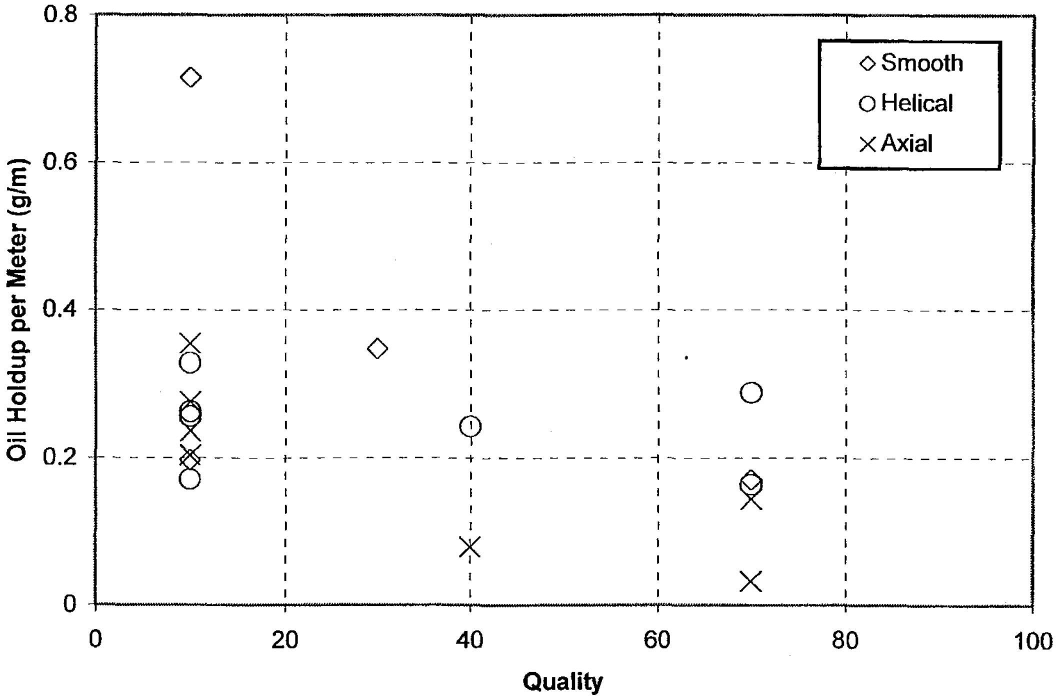

Figure 3: Oil Holdup per Meter vs. Quality at Adiabatic and Low Oil Concentration Conditions - Separated by Tube Geometry

