The Effect of Oil on Condensation in a Microfinned Tube

K. A. Sweeney, J. C. Chato, M. Ponchner, and N. L. Rhines

ACRC TR-87

October 1995

For additional information:

Air Conditioning and Refrigeration Center
University of Illinois
Mechanical & Industrial Engineering Dept.
1206 West Green Street
Urbana, IL 61801

(217) 333-3115

Prepared as part of ACRC Project 37
Effect of Geometric Variables and R-22 Alternatives
on Refrigerant-Side Evaporation and Condensation
J. C. Chato, Principal Investigator

The Air Conditioning and Refrigeration Center was founded in 1988 with a grant from the estate of Richard W. Kritzer, the founder of Peerless of America Inc. A State of Illinois Technology Challenge Grant helped build the laboratory facilities. The ACRC receives continuing support from the Richard W. Kritzer Endowment and the National Science Foundation. The following organizations have also become sponsors of the Center.

Acustar Division of Chrysler
Amana Refrigeration, Inc.
Brazeway, Inc.
Carrier Corporation
Caterpillar, Inc.
Delphi Harrison Thermal Systems
Eaton Corporation
Electric Power Research Institute
Ford Motor Company
Frigidaire Company
General Electric Company
Lennox International, Inc.
Modine Manufacturing Co.
Peerless of America, Inc.
U. S. Army CERL
U. S. Environmental Protection Agency
Whirlpool Corporation

For additional information:

Air Conditioning & Refrigeration Center
Mechanical & Industrial Engineering Dept.
University of Illinois
1206 West Green Street
Urbana IL 61801

217 333 3115

The Effect of Oil on Condensation in a Microfinned Tube

Abstract

The effects of an ester oil, in concentrations up to 5% by mass, on the behavior of R-134a condensing in a microfinned tube with an 18° helix angle were studied experimentally.

The flow patterns were only minimally affected with some indication that a shift from wavy towards annular flow may be caused by the oil at the low mass fluxes. The heat transfer followed similar trends due to the presence of oil in a microfinned tube as those that occurred in a smooth tube. At low qualities there was no significant effect but, as quality increased, the heat transfer in the oil carrying refrigerant began to be depressed compared to the pure refrigerant. At some high quality the heat transfer reached a peak value. Beyond this quality the heat transfer decreased rather rapidly. The oil did not seem to have a large effect on the pressure drop in the test section. Only at the highest qualities were slight increases measured at increased oil concentrations.

Introduction

As the refrigeration and air conditioning industries move toward the future, there is a growing need for enhancing refrigerant side heat transfer. As the industry increases its use of enhanced tubes, more experimental data and analyses will be needed in order to understand the phenomena that occur in these enhanced tubes. Currently, there exists no accurate way to predict the effect of oil in an enhanced tube. The effect of oil on the condensation of R-134a in a smooth tube was reported by several researchers, including Hinde et al. [1992].

In this present study the effect of an ester oil on R-134a in a microfinned tube with an 18° helix angle is researched, in order to obtain information about the local behavior of refrigerant oil mixtures in an enhanced tube. This information is necessary to develop correlations that will be able to predict the behavior of refrigerant oil mixtures during condensation inside microfinned tubes and, consequently, provide a reliable tool for the design of condensers.

Experimental Setup

The experiments in this study were performed using the apparatus described in detail by Ponchner et al. [1995]. The apparatus consists of a refrigerant loop that includes a water cooled, counterflow condenser test section. Refrigerant and oil are circulated through the refrigerant loop by a centrifugal pump. After the pump, the refrigerant is set to the desired conditions by the use of a preheater. The refrigerant-oil mixture then enters the test section. After the refrigerant leaves the test section, it is cooled down to a subcooled liquid by an aftercondenser and a heat exchanger. It is then recirculated through the pump.

The test section in this study is a 3/8" o.d. tube, by Modine Mfg. Co., containing 60 trapezoidal fins, that are arranged helically inside the tube at an angle of 18°. Figure 1 shows cross sections of this tube.

The experiments run here were all at a saturation temperature of 95° F (35° C). Four oil concentration were tested at 0, 1, 3, and 5% oil by weight. Three mass fluxes were tested at each oil concentration: (at) 55, 220, and 295 klbm/ft^2-hr (75, 300, and 400 kg/m^2-s). The range of qualities varied from 15 to 90%. A total of 72 test were run.

