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Condensation of Refrigerant-11 on the Outside of Vertical Enhanced Tubes

N. Domingo

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Engineering Technology Division

**CONDENSATION OF REFRIGERANT-11 ON THE OUTSIDE
OF VERTICAL ENHANCED TUBES**

N. Domingo

Date Published: August 1981

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$\frac{1}{\sqrt{\pi}} \int_{-\infty}^{\infty} f(x) e^{-x^2} dx = \frac{1}{\sqrt{\pi}}$

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LIST OF SYMBOLS

a_0	y-intercept on the Wilson plot representing the composite resistance of the condensing side and wall, Eq. (4.12)
a_1	slope of the line on the Wilson plot
A	heat transfer surface area of test tube
A_c	cross-sectional flow area of the annulus in the test section
A_o	outside surface area of test tube
c_p	specific heat
D	tube diameter
D_r	diameter of rod inserted through center of test section
F	volume flow rate
h	average or mean individual heat transfer coefficient
h_{fg}	latent heat of vaporization
h_v	condensing heat transfer coefficient on the vapor side
h_c	composite condensing heat transfer coefficient including both the wall and the condensing film
k	thermal conductivity
L	tube length
$\dot{m}$	mass flow rate
P	pressure
Q	heat load
Q/A	heat flux
r	radius
R	resistance to heat flow
Re	Reynolds number
T	temperature
ΔT	temperature difference

$\overline{\Delta T}$	mean temperature difference between the condensing vapor and coolant
ΔT_c	composite temperature difference including both condensing film and wall
U	overall condensing heat transfer coefficient
v	water velocity

Greek Symbols

Δ	finite difference
ρ	mass density

Subscripts

avg	average
c	condensate
fi	inside fouling
fo	outside fouling
i	inside
in	inlet
o	outside
out	outlet
sat	saturation
v	vapor; vapor (condensing) side
w	water; water side
wall	wall; surface

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CONDENSATION OF REFRIGERANT-11 ON THE OUTSIDE OF VERTICAL ENHANCED TUBES

N. Domingo

ABSTRACT

Experiments were conducted to determine heat transfer performance of single vertical tubes with Refrigerant-11 condensing on its outside surface. Twelve enhanced (fluted, spiraled, roped, and corrugated) tubes of 2.54-cm (1-in.) nominal outside diameter and 1.2-m (4-ft) length were tested. Several of the tested tubes featured internal enhanced geometries. A previously tested smooth tube served as the basis for comparison.

Composite heat transfer coefficients (coefficients that include the resistances of both the condensing film and the tube wall), based on the total tube outside surface area, ranged from 850 to 6,530 $\text{W/m}^2\cdot\text{K}$ (150 to 1,150 $\text{Btu/h}\cdot\text{ft}^2\cdot^\circ\text{F}$) over the heat flux range of 5,675 to 31,375 W/m^2 (1,800 to 9,950 $\text{Btu/h}\cdot\text{ft}^2$). The primary conclusions from this study are: (1) for a given heat flux, an external fluted tube can increase composite condensing heat transfer coefficients by up to 5.5 times the smooth tube values, giving better condensing performance than any of the other geometries tested; (2) further increase in composite condensing coefficients can be achieved by using skirts to divide the fluted tube into equal condensing lengths; and (3) for a given overall temperature difference and water flow rate, internal flutes can increase the overall performance by up to 17% over that for a tube with identical outside flutes and a smooth inside surface.

---

1. INTRODUCTION

Fundamental to all heat power systems is the condition that a portion of the heat supplied to the cycle must be rejected. In a geothermal power plant, using a Rankine cycle, where the relatively low temperature heat source inherently yields a low thermal efficiency, the amount of heat rejected per kilowatt-hour of output is three to six times greater than that of a fossil- or nuclear-fueled power plant.¹

This condition is further complicated in geothermal power cycles using a secondary working fluid, typically a fluorocarbon or hydrocarbon. In these binary cycles, the temperature of heat addition from

the geothermal fluid to the secondary working fluid tends to be lower, thereby increasing the amount of heat rejected per kilowatt-hour of output. The waste heat is also more difficult to reject, because the condensing film coefficients for these secondary working fluids are quite low. Therefore, in an energy conversion system using such secondary fluids, the heat exchangers would be relatively large and would constitute a major part of the total system capital costs.

Improvements in heat exchanger thermal performance can result in substantial cost reductions and will favorably affect the overall feasibility of developing the geothermal resource. One method for improving the condensing heat transfer characteristics of heat exchangers is through the use of enhanced surfaces to increase heat transfer coefficients. Achieving higher condensing coefficients is significant to heat exchanger design, because the condensing film resistance can be dominant in a conventional smooth tube heat exchanger utilizing fluorocarbons or hydrocarbons.

Earlier studies^{2,3} at Oak Ridge National Laboratory (ORNL) investigated the performance of vertical tubes with enhanced outside surfaces on which various fluorocarbons, ammonia, and isobutane were condensed. With fluorocarbons or isobutane as the working fluid, condensing heat transfer coefficients improved by factors up to 6 to 7 times that of a smooth tube, depending on the fluid properties, tube geometries, and heat flux. These experiments and field data produced the design parameters from which prototype condensers for geothermal applications have been built and tested.^{4,5}

Like earlier ORNL studies, this report presents experimental data for Refrigerant-11 (R-11) (trichlorofluoromethane) condensing on a variety of vertical enhanced tubes. This study includes data on the effect of condensing length on heat transfer performance and overall heat transfer data for a double fluted tube. The choice of R-11 as the working medium was based on its advantageous low boiling point and safety-related, nonflammable characteristics. Earlier studies³ had also shown R-11 and isobutane (R-600a) give similar heat transfer performance for a given tube and heat load.

Background material for this study was given in a previous report,³ with detailed descriptions of the equipment, procedures, and instrumentation, all of which remained the same throughout this study. Therefore, only brief descriptions of these items are provided in this report.

2. DESCRIPTION OF EQUIPMENT

The equipment used in this investigation is shown schematically in Fig. 2.1 and is presented in an overall view in Fig. 2.2. The system (designed for a maximum heat load of 5 kW) consisted of three circuits: working fluid, primary cooling, and secondary loops. The working fluid loop was designed for fluorocarbons with the maximum operating pressure and temperature set at 1.65×10^6 Pa (240 psia) and 339 K (150°F). In this study, R-11 was used as the working fluid.