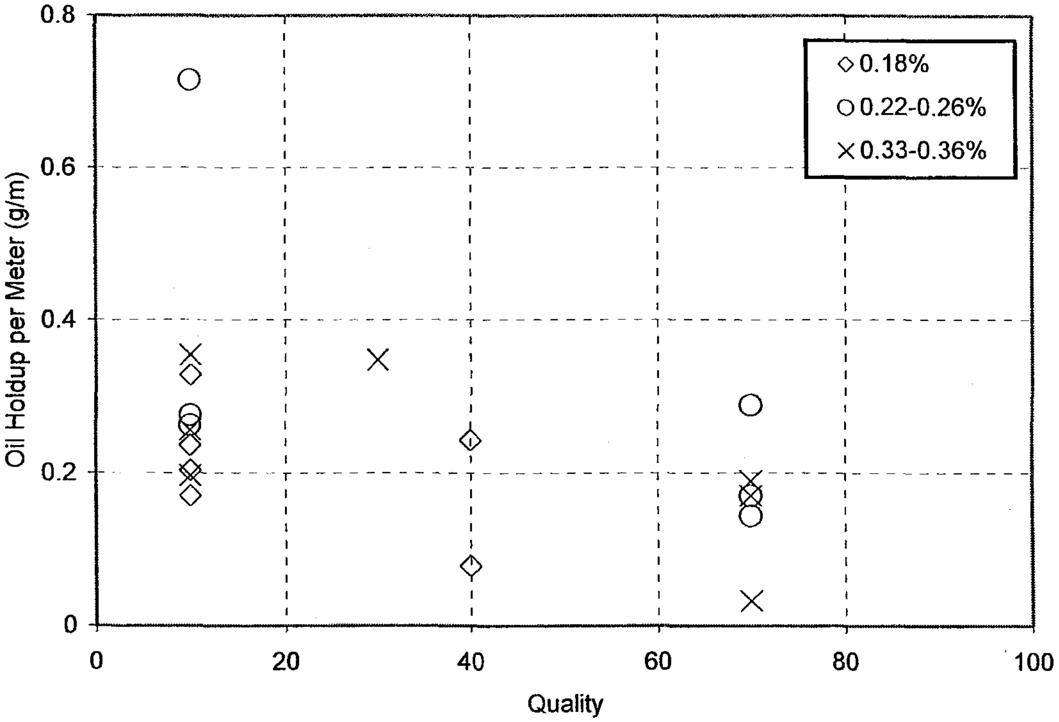

Figure 4: Oil Holdup per Meter vs. Quality at Adiabatic and Low Oil Concentration Conditions - Separated by Oil Concentration

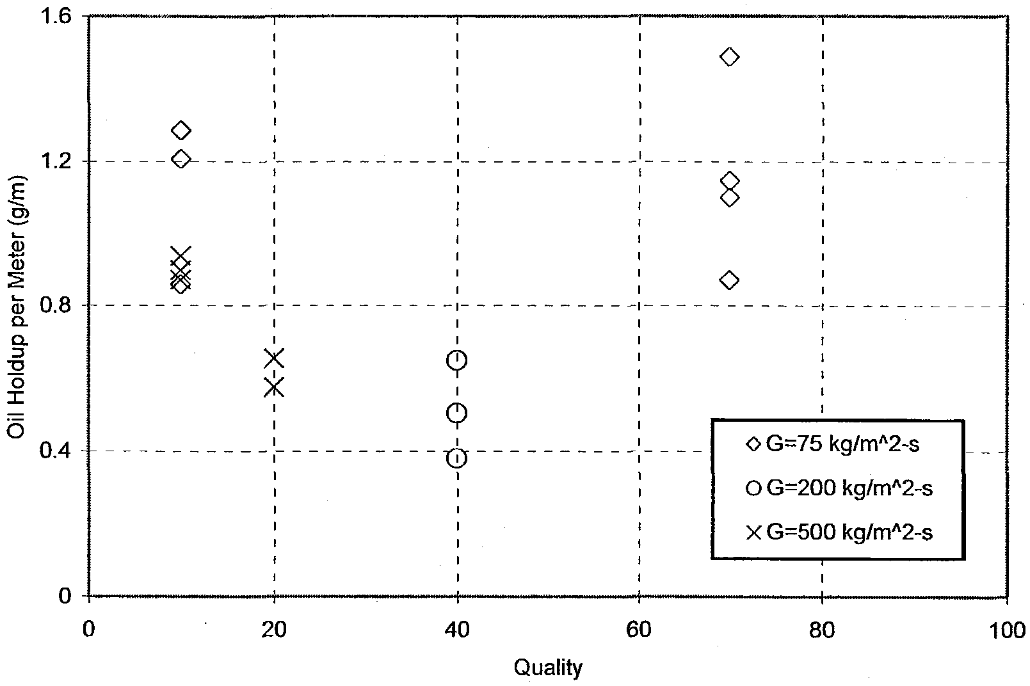

Figure 5: Oil Holdup per Meter vs. Quality at Adiabatic and High Oil Concentration Conditions - Separated by Mass Flux