Oil Concentration Measurement

The oil was added to the refrigerant loop at the nominal concentration level before each set of experiments. After all of the tests at a certain oil concentration were completed, the oil concentration was measured using the ASHRAE standard procedure. A sample of approximately 1.1 lbm (500 grams) of the refrigerant-oil mixture was added to a container. Then, the refrigerant alone was bled off of the sample, leaving the oil in the container. The amount of oil remaining in the container was weighed, and from this measurement the oil concentration of the sample was calculated. The concentrations for each set of tests were found to be within 4% of the nominal.

Refrigerant-Oil Mixture Properties

In order to accurately measure the heat transfer and pressure drop of oil refrigerant mixtures, correct mixtures properties must be used in the calculations. Many researchers have used mixture equations in order to approximate the effect of oil on the refrigerant properties. Schlager [1988] compared the values obtained with these equations for both thermodynamic and transport properties. He determined that for the small concentrations of oil tested, the difference between the mixture properties (conductivity, density, specific heat, and enthalpy of vaporization) and those of a pure refrigerant was never more than 2%. Therefore, for the experiments conducted in this study, pure refrigerant properties were used as an accurate approximation of the mixture properties. These pure refrigerant properties were provided by the refrigerant manufacturer.

Flow Patterns

Both heat transfer and pressure drop depend on the flow pattern which is controlled primarily by the relative strength of the vapor shear to gravity. Thus, at low mass fluxes and/or vapor velocities (i.e. qualities) gravity dominates and the liquid tends to collect at the bottom of the horizontal tube. The corresponding flow patterns are, in order of increasing mass flux and/or quality: Plug (P), Stratified (S), Wavy (W), Wavy-Annular (WA), and Annular-Wavy (AW). At high mass fluxes and/or qualities the vapor shear dominates and the liquid forms a fairly uniformly distributed annulus around the circumference, or, at the highest velocities, the liquid is torn off the wall in small droplets. The corresponding flow patterns become: Annular (A), Annular-Mist (AM), and Mist (A). Within our range of mass fluxes we never observed stratified flow. This regime was studied, among others, by Chato [1962].

The inlet and outlet flow patterns for each test are given with the data in the Appendix. As these data show, the flow patterns for the lowest mass flux of 55 klbm/ft^2-hr (75 kg/m^2-s) are predominantly wavy (W), whereas for the two high mass fluxes they are predominantly annular (A). Mist flow (AM or M) occurs only at the very highest qualities with the two high mass fluxes. The effect of the oil is not very pronounced and it is somewhat ambiguous. For the lowest mass flux at 5% oil concentration the patterns definitely shifted from wavy to annular, but no consistent shifts can be observed at the higher mass fluxes.

Heat Transfer Results

We found that the trends due to the presence of oil in a microfinned tube followed those that occurred in a smooth tube. In Figs. 2-4 it is apparent that for a pure refrigerant heat transfer increases as quality increases. The qualities shown in the figures represent the average values in the test section. Because the quality has to decrease as heat is removed, the inlet quality is always higher than the outlet quality. The difference between the two is governed primarily by the required accuracy in the measurements, particularly those of the temperature differences. When oil is added to the pure refrigerant, the heat transfer increases with quality until at some high quality it reaches a peak after which it begins to decrease. This peak occurs at a lower quality and its magnitude becomes less as the concentration of oil is increased. At the low mass flux of 55 klbm/ft^2-hr (75 kg/m^2-s), as Fig. 2 illustrates, the peak heat transfer for 1% oil occurs at a quality of approximately 75%. On the other hand, this peak occurs at 70% quality for the 3% oil mixture and at 65% quality for the 5% mixture. At the higher mass fluxes of 220 and 295 klb_m/ft^2-hr (300 and 400 kg/m^2-s), as shown in Figs. 3 and 4, the peaks in heat transfer occur at higher qualities as mass flux increases. As before, the peaks occur at lower qualities and become smaller with increasing oil concentration.