The test section was a single tube vertical condenser made of stainless steel and was built to accommodate tubes of 2.54-cm (1-in.) nominal diameter and 1.2-m (4-ft) length. The system was manually controlled, and the heat load was set by the power output to the boiler. View ports on the condenser module permitted visual observation of the tube's condensing surface, with the aid of a light at suitable locations.

Fig. 2.1. Schematic diagram of experimental apparatus.

Fig. 2.2. Overall view of test facility.

Major components of the ORNL test loop include (1) boiler, (2) entrainment separator, (3) condenser module, and (4) condenser water storage tank and pump. A detailed description of each component was presented in an earlier study³ and, therefore, will not be repeated in this report. Only a brief summary of the general flow description and condenser tube installation will be given in succeeding sections.

2.1 General Flow Description

Flow directions are indicated by arrows in the simplified schematic diagram (Fig. 2.1). The working fluid was vaporized in the boiler and passed through an entrainment separator before entering the condenser test section. The vapor entered at the top of the condenser, and the liquid collected in the separator returned to the boiler. Vapor condensed on the outer surface of the test tube in the test section, exited as a saturated liquid at the condenser bottom, and passed through a condensate measuring station before returning to the bottom of the boiler to complete the closed loop. A pump was not needed for the circulation of R-11 because the liquid head in the test section side of the loop furnished the driving force required for flow through the condensate measuring station.

In the primary cooling loop, demineralized water was circulated by a small centrifugal pump from a storage tank upward through the condenser test section and back to the storage tank. The primary coolant flow was measured by rotameters upstream of the test section and was controlled by a manually operated valve located downstream of the test section.

The secondary cooling loop removed the heat load from the system by transferring the heat from the primary cooling water to the plant process water that circulated through a cooling coil in the storage tank. The secondary coolant flow rates were regulated by manually operated valves and were measured by rotameters located upstream of the cooling coil. Plant process water-line pressure furnished adequate circulation through the secondary cooling loop.

2.2 Condenser Tube and Installation

The heads on the condenser test section (Fig. 2.3) were designed to seal around a smooth 2.54-cm-OD (1-in.) tube. Experimental test tubes, other than a smooth 2.54-cm-OD (1-in.), were prepared by soldering or welding a 2.54-cm (1-in.) sleeve 13.34 cm (5.25 in.) long to each end of a 1.17-m (46-in.) length of tube. For installation, the upper section of the top head was removed and the test tube was inserted downward into the test section until the bottom sleeve slid through the three O-ring seals in the bottom head. The upper section of the top head was then slipped over the top sleeve and bolted to the lower section to complete the shell-side sealing operation. Then, the required connections were made to the primary cooling loop.

A 1.27-cm-OD (0.5-in.) stainless steel rod was installed through the center of the condenser section (inside the test tube) to decrease the hydraulic diameter and to increase the water velocity for a given primary cooling volume flow. Both variations tended to increase the water-side heat transfer coefficients and, as a result, improved the accuracy of the Wilson-plot technique⁶ used to interpret the experimental data.

2.3 Test Tubes

In an earlier report,³ the heat transfer performance of 14 tubes of 6 distinct types was presented for a variety of fluorocarbons (including R-11) condensing vertically on the outside tube wall. Letter designations (A, B, C, D, ..., K) were used to identify these tubes. Other tubes tested were designated by D-1, F-1, F-3, and F-7; these tubes were a variation of tube type D and F created by attaching rubber skirts (Fig. 2.4) to the outside wall (the integer denotes the number of skirts on the tube). The skirts divided the tubes into two, four, or eight equal condensing lengths and aided condensate drainage from the outside tube surface.

Data for 12 additional tubes and the previously tested smooth Tube A are reported in this study. A letter designation and integer notation

Fig. 2.3. Details of condenser test section.

Fig. 2.4. Photograph of a sample test tube with a neoprene skirt attached at midpoint of condensing length.

are also used to identify the tubes. Detailed descriptions and letter designations of the tubes are given in Table 2.1. Enlarged photographs of sample test tubes are presented in Figs. 2.5 through 2.8.

All tubes were made of aluminum except types M (90/10 cupronickel), R (304 stainless steel), S (409 stainless steel), T (carbon steel), and U (aluminum-brass). Tubes L, L-1, and L-3 had a smooth inside surface and 60 external rounded flutes, with zero, one, and three skirts, respectively. Tube L* had 90 internal and 60 external flutes (identical to Tube L). Tubes M and N had roped type surfaces, whereas Tubes O, R, and S featured asymmetrical spiral surfaces. Tube T (similar to Tube E in

Table 2.1. Characteristics of tubes
[Nominal 2.54-cm (1-in.) OD, 1.2-m (4-ft) length]

Tube	Description	Material	External surface area (m ²)	Flutes		Pitch (cm)
				External	Internal	
A	Smooth wall	Aluminum 6061	0.0973	0	0	
L	Precision Extrusions, Inc. (single fluted)	Aluminum 6061	0.1397	60	0	
L*	Precision Extrusions, Inc. (double fluted)	Aluminum 6061	0.1397	60	90	
M	Wolverine Korodense (roped type)	Cupronickel	0.0980 ^a			0.975
N	Wolverine Korodense (roped type)	Aluminum	0.0982 ^a			1.283
O	Turbotec (spiral tube)	Aluminum 3003 H-14	0.1031 ^a			0.991-1.069
R	General Atomic (spiral)	Stainless steel 304	0.1054 ^a			
S	General Atomic (spiral)	Stainless steel 409	0.0985 ^a			^b
T ^c	Grob Inc. (single fluted)	Carbon steel 1010	0.1491	60	0	^d
U	Yorkshire, U.K. (corrugated)	Aluminum-brass	0.1150	24	24	

^a Values for outside surface area were provided by tube manufacturer.

^b Spiral flutes 30° from vertical.

^c This tube was used in fabrication of a 500-kW condenser to be installed at a geothermal test facility in East Mesa, California.

^d Spiral flutes 45° from vertical.

Fig. 2.5. Photographs of tube samples - Tubes A, L, and L*.

Fig. 2.6. Photographs of tube samples — Tubes M and N.

Fig. 2.7. Photographs of tube samples — Tubes O, R, and S.

Fig. 2.8. Photographs of tube samples — Tubes T and U.