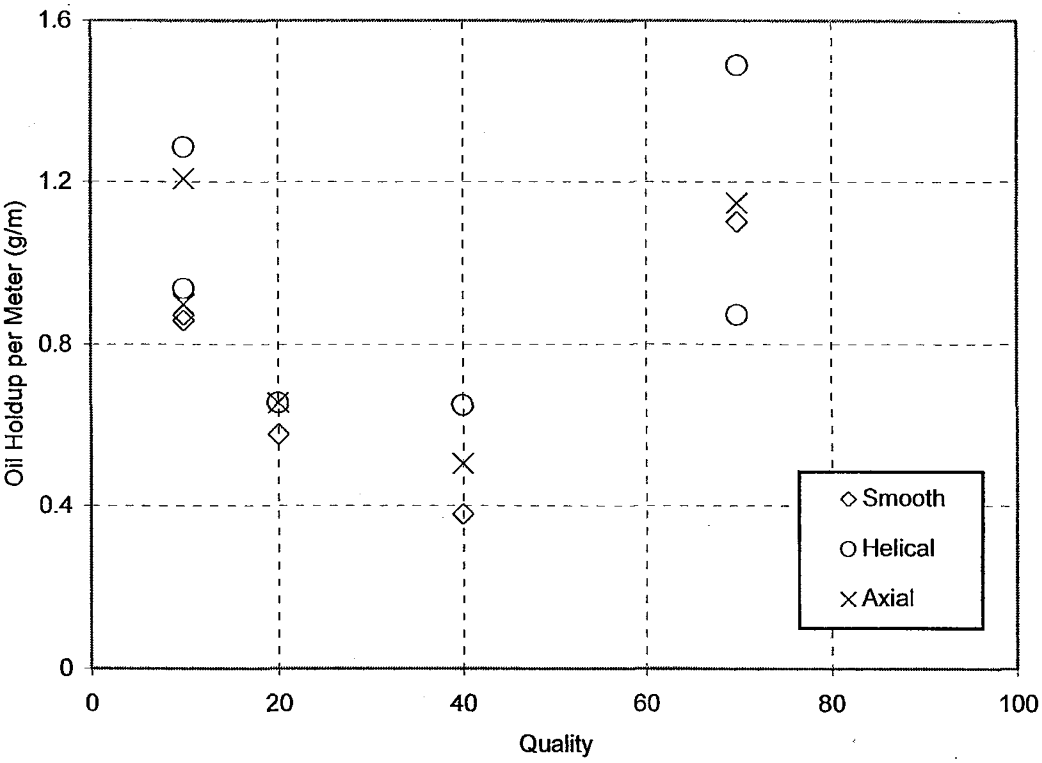

Figure 6: Oil Holdup per Meter vs. Quality at Adiabatic and High Oil Concentration Conditions. - Separated by Tube Geometry

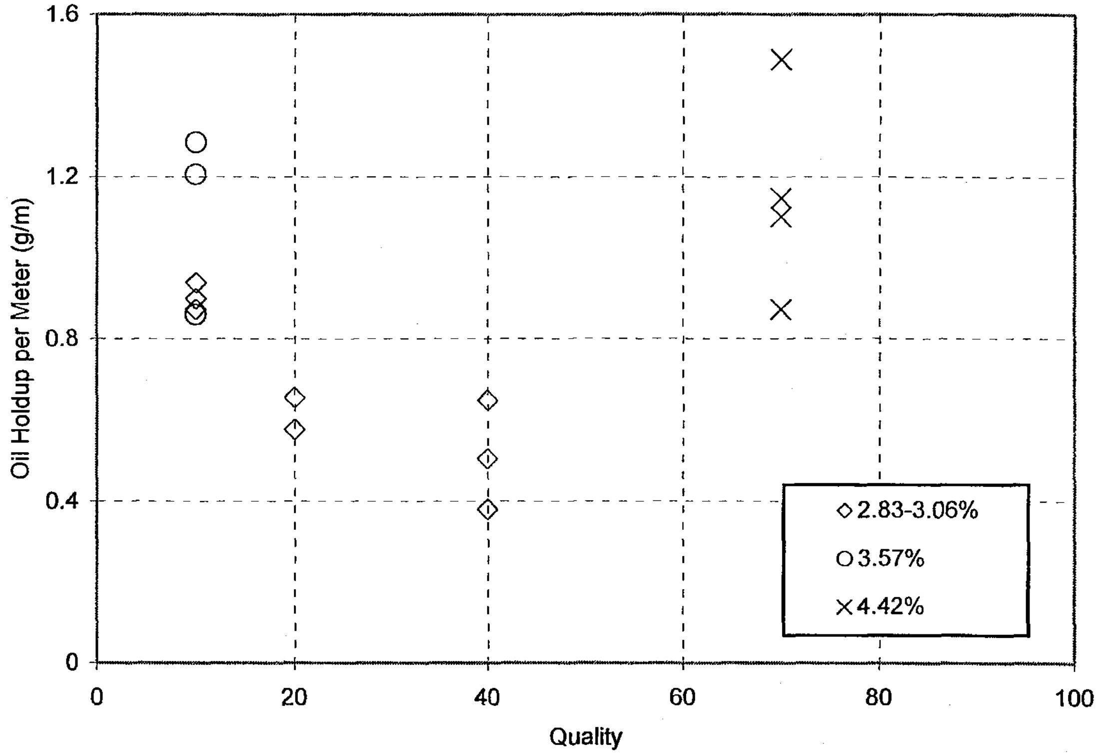

Figure 7: Oil Holdup per Meter vs. Quality at Adiabatic and High Oil Concentration Conditions - Separated by Oil Concentration