At low qualities the presence of oil did not effect the heat transfer. However, at the lowest mass flux the presence of oil reduced the Nusselt number by about 14%, starting around 20% quality. At the higher mass fluxes the reduction of the Nusselt number started at higher qualities and was a much more gradual effect. In general, as the concentration of oil increased, the heat transfer decreased from that of the pure refrigerant. As to be expected, the mixture which contained only 1% oil deviated the least from the heat transfer of the pure fluid, while the mixture with a 5% oil concentration deviated the most. This decrease became larger as quality increased. Figures 3 and 4 show that at higher mass fluxes the degradation in heat transfer becomes less apparent and that the decrease does not occur until higher qualities are achieved. For a mass flux of 55 klb_m/ft^2-hr (75 kg/m^2-s), the degradation starts, rather abruptly, as early as 20% quality. On the other hand, the degradation starts at a quality of 40% for a mass flux of 220 klb_m/ft^2-hr (300 kg/m^2-s) and at 55% for a mass flux of 295 klb_m/ft^2-hr (400 kg/m^2-s).

Pressure Drop Results

For the experiments conducted here, pressure drop data could only be obtained for the higher mass fluxes tested. For the lowest mass flux of 55 klb_m/ft^2-hr (75 kg/m^2-s), the pressure drop was too low to be measured accurately with the existing equipment. The highest mass flux obtainable was 295 klb_m/ft^2-hr (400 kg/m^2-s), due to the large cross sectional area of the enhanced tube.

In Figures 5 and 6 it is shown that for both mass fluxes of 220 and 295 klb_m/ft^2-hr (300 and 400 kg/m^2-s) the addition of oil does not seem to have a large effect on the pressure drop in the test section. The only effect indicated is that at high qualities there is a slight increase in the pressure drop with the addition of oil. At a mass flux of 220 klb_m/ft^2-hr (300 kg/m^2-s), this increase occurs above a quality of approximately 65% quality. At the higher mass flux of 295 klb_m/ft^2-hr (400 kg/m^2-s) this increase moved to a quality of 75%.

Conclusions and Recommendations

Overall, it was found that the addition of oil to a pure refrigerant degraded the heat transfer during condensation. This degradation varied as a function of quality, mass flux, and the amount of oil added to the refrigerant. The degradation was generally more pronounced at the low mass flux and at the higher qualities for all mass fluxes. Increasing the oil concentration also increased the degradation.

The oil had very minimal effects on the pressure drop which increased with increasing oil concentrations only at the highest qualities. The effect of the oil on the flow patterns was discernible only at the lowest mass flux and the highest oil concentration where a shift from wavy to annular occurred.

Because of the complicated behavior generated by the microfins in the tubes, a large amount of testing will be needed in order to fully understand the effect of the fin geometry, spacing, size and placement on the heat transfer and pressure drop. To develop correlations that will predict the heat transfer and pressure drop of refrigerant-oil mixtures in microfinned tubes, the behavior of the mixture must first understood. The experiments conducted here reveal the trends that occur during condensation of refrigerant-oil mixtures and should contribute to the development of such correlations.

References

Chato, J.C.,"Laminar Condensation Inside Horizontal and Inclined Tubes, 1962," ASHRAE Journal, Vol. 4 (2), pp. 52-60.

Hinde, D.K., M.K. Dobson, J.C. Chato, M.E. Mainland, and N.L Rhines, 1992, "Condensation of Refrigerants 12 and 134a in Horizontal Tubes With and Without Oils," ACRC Technical Report-26, University of Illinois at Urbana-Champaign.

Ponchner, M., J.C. Chato, K.A. Sweeney, et al, 1995,"Condensation of HFC-134a in an 18° Helix Angle Micro-finned Tube," ACRC Technical Report-75, University of Illinois at Urbana-Champaign.

Schlager L.M., 1988, "The Effect of Oil on Heat Transfer and Pressure Drop During Evaporation and Condensation of a Refrigerant Inside Augmented Tubes," Ph.D. Dissertation, Dept. of Mechanical Engineering, Iowa State University, Ames, IA.