Ref. 3) had a smooth inside surface and 60 external squared flutes. Tube U featured a similar internal and external corrugated surface.

Tube A was a standard commercial smooth tube.³ Tubes L and L* were experimental tubes designed by ORNL and custom made by Precision Extrusions, Inc. Tubes M and N were designed and supplied by the Wolverine Tube Division of the Universal Oil Products Company under the trade name "Korodense." Tube O was designed and supplied by Turbotec Products, Inc. Tubes R and S were designed and supplied by the General Atomic Company. Tube T was custom made by Grob, Inc. Tube U was designed and supplied by Yorkshire Imperial Metals Ltd., United Kingdom.

The external perimeter of most tubes was measured as the length of thin tape forced to conform closely and completely around the tube's outside surface. Measurements were also made from enlarged photographic cross sections of available tube samples. The area of smooth Tube A is based on a 1.22-m (48-in.) length — the total length available within the test section. However, the areas of the enhanced tubes are based on a 1.17-m (46-in.) effective length to account for the 12.7-mm (0.5-in.) adapter sleeve and installation clearance on each end of the enhanced tubes.

3. PROCEDURES AND INSTRUMENTATION

The objective of this study was the determination of composite heat transfer coefficients for R-11 condensing on the outside surface of vertical tubes. To apply the Wilson-plot technique to the condensation process, heat rates and temperature differences were calculated from data taken during steady-state operations (see Appendix A for sample calculations). Accurate temperature measurements were critical to the evaluation of condenser performance, because measurement of temperature differences as small as 0.11 K (0.2°F) within ± 0.02 K (0.04°F) was sometimes necessary. Very small condensate flows, 0.19 to 1.89×10^{-5} m³/s (0.03 to 0.3 gpm), also had to be measured accurately for good interpretation of the experimental data.

Because the details of the operating procedures and instrumentation are given in a previous report,³ only a brief summary will be presented in the following sections.

3.1 Steady-State Operation

The heat rate to the boiler was controlled by a stack of four Variacs. Each Variac regulated the voltage to two tubular heaters, and any combination of the four Variacs could be used to obtain experimental heat rates. After setting the heat rate to the boiler, the primary cooling flow rate was set by the valve downstream of the test section. The inlet temperature of the secondary cooling water was determined by the process plant water conditions. The flow rate of the secondary cooling water was used to control the temperature of the primary cooling water, which, in turn, controlled the vapor temperature in the test section. Temperatures and pressures throughout the system were monitored to determine when a steady state was reached; a steady state existed when no significant change in temperatures [± 0.06 to ± 0.11 K (± 0.1 to ± 0.2 °F)] occurred through the system over a 5- to 10-min span.

Once a steady state was achieved, the experimental data were recorded. The recorded information included (1) vapor temperature and

pressure in both the condenser and boiler, (2) flow rate and temperature of the condensate, (3) inlet and outlet temperatures and flow rates of the primary and secondary coolants, and (4) voltage and current to each pair of heater rods. These data were then used to calculate heat transfer rates and temperature differences in the system and to check pressure-temperature values against saturation data in the literature (see Appendix A for examples).

After the data were recorded for a given steady-state condition, the flow rates of the primary and secondary cooling water were adjusted until the system reached a new steady state. The experimental data were again recorded. This same procedure was repeated until data were collected for three to five primary coolant flow rates at the same boiler heat rate. In the experiments, the five primary cooling rates ranged from 0.13 to $1.48 \times 10^{-3} \text{ m}^3/\text{s}$ (2.0 to 23.5 gpm). The heat rate to the boiler was then changed, and the procedure was repeated at the new heat rate.

3.2 Instrumentation

The power input to the boiler was monitored by voltage and current measurements for each pair of tubular heaters. The pressures in the boiler and condenser were measured with Bourdon gauges (Heise Model H-19178). The R-11 loop was also equipped with a compound gauge for reading both low and subatmospheric pressures. Alternatively, subatmospheric pressures could be measured by means of a mercury manometer containing traps to prevent mercury from entering the test section.

Throughout this study, Chromel-Alumel thermocouples and thermistors (Thermometrics Part No. S-10-4 Wire) were used as temperature measurement elements in the system. Thermocouples were located (1) in the liquid and vapor of the boiler, (2) in the vapor feed to the test section, (3) in the inlet and outlet of both cooling water loops, (4) near the condensate measuring station, and (5) on each heater. The recorded thermocouple data were used in deciding when the system reached a steady state.

Thermistors were added to the system for greater accuracy. These thermistors were installed in the water inlet and outlet lines of the test section and in the vapor feed to the test section. A thermistor was also located near the condensate measuring station. All thermistors were wired to a switch box that permitted individual resistance readout on a digital multimeter -- Hewlett-Packard Model 3465 A for the initial experiments and Data Precision Model 3500 for later investigations. The information from the thermistors was used for data reduction because of the greater accuracy attributed to these instruments. The two sets of temperature measuring instruments were checked against each other to increase confidence in their measurements.

The condensate flow in the R-11 loop could be measured by two instruments, an integral orifice meter and a turbine flow transducer. These two instruments were arranged in parallel, and the piping permitted the flow to pass through either device. During this investigation, the turbine flow transducer (Flow Technology, Model FTM-A15-LJS) equipped with a range-extending amplifier (Flow Technology, Model LFA-300 A) was used to facilitate operation because the integral orifice meter would have required frequent changes in orifice plates to accommodate various flow ranges. The range-extending amplifier made it possible to cover the full range of interest, 0.19 to $1.89 \times 10^{-5} \text{ m}^3/\text{s}$ (0.03 to 0.3 gpm), with only one instrument. Earlier work had shown that measured values from the two instruments agreed to within a few percent.

The primary cooling water flow was measured by one of two rotameters in parallel upstream of the test section. The rotameters were capable of covering the operating range of 0.13 to $1.48 \times 10^{-3} \text{ m}^3/\text{s}$ (2 to 23.5 gpm). The information from these two rotameters is utilized in the data reduction (see Appendix A).

The secondary cooling water flow was measured by one of two rotameters in parallel upstream of the cooling coil. The rotameters were used for monitoring secondary coolant flows up to $2.52 \times 10^{-4} \text{ m}^3/\text{s}$ (4 gpm).