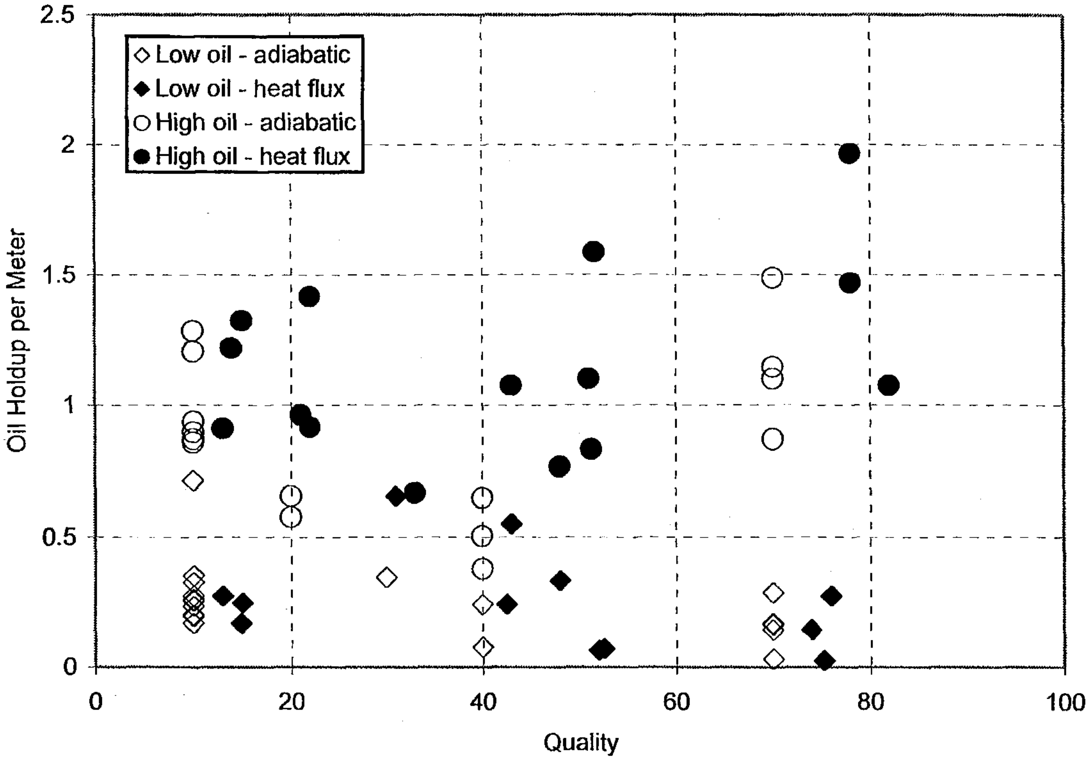

Figure 8: Oil Holdup per Meter vs. Quality - Separated by Oil Concentration and Heat Flux