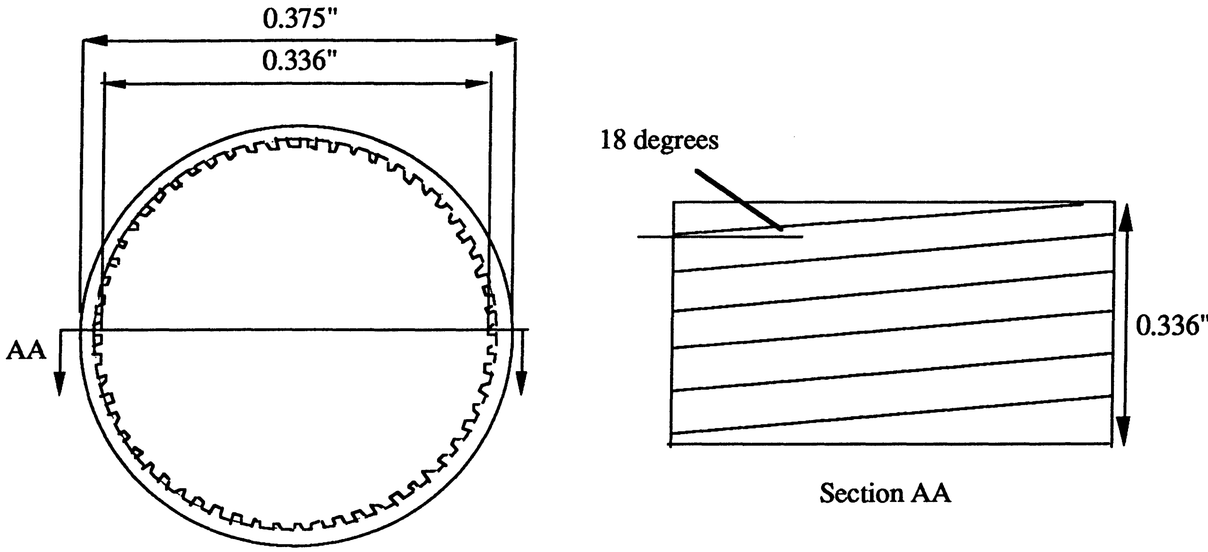

Figure 1. Cross Sections of the Microfinned Tube

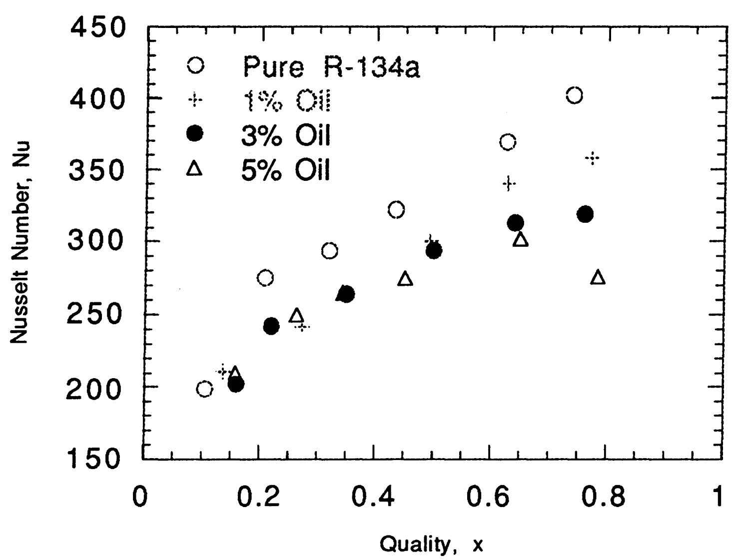

Figure 2: Effect of Oil Concentration on Heat Transfer for
G=55 klb_m/ft^2-hr (75 kg/m^2-s)