4. ANALYSIS

4.1 Overall Condensing Coefficients

The overall heat transfer conductance (coefficient) in the condenser is given by:

$$U = \frac{Q}{A_o \overline{\Delta T}}, \quad (4.1)$$

where $\overline{\Delta T}$ is the overall mean temperature difference between the condensing refrigerant vapor and the primary cooling water, A_o is the total outside heat transfer surface area of the tube, and Q is the condenser heat rate.

The arithmetic mean difference is used for $\overline{\Delta T}$, because, in most cases, the temperature difference across the water was relatively small. Therefore:

$$\overline{\Delta T} = T_v - (T_{w,in} + T_{w,out})/2, \quad (4.2)$$

where T_v is the vapor temperature and the second term on the right is the average of the inlet water temperature ($T_{w,in}$) and the outlet water temperature ($T_{w,out}$).

Three independent ways to determine the heat rate (Q) of the condenser test section are (1) from the refrigerant side of the condenser, (2) from the primary cooling water passing through the condenser, and (3) from the secondary cooling water passing through a coil located within the primary cooling water storage tank. For this study, the first method was the most accurate and was used exclusively in all calculations in this report, but other methods agreed well. The condenser heat transfer rate may be determined according to the relation

$$Q = \dot{m}_c h_{fg}, \quad (4.3)$$

where $\dot{m}_c$ is the condensate mass flow rate and h_{fg} is the latent heat of the condensing fluid. In this analysis, all physical property data for R-11 are taken from ASHRAE handbooks.⁷⁻⁹

The overall heat transfer coefficient, based on the total tube outside surface area, can be calculated from Eq. (4.1) using Eq. (4.2) to calculate $\overline{\Delta T}$ and Eq. (4.3) to calculate Q .

4.2 Individual Heat Transfer Coefficients

The overall resistance to heat flow ($\Sigma R = 1/U$) in the condenser is equal to the sum of the individual resistances; therefore,

$$\frac{1}{U} = R_v + R_{wall} + R_w + R_{fo} + R_{fi} , \quad (4.4)$$

where R_v is the resistance on the vapor (condensing) side, R_{wall} is that of the wall, R_w is that of the water side, and R_{fo} and R_{fi} account for any fouling resistance on the outside and inside surfaces of the tube, respectively. If fouling is neglected and individual heat transfer coefficients (h) are introduced, the overall resistance based on the outside surface area becomes:

$$\frac{1}{U} = \frac{1}{h_v} + R_{wall} + \frac{A_o}{A_i h_w} , \quad (4.5)$$

where h_v is the condensing side heat transfer coefficient, h_w is the water-side coefficient, and A_i and A_o are the total inside and outside surface areas of the tube, respectively.

For a smooth tube, the wall resistance based on the outside tube area is given by:

$$R_{wall} = r_o \ln (r_o/r_i)/k , \quad (4.6)$$

where k is the tube wall thermal conductivity, r_o is the outside radius, and r_i is the inside radius of the tube. However, the wall resistance caused by the more complicated wall geometry and heat distribution

is very difficult to estimate for enhanced tubes. To compare the performance between smooth and enhanced tubes, a combined resistance (or inverse conductance) comprised of the condensing side and wall resistance of the tube was defined. Thus a "composite" resistance ($1/h_c$) can be represented as:

$$\frac{1}{h_c} = \frac{1}{h_v} + R_{wall} . \quad (4.7)$$

Substituting Eq. (4.7) into Eq. (4.5) and rearranging in a composite coefficient (h_c) form gives:

$$h_c = 1 / \left(\frac{1}{U} - \frac{A_o}{A_i h_w} \right) . \quad (4.8)$$

Similarly, a corresponding composite (combined) temperature difference can be defined as:

$$\Delta T_c = \frac{Q}{h_c A_o} , \quad (4.9)$$

which represents the temperature difference between the condensing vapor and the inside tube wall.

The composite quantities are derived by elimination of the water-side film coefficient contribution to the overall resistances. The next step in the analysis is the evaluation of the water-side coefficients.

4.3 Evaluation of Water-Side Coefficients by the Wilson-Plot Method

The method used in this study for determining water-side coefficients was a technique introduced by Wilson;⁶ this technique is a graphic method of interpreting overall coefficients so that individual condensing-side coefficients can be evaluated. The following treatment presents this method and describes its application to the data in this study.

Neglecting the effects of changes in water temperature, the water-side resistance ($1/h_w$) for turbulent flow¹⁰⁻¹² as a function of water velocity (v) may be approximated by:

$$(1/h_w) \propto (1/v^{0.8}) ; \quad (4.10)$$

therefore, Eq. (4.5) can be rewritten as:

$$\frac{1}{U} = \frac{1}{h_v} + R_{wall} + a_1 v^{-0.8} . \quad (4.11)$$

If, following Wilson, the sum of the first two resistances ($1/h_v + R_{wall}$) is taken as approximately constant, Eq. (4.11) becomes:

$$\frac{1}{U} = a_0 + a_1 v^{-0.8} . \quad (4.12)$$

In this form, a plot of $1/U$ vs $v^{-0.8}$ on rectangular coordinates should give a straight line from which the constants a_0 (y-intercept) and a_1 (slope) can be determined. Because a_0 is the sum of the first two resistances (vapor side plus wall) in Eq. (4.11), substitution and rearrangement of Eq. (4.7) yields:

$$h_c = 1/a_0 , \quad (4.13)$$

which is the parameter of interest in this analysis.

For the experimental data points used in the construction of the Wilson plot, a constant heat load and a condensate flow rate were maintained while varying the water-side velocities. Because properties for R-11 did not vary significantly over the small range of temperatures covered in this study, no appreciable error was introduced by assuming the sum of the vapor side and tube wall resistances ($1/h_v + R_{wall}$) to be essentially constant.

5. RESULTS AND DISCUSSION

Experimental tests in this study were divided into six categories: (1) tests on two external fluted tubes (L and T); (2) tests on three skirted tubes (A-1, L-1, and L-3), one with a smooth outside surface, the others with external fluted surfaces; (3) tests on two tubes with roped type surfaces (M and N); (4) tests on three spiral type tubes (O, R, and S); (5) tests on a corrugated type tube (U); and (6) tests on a double fluted tube (L^{*}).

Figures 5.1 to 5.9 present heat transfer results from this study. Condensing experiments conducted in this investigation (113 runs yielding 450 heat transfer data points) are documented in Appendix C (Tables C.2 through C.13), where the data are tabulated with the overall condensing heat transfer coefficients and heat balance checks for the

Fig. 5.1. Wilson-plot results for fluted tubes on a composite heat transfer coefficient vs heat flux basis.