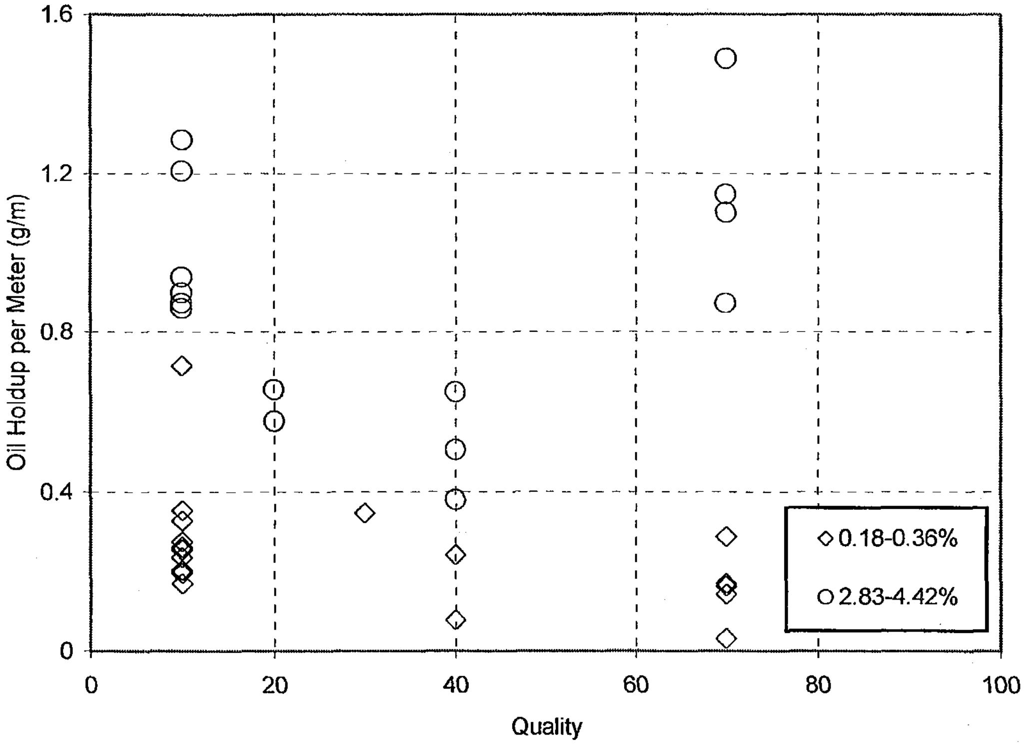

Figure 9: Oil Holdup per Meter vs. Quality at Adiabatic Conditions - Separated by High and Low Oil Concentrations

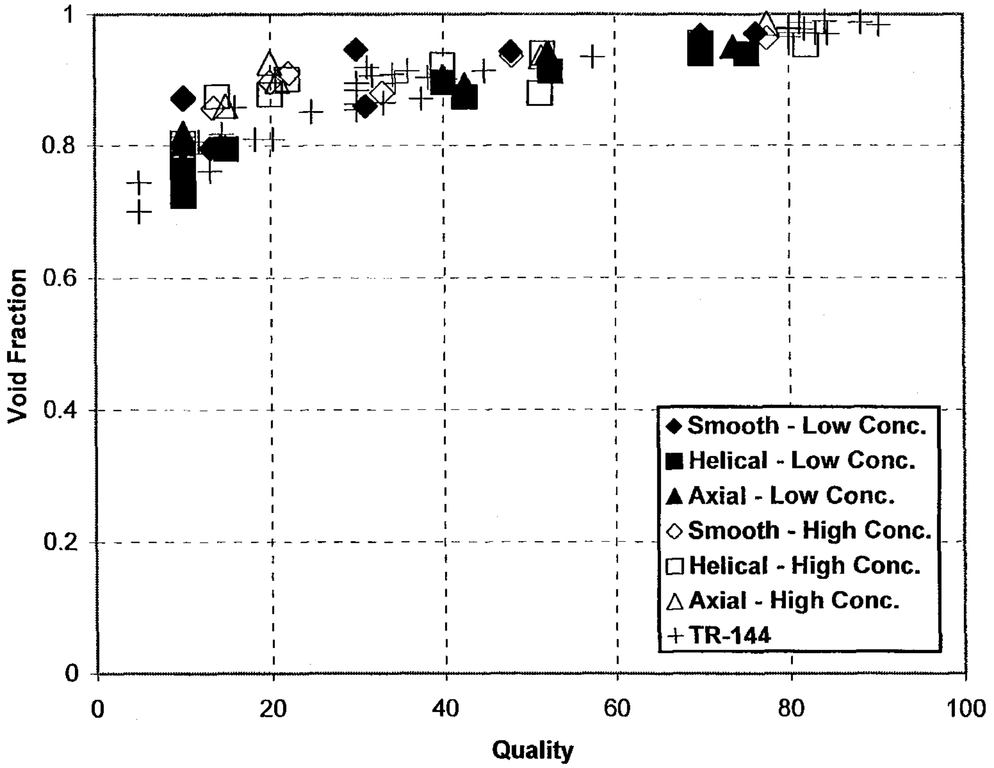

Figure10: Void Fraction vs. Quality, Oil Data Compared to Pure Data (TR-144)