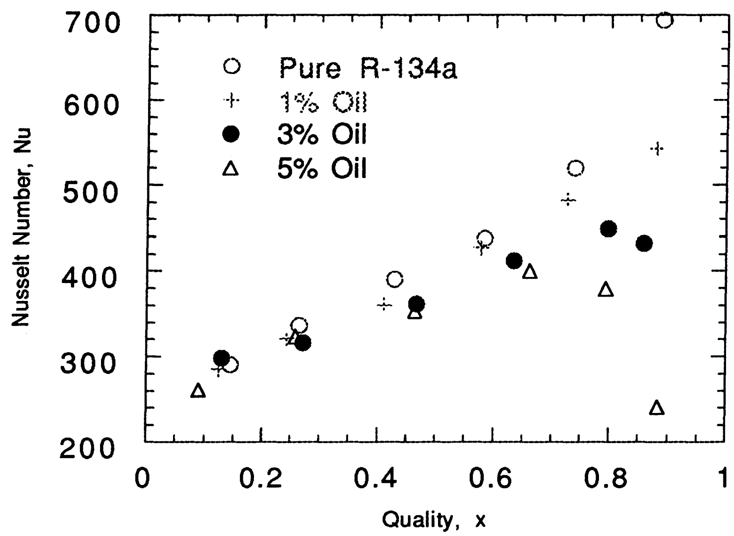

Figure 3: Effect of Oil Concentration on Heat Transfer for $G=220\ klb_m/ft^2\text{-}hr$ ($300\ kg/m^2\text{-}s$)

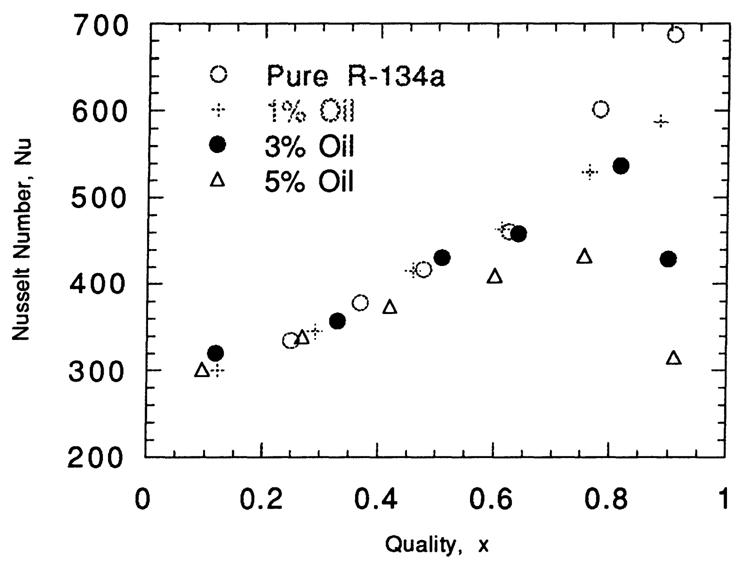

Figure 4: Effect of Oil Concentration on Heat Transfer for $G=295\ klb_m/ft^2\text{-}hr$ ($400\ kg/m^2\text{-}s$)

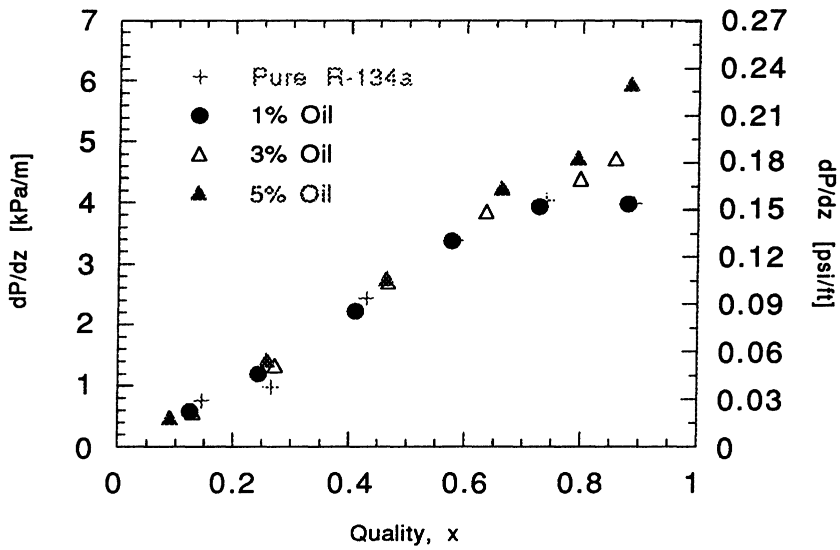

Figure 5: Effect of Oil Concentration on Pressure Drop per Unit Length for G=220 klb_m/ft^2-hr (300 kg/m^2-s)