Fig. 5.2. Wilson-plot results for Tubes M, N, O, R, and S on a composite heat transfer coefficient vs heat flux basis.

Fig. 5.3. Wilson-plot results for Tube L and duplicate tubes (containing equally spaced drainage skirts) on a composite heat transfer coefficient vs heat flux basis.

Fig. 5.4. Wilson-plot results for fluted tubes on a heat load vs composite temperature difference basis.

Fig. 5.5. Wilson-plot results for Tubes M, N, O, R, and S on a heat load vs composite temperature difference basis.

Fig. 5.6. Wilson-plot results for Tube L and duplicate tubes (containing equally spaced drainage skirts) on a heat load vs composite temperature difference basis.

Fig. 5.7. Overall heat transfer performance of Tubes L and L* with water flowing through an annulus at $1.4 \times 10^{-3} \text{ m}^3/\text{s}$ (22 gpm).

Fig. 5.8. Overall heat transfer performance of Tubes L and L* with water flowing through an annulus at $4.8 \times 10^{-4} \text{ m}^3/\text{s}$ (7.6 gpm).

Fig. 5.9. Overall heat transfer performance of Tubes L and L* with water flowing through an annulus at $1.9 \times 10^{-4} \text{ m}^3/\text{s}$ (3.0 gpm).

condenser test section. Table C.1, which serves as the data basis for comparison, is taken from Ref. 3.

Wilson-plot results are tabulated in Appendix B, and a sample Wilson plot is given in Appendix A with sample calculations.

Parameter ranges for the experiments were

- condensing temperature: 306 to 326 K (92 to 128°F),
- condensing pressure: 137.9 to 255 kPa (20 to 37 psia),
- heat load: 790 to 3,090 W (2,700 to 10,550 Btu/h),
- heat flux: 5,675 to 31,375 W/m² (1,800 to 9,950 Btu/h·ft²).

The resulting composite condensing heat transfer coefficients (h_c) ranged from 850 to 6530 W/m²·K (150 to 1150 Btu/h·ft²·°F); composite condensing temperature differences (ΔT_c) range from 0.9 to 27 K (1.7 to 48°F).

Dimensional plots (Figs. 5.1 to 5.9) are intended as aids for design of heat exchanger equipment operating within the specified parameter ranges.

5.1 Enhanced Tube Results

The R-11 data for all tubes, except the double fluted tube L*, are shown in Figs. 5.1 through 5.3 in dimensional form as composite condensing heat transfer coefficient (h_c) vs heat flux (Q/A). Because of the uncertainties and difficulties involved in computing the wall resistance for the enhanced tubes, Figs. 5.1 through 5.3 present a composite condensing film coefficient (h_c) that includes both the vapor-side and wall resistances. Both ordinate and abscissa are also based on the total condensing area for each tube (Table 2.1). Therefore, any observed augmentation resulting from an area effect is essentially accounted for.

In a previous study,³ data were presented for R-11 condensing vertically on the outside of Tube A (smooth walls). Data for Tube A from

Fig. 15 in Ref. 3 are plotted in Figs. 5.1 and 5.3 for baseline comparison with the tubes tested in this study. As indicated in these figures, the data for Tube A showed very little variation in heat transfer coefficient for the heat flux range tested.

In Figs. 5.1 and 5.2, the R-11 data for Tubes M and N (roped surfaces) show no significant variation in heat transfer coefficient with increasing heat flux. In fact, the data for Tubes M and N (Fig. 5.1) fall within the normal scatter of the data for Tube A. Therefore, for Tubes M and N, the surface characteristic (geometry) and/or differences in material (Table 2.1) apparently had little effect on heat transfer performance during vertical condensation.

In Figs. 5.1 and 5.2, the heat transfer coefficients for Tube O (spiral surface) are somewhat higher than those for Tubes M and N and decrease very slightly with increasing heat flux.

Coefficients for Tubes R and S (also spiral) start considerably above those for Tube O and decrease more rapidly with increasing heat flux. Coefficients for Tube S are also higher than those for Tube R at the lower heat fluxes, but decrease to approximately Tube R values at high heat fluxes.

In Fig. 5.1, coefficients for Tube U (corrugated) lie slightly above those for Tube S at low fluxes but decrease quite sharply to values below Tube R at high fluxes. Coefficients for Tubes T and L (externally fluted) start somewhat above those for Tube U at the low heat fluxes, decreasing to values above Tube S at high fluxes.

At the low heat fluxes [$<14,190 \text{ W/m}^2$ ($<4,500 \text{ Btu/h}\cdot\text{ft}^2$)], Tubes T and L seem to have approximately the same performance; whereas at the higher fluxes [$>14,190 \text{ W/m}^2$ ($>4,500 \text{ Btu/h}\cdot\text{ft}^2$)], the coefficients for Tubes T and L decrease rapidly, with values for Tube T falling below those for Tube L.

In many cases for R-11, the condensing side resistance appears to dominate the heat transfer process, so that water-side enhancement is of less interest. However, many tubes tested in this study (roped, spiral, and double fluted) offer some enhancement on the cooling water side. Except for Tube L* (double fluted), the use of the Wilson-plot method on

these water-side enhanced tubes gave satisfactory condensing-side results. For the double fluted Tube L*, however, some appreciable error was introduced when the Wilson-plot method was used to determine composite condensing coefficients. Consequently, no Wilson-plot results for Tube L* are presented in this report. The reason that the Wilson-plot method gave somewhat inaccurate results for Tube L* is not clear. One possible explanation is that the water-side coefficient for Tube L* may not be the simple function of water velocity assumed for the Wilson plot. More specifically, because the Wilson-plot procedure is based on an 0.8 power dependence of the water-side coefficient on flow rate, such an assumption may not necessarily apply to the water-side characteristic of Tube L*.

A better presentation of the data for Tube L* is shown in Figs. 5.7 through 5.9, where only overall heat transfer results are plotted in the form of heat load vs overall mean temperature difference. A discussion describing the overall heat transfer results for Tube L* will be presented in a later section.