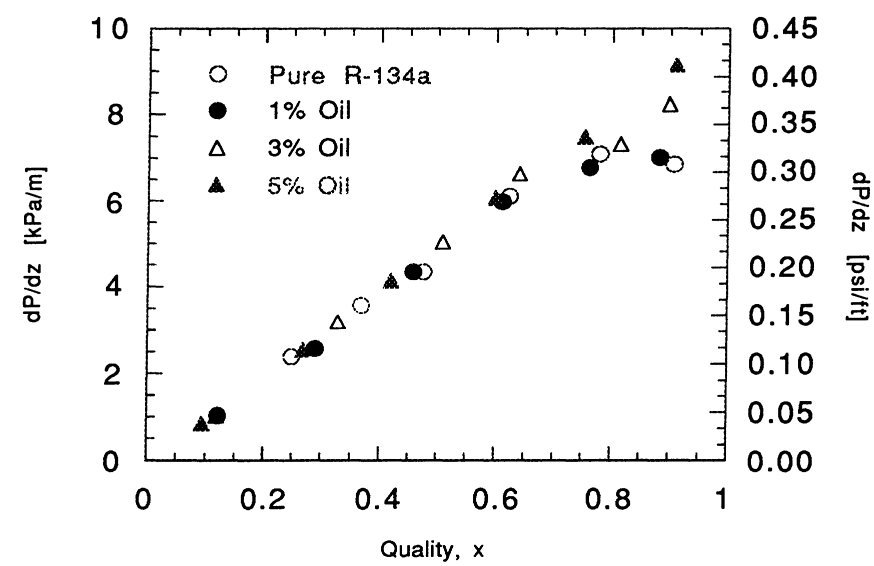

Figure 6: Effect of Oil Concentration on Pressure Drop per Unit Length for G=295 klb_m/ft^2-hr (400 kg/m^2-s)

Appendix: Data

The data collected for this study are listed here in SI units, in which they were collected.

The flow pattern symbols are:

P=Plug, W=Wavy, WA=Wavy-Annular, AW=Annular-Wavy, A=Annular, M=Mist

A combination of two letters indicates that the flow exhibited characteristics of both patterns. The pattern listed first was the dominant one.

Mass Flux [kg/m^2-s]	Percent Oil [%]	Xavg	ΔX	Tsat-Twall [C]	h [W/m^2-K]	Nu	DP [kPa]	Flow Pattern Inlet-Outlet
72.9	0.0	0.11	0.21	2.07	1750	199	0.10	W-P
77.6	0.0	0.21	0.23	1.76	2425	275	0.00	W-W
77.0	0.0	0.32	0.29	2.01	2573	294	0.00	WA-W
75.8	0.0	0.43	0.34	2.14	2821	322	0.00	WA-W
71.4	0.0	0.63	0.37	1.94	3230	369	0.00	A-W
74.3	0.0	0.74	0.35	1.74	3536	402	0.00	A-W
298.6	0.0	0.14	0.08	2.16	2553	290	0.90	A-W
297.9	0.0	0.26	0.09	2.03	2956	336	1.71	A-WA
296.4	0.0	0.43	0.09	1.86	3435	390	2.92	A-A
297.2	0.0	0.58	0.09	1.71	3848	438	4.06	A-A
299.6	0.0	0.74	0.10	1.60	4580	520	4.83	AM-AM
300.9	0.0	0.89	0.13	1.49	6088	693	4.77	M-AM
399.0	0.0	0.25	0.06	2.03	2948	335	2.86	A-WA
397.8	0.0	0.37	0.07	1.91	3331	378	4.27	A-A
398.1	0.0	0.48	0.07	1.92	3663	417	5.45	AM-A
398.5	0.0	0.62	0.08	1.83	4058	461	7.31	M-AM
396.5	0.0	0.78	0.09	1.64	5296	601	8.50	M-AM
398.6	0.0	0.91	0.10	1.56	6045	687	8.16	M-M
73.4	1.0	0.14	0.23	2.12	1860	211	0.00	W-W
71.8	1.0	0.27	0.26	2.10	2130	242	0.00	W-W
76.2	1.0	0.49	0.27	1.82	2644	300	0.00	AW-W
76.0	1.0	0.63	0.31	1.83	2994	340	0.00	A-W
76.0	1.0	0.77	0.31	1.74	3161	358	0.00	A-WA
296.5	1.0	0.13	0.07	1.84	2505	285	0.70	WA-W
301.0	1.0	0.24	0.07	1.86	2828	321	1.43	A-WA
297.0	1.0	0.41	0.09	2.03	3171	360	2.65	A-AW
300.7	1.0	0.58	0.10	1.89	3763	427	4.04	A-A
297.7	1.0	0.73	0.11	1.86	4251	482	4.72	AM-A
297.6	1.0	0.88	0.12	1.72	4798	543	4.77	M-AM
396.8	1.0	0.12	0.05	1.96	2637	300	1.23	AW-WA
395.2	1.0	0.29	0.06	1.91	3030	345	3.09	AW-WA
395.6	1.0	0.46	0.06	1.64	3662	416	5.21	A-A
399.3	1.0	0.61	0.07	1.63	4085	464	7.16	A-A
394.0	1.0	0.76	0.08	1.56	4666	530	8.12	A-A
398.1	1.0	0.88	0.09	1.72	5169	587	8.40	AM-A

Mass Flux [kg/m^2-s]	Percent Oil [%]	Xavg	ΔX	Tsat-Twall [C]	h [W/m^2-K]	Nu	DP [kPa]	Flow Pattern Inlet-Outlet
74.9	3.0	0.16	0.20	1.96	1776	202	0.00	W-W
74.9	3.0	0.22	0.26	2.17	2125	242	0.00	W-W
75.1	3.0	0.35	0.29	2.23	2325	264	0.00	W-W
76.0	3.0	0.50	0.30	2.10	2593	294	0.00	W-W
77.3	3.0	0.64	0.33	2.19	2767	313	0.00	WA-W
75.7	3.0	0.76	0.33	2.09	2810	319	0.00	WA-W
298.6	3.0	0.13	0.07	1.82	2621	298	0.57	AW-A
297.7	3.0	0.27	0.08	2.03	2776	316	1.33	A-W
296.6	3.0	0.47	0.08	1.79	3186	361	2.70	A-A
300.7	3.0	0.64	0.09	1.80	3633	412	3.85	A-A
301.2	3.0	0.80	0.10	1.79	3954	449	4.39	A-A
304.8	3.0	0.86	0.09	1.69	3802	432	4.72	AM-A
405.8	3.0	0.12	0.06	1.93	2817	320	1.02	A-AW
399.1	3.0	0.33	0.06	1.83	3152	357	3.18	A-A
402.3	3.0	0.51	0.07	1.75	3805	431	5.04	A-A
404.0	3.0	0.64	0.07	1.71	4057	459	6.62	A-A
398.3	3.0	0.82	0.09	1.72	4723	537	7.32	A-A
405.6	3.0	0.90	0.06	1.65	3777	429	8.26	A-A
75.6	5.0	0.16	0.22	2.11	1850	210	0.00	W-W
75.6	5.0	0.26	0.28	2.30	2196	250	0.32	W-W
80.7	5.0	0.34	0.26	2.08	2310	265	0.00	W-W
78.9	5.0	0.45	0.28	2.14	2392	275	0.00	A-W
76.9	5.0	0.58	0.24	1.79	2459	277	0.00	A-W
77.1	5.0	0.65	0.26	1.75	2675	302	0.00	A-W
75.3	5.0	0.78	0.30	2.19	2440	276	0.00	A-AW
294.6	5.0	0.09	0.07	2.22	2294	261	0.48	WA-WA
301.0	5.0	0.26	0.07	1.77	2847	323	1.42	A-AW
297.4	5.0	0.46	0.07	1.69	3102	353	2.75	A-A
302.9	5.0	0.66	0.07	1.52	3524	400	4.24	A-A
301.7	5.0	0.79	0.08	1.64	3334	379	4.73	A-A
308.6	5.0	0.88	0.04	1.50	2130	241	5.94	A-A
404.4	5.0	0.10	0.06	2.07	2638	301	0.85	A-WA
398.9	5.0	0.27	0.06	1.97	2992	339	2.54	A-AW
398.8	5.0	0.42	0.07	2.05	3295	374	4.14	A-A
399.5	5.0	0.60	0.07	1.91	3624	410	6.07	A-A
399.0	5.0	0.75	0.07	1.83	3825	433	7.49	A-A
397.3	5.0	0.91	0.04	1.51	2777	315	9.15	AM-A