For a given heat flux, the maximum composite heat transfer coefficient achieved for a nonskirted fluted tube was 5.5 times the smooth tube value (Fig. 5.1), occurring at the lowest test heat flux $5,991 \text{ W/m}^2$ ($1,900 \text{ Btu/h}\cdot\text{ft}^2$) with Tube L. The corresponding minimum composite coefficient for Tube L was 3.5 times at a higher heat flux of $24,754 \text{ W/m}^2$ ($7,850 \text{ Btu/h}\cdot\text{ft}^2$).

Previous work at ORNL with refrigerants^{3,5} had indicated that vertical fluted tube performance can be further enhanced by the use of drain-off skirts, which effectively act to divide the tube into shorter condensing lengths. These drain-off skirts provided improvement at the higher heat fluxes where flooding in the grooves was more pronounced. The effectiveness of skirts on the smooth Tube A and fluted Tube L is shown in Figs. 5.1 and 5.3, respectively. The tube integer notation denotes the number of attached equally spaced drain-off skirts.

Coefficients for Tube A-1 (0.6-m-long condensing lengths) were enhanced from 1.3 to 1.1 times smooth Tube A values at low and high heat fluxes, respectively (Fig. 5.1). The use of a single skirt on Tube A

does not appear to be very effective at the higher heat fluxes, where condensate flow rates reach high values. However, the heat transfer performance for Tube A-1 (Fig. 5.1) is somewhat better than that achieved with the commercially enhanced Tubes M and N.*

Unlike Tube A-1, the use of skirts on Tube L effectively aided condensate drain-off of flooded grooves and increased the heat transfer coefficients at the higher fluxes. Figure 5.3 shows that coefficients were enhanced from 1.1 to 1.3 times for Tube L-1 as compared with Tube L at low and high heat fluxes, respectively.

Even further enhancement was possible using additional skirts on Tube L. At a low heat flux [$5,991 \text{ W/m}^2$ ($1,900 \text{ Btu/h}\cdot\text{ft}^2$)], coefficients for Tube L-3 compared with L resulted in an enhancement ratio of 1.2. For the higher fluxes [$28,860 \text{ W/m}^2$ ($\sim 9,152 \text{ Btu/h}\cdot\text{ft}^2$)], an enhancement ratio of 1.4 was achieved. From Fig. 5.3, the superiority of Tube L-3 can be clearly recognized. At a low heat flux of $5,991 \text{ W/m}^2$ ($1,900 \text{ Btu/h}\cdot\text{ft}^2$), the maximum enhancement in heat transfer achieved with Tube L-3 was $6,570 \text{ W/m}^2\cdot\text{K}$ ($1,157 \text{ Btu/h}\cdot\text{ft}^2$) compared with $908 \text{ W/m}^2\cdot\text{K}$ ($160 \text{ Btu/h}\cdot\text{ft}^2\cdot^\circ\text{F}$) for the smooth Tube A, providing an enhancement ratio of 7.2. This represents the maximum enhancement ratio achieved for any of the tubes discussed in this report. The corresponding minimum enhancement for Tube L-3 was 4.7 times the smooth tube value at a heat flux of $24,754 \text{ W/m}^2$ ($7,850 \text{ Btu/h}\cdot\text{ft}^2$).

Conclusions from Figs. 5.1 through 5.3 include:

1. External fluted tubes gave better condensing performance than other geometries tested in the vertical condensation mode.
2. The best external fluted tube tested (Tube L) can increase condensing heat transfer coefficients up to 5.5 times smooth tube values for R-11 condensing at a given heat flux.
3. Such an enhancement cannot be accounted for by the increased area of the fluted tube, but it may be attributed to surface tension effects as described by Gregorig.¹³

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*However, these tubes may be intended for use in the horizontal mode, and the enhancement is mostly for water-side improvement.

4. As found in an earlier study,³ the use of skirts on a fluted tube can increase condensing heat transfer coefficients up to 7.2 times smooth tube values at the lower heat fluxes.

5. At the higher fluxes, composite coefficients for a fluted tube with one skirt can be increased up to 1.3 times the corresponding value for a fluted tube with no skirts.

Although Figs. 5.1 through 5.3 are useful for determining whether the observed enhancement was merely an area effect, other dimensional presentations may be more meaningful for particular design situations. In Figs. 5.4 through 5.6, the condensation data are plotted in heat-load-vs-composite-condensing-temperature-difference form. This form, an alternative to the previous total area basis, allows the designer to take "credit" for the increased area of the fluted tube. Therefore, for a fixed heat load or condensing temperature difference, enhancement ratios can be evaluated. As illustrated in Figs. 5.4 through 5.6, the performance rank order of the test tubes is essentially unchanged from that indicated in Figs. 5.1 through 5.3, that is, Tube A (worst) through Tube L-3 (best). However, positions of Tubes R and U data relative to that of Tube S data improve considerably when compared on the heat-load-vs-condensing-temperature basis (Fig. 5.4), because their total surface areas are greater than that of Tube S (Table 2.1). In fact, the heat transfer performances for Tubes R, S, and U appear to be similar at the higher heat loadings.

A similar observation may be made about Tube T. As indicated in Fig. 5.4, the excellent performance of Tube T is more evident, reflecting its considerable advantage in total area. In this plot, the performance of Tubes L and T becomes virtually identical, particularly at the higher heat loads.

For a given condensing temperature difference, fluted tubes can accommodate heat loads up to 4.7 times smooth tube values. At a condensing temperature difference of 6.4 K (11.6°F), Tube L can accommodate a heat load of 2871 W (9800 Btu/h), while Tube A can handle only 7167 W (2100 Btu/h), therefore giving a heat load ratio of 4.7 (Fig. 5.4). Alternatively, for a given heat load, the smooth Tube A required condensing temperature differences up to 7.8 times fluted tube values. For

example, at a heat load of 806 W (2750 Btu/h), the condensing temperature difference required for Tube A was 8.7 K (15.6°F) as compared with 1.1 K (2°F) for Tube L, therefore, providing a temperature difference ratio of 7.8.

An analysis on the effectiveness of skirts like those described previously may be made for Tubes L-3 and L-1 vs plain Tube L. The use of skirts on Tube L offered significant improvement throughout the range of heat loads tested (Fig. 5.6). In this form, for a given condensing temperature difference, both maximum and minimum heat loads achieved with Tube L-3 were 1.2 times Tube L values. However, for a given heat load, the maximum condensing temperature difference ratio (Tube L to Tube L-3) was 1.4 at the highest heat load [4,029 W (13,750 Btu/h)]. The corresponding minimum condensing temperature difference ratio was 1.3 at the lowest heat load [850 W (2,900 Btu/h)]. Therefore, at the higher loads where condensate flooding was more pronounced, Tube L-3 appears to give the greatest performance improvement over Tube L. This behavior supports similar findings on previously tested skirted fluted tubes.³

The increased performance of Tube L-3 may also be compared with that of smooth Tube A. For a given condensing temperature difference, the maximum heat load achieved with Tube L-3 was 6 times the smooth tube value (Fig. 5.6), occurring at the lowest condensing temperature difference [6 K (11°F)]. The corresponding minimum heat load ratio with Tube L-3 was 5.5 at the highest condensing temperature difference [7.8 K (14°F)].

For a given heat load, the maximum condensing temperature difference ratio (Tube A to Tube L-3) was 10 at the lowest heat load [850 W (2900 Btu/h)]. The corresponding minimum condensing temperature difference ratio was 7.1 at the highest heat load [2403 W (8200 Btu/h)].

Conclusions from Figs. 5.4 through 5.6 include:

1. The best external fluted tube can increase heat load capability to 4.7 times the smooth tube value for R-11 condensing at a given condensing temperature difference; conversely, for a given heat load, a smooth tube can require a condensing temperature difference up to 7.8 times that for the same fluted tube.

2. The use of skirts on a fluted tube can increase the heat load capability up to six times the smooth tube value for a given condensing temperature difference. Conversely, for a given heat load, a smooth tube can require a condensing temperature difference up to ten times skirted fluted tube value.

5.2 Double Fluted Tube Results

As previously mentioned, the favored Wilson-plot method for determining condensing-side heat transfer coefficients was somewhat inaccurate when applied to the double fluted Tube L*. One possible explanation is that, unlike a smooth inside tube wall, the water-side coefficient for an inside fluted tube is not the simple function of water velocity assumed for the Wilson plot. Therefore, as a result, some appreciable error is introduced when the method is used in determining composite condensing performance of double fluted tubes. Consequently, comparisons of Wilson-plot results between Tube L* and other tubes have the unavoidable penalty of possible substantial uncertainties.

Tests were conducted with Tube L* to determine the effect of inside flutes on the overall heat transfer performance.

To determine such an effect, test results for Tube L* were compared with overall data (collected as a prerequisite to the Wilson-plot method) for Tube L, which is externally identical to Tube L* but features a smooth inside tube wall. Experimental overall heat transfer data were obtained for Tube L* with cooling water flowing through an annulus [1.3-cm-diam (0.5-in.) rod inside the tube]. Such a water-side arrangement was necessary to match the water-side configuration used in testing Tube L.

Overall heat transfer results for Tubes L* and L are presented in Figs. 5.7 through 5.9 as heat load vs overall mean temperature difference for a series of water flow rates. These figures show how the overall performance for Tubes L* and L increase as the water flow rate increases. In Fig. 5.8, for a given overall temperature difference and a water flow rate of $4.8 \times 10^{-4} \text{ m}^3/\text{s}$ (7.6 gpm), the maximum improvement

in heat load achieved with Tube L* was 17% above the comparable Tube L value, occurring at the lowest overall temperature difference [2.2 K (4°F)]. At the same water flow rate, the corresponding minimum heat load ratio with Tube L* was 1.09 for an overall temperature difference of 10.4 K (18.7°F). Alternatively, for a given heat load (Fig. 5.8), the maximum overall temperature difference ratio (Tube L to Tube L*) was 1.29 at the lowest heat load [791 W (2,700 Btu/h)]. The corresponding minimum was 1.12 at a heat load of 2,930 W (10,000 Btu/h). A similar comparison may be made with Figs. 5.7 and 5.9.

Figures 5.7 through 5.9 show that the inside flutes enhance to some degree the overall heat transfer coefficients of Tube L* over those for Tube L. However, a question arises concerning whether the inside flutes result in water-side heat transfer coefficient enhancement or whether such an increase in overall coefficient is merely caused by an increase in inside surface area alone. The inside surface area of Tube L* is ~1.32 times that of Tube L. For the test conditions in this report, an area increase of this order could explain the observed increase in overall performance with no increase in water-side heat transfer coefficient.

When condensing-side heat transfer coefficients are very large (low resistance to heat flow) as a result of external enhancement, the water-side coefficients will tend to become more dominant (a larger fraction of the total overall resistance) in determining heat flow. In this case, the use of internal flutes appears worthwhile, because additional overall performance improvements may be realized. However, excessive cooling water pressure drop and fabrication costs, resulting from the implementation of internal flutes, could represent a considerable penalty to be weighed against any significant performance gains. This represents an area for future trade-off/optimization studies.

6. CONCLUSIONS

The main conclusions drawn from this study of R-11 condensing on the outside of vertical enhanced tubes may be summarized as follows:

1. With condensing performance judged on a heat-load-vs-composite-condensing-temperature-difference basis, the rank order (best to worst) of the enhanced tube geometries tested was external fluted tubes, corrugated tube, spiral tubes, and roped type tubes.

2. The best external fluted tube (Tube L) gave much better condensing performance than that of a conventional smooth tube (Tube A). For a given heat flux, the maximum composite heat transfer coefficient achieved with Tube L was 5.5 times the Tube A value, occurring at the lowest test heat flux. For a given condensing temperature difference, Tube L was capable of accommodating a heat load up to 4.7 times the Tube A value. For a given heat load, Tube A required a condensing temperature difference of up to 7.8 times the fluted Tube L value.

3. The use of skirts on the best fluted tube further increased composite condensing coefficients, therefore yielding an improved performance factor of 7.2 over smooth tube values, at the lower heat fluxes. These results support earlier findings with other skirted fluted tubes.^{3,5}

4. For a double fluted tube, the inside tube fluting increased the overall heat transfer coefficient to as much as 17% over that for a tube with identical outside flutes and a smooth inside surface.

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Appendix A

SAMPLES OF DATA REDUCTION

A.1 Physical Properties for R-11

All property data for R-11 used in the data reduction were taken from American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) handbooks.⁷⁻⁹ The accuracy of thermophysical properties is discussed in Ref. 8.

A.2 Fluted Tube

A sample of the experimental data required for computing the composite condensing film coefficient for a given vapor temperature and heat flux is listed in Table A.1. Data are for R-11 condensing on Tube L (60 external corrugations and smooth inside wall). Experimental run R-11-001 L is used to demonstrate the data reduction procedure, and the series of runs R-11-001 L through R-11-004 L are used to demonstrate the Wilson-plot technique.

The measured pressure (P) of the vapor should agree with the saturation pressure (P_{sat}) of R-11 at the vapor temperature (T_v), assuming that no contaminants or superheat are present. In this study, the pressure data for R-11 from ASHRAE⁷⁻⁹ were fitted as polynomial functions of temperature for the range of 70 to 120°F, resulting in the following equations:

$$P_{sat} = 1.74693 + 0.105969 (T_v) + 2.5 \times 10^{-4} (T_v)^2 + 8.61134 \times 10^{-6} (T_v)^3, \quad (A.1)$$

$$\rho_c = 98.1541 \times 7.3367 \times 10^{-2} (T_c) - 6.08035 \times 10^{-5} (T_c)^2, \quad (A.2)$$

$$h_{fg} = 83.6357 - 7.53477 \times 10^{-2} (T_v) - 8.61023 \times 10^{-5} (T_v)^2. \quad (A.3)$$

Table A.1. Sample of experimental data — R-11 condensing on Tube L

Run No.	Vapor feed to test section		Condensate		Primary cooling water through test section			
	Temperature, ^a	Pressure, ^b	Flow rate, ^c	Temperature, ^a	Flow rate, ^d	Inlet temperature ^a	Outlet temperature, ^a	Temperature difference, ^{a, e}
	T_v (°F)	P (psia)	F_c (gpm)	T_c (°F)	F_w (gpm)	$T_{w,in}$ (°F)	$T_{w,out}$ (°F)	ΔT_w (°F)
R-11-001 L	94.08	21.0	0.1419	91.27	22.0	83.41	84.14	0.70
R-11-002 L	97.35	22.2	0.1410	94.44	7.6	83.08	85.13	2.03
R-11-003 L	99.65	23.2	0.1418	96.50	5.2	82.91	85.86	2.95
R-11-004 L	104.68	25.2	0.1417	101.05	3.0	82.64	87.61	4.97

^aMeasured by thermistors (Thermometrics Part No. S-10-4 Wire).

^bMeasured by pressure gauges (Heise).

^cMeasured by turbine flow transducer (Flow Technology, Model FTM-A15-LJS).

^dMeasured by one of two rotameters (Fisher and Porter Company and Brooks Rotameter Company).

^eCorrected for temperature offset and temperature rise from heat generated by friction between fluid and tube wall.

From Eq. (A.1), the saturation pressure (P_{sat}) corresponding to a temperature of 94.08°F is 21.1 psia, which agrees well (0.5%) within the experimental accuracy of the instruments to the measured pressure (P) of 21.0 psia for run R-11-001 L. This agreement also indicates the absence of appreciable amounts of noncondensables in the condenser during operation. The quantities ρ_c and h_{fg} are used later for calculating the heat transfer rates in the condenser from the condensate flow.

The heat transfer rate or heat load in the condenser can be computed by two separate sets of measurements — one on the refrigerant side and one on the water side. To calculate the heat transfer rate from the refrigerant side, condensate flow rate (F_c) requires the latent heat (h_{fg}) of R-11 at the vapor temperature (T_v) and the density of liquid R-11 at the condensate temperature (T_c) near the condensate flow measuring station. From Eqs. (A.2) and (A.3) for

$$T_c = 91.27^\circ\text{F} \rightarrow \rho_c = 90.95 \text{ lb/ft}^3 ,$$

$$T_v = 94.08^\circ\text{F} \rightarrow h_{fg} = 75.78 \text{ Btu/lb} .$$

The heat transfer rate can then be calculated from Eq. (4.3), presented in the main text, where the condensate flow rate is given by

$$\dot{m}_c = F_c \rho_c , \tag{A.4}$$

so that

$$\begin{aligned} Q_c &= F_c \rho_c h_{fg} \\ &= (0.1419 \text{ gpm})(90.95 \text{ lb/ft}^3)(75.78 \text{ Btu/lb}) \\ &\quad \times (1 \text{ ft}^3/7.481 \text{ gal})(60 \text{ min/h}) \\ &= 7843 \text{ Btu/h} . \end{aligned}$$

The heat transfer rate computed from the primary cooling water is given by:

$$Q_w = F_w \rho_w C_{p_w} \Delta T_w , \tag{A.5}$$

where F_w and ΔT_w are the volume flow rate and temperature rise of the

primary cooling water, respectively. The term C_{p_w} is the average heat capacity of the primary cooling water, and ρ_w is the average density of the primary cooling water; both C_{p_w} and ρ_w are calculated at the average temperature of the primary water $T_{w,avg}$. In this particular example, the change in water temperature ΔT_w is so small that the variation in properties is insignificant. The average temperature of the primary cooling water is the average of the inlet temperature (83.41°F) and the outlet temperature (84.14°F). The properties for water at an average temperature of 83.78°F are $\rho_w = 62.29 \text{ lb}_m/\text{ft}^3$, and $c_{p_w} = 1.0 \text{ Btu}/\text{lb}_m \cdot ^\circ\text{F}$, so that, from Eq. (A.5), the heat transfer rate for run R-11-001 L becomes

$$\begin{aligned} Q_w &= (22.0 \text{ gpm})(62.29 \text{ lb}_m/\text{ft}^3)(1 \text{ Btu}/\text{lb}_m \cdot ^\circ\text{F})(0.70^\circ\text{F}) \\ &\quad \times (1 \text{ ft}^3/7.481 \text{ gal})(60 \text{ min}/\text{h}) \\ &= 7694 \text{ Btu}/\text{h} . \end{aligned}$$

The percent of difference between the two heat loads is given by:

$$\frac{\Delta Q}{Q} \times 100 = \frac{(Q_c - Q_w)}{Q_c} \times 100 = \frac{(7843 - 7694)}{7843} \times 100 \quad (\text{A.6})$$

$$\Delta\% = 1.90 .$$

This value illustrates the agreement between the two different methods.

The overall condensing heat transfer coefficient can be computed from Eq. (4.1) with either Q_c or Q_w . However, the heat rate from the condensate flow (Q_c) is used in the calculation because it is considered the more accurate of the two. The overall mean temperature difference ($\overline{\Delta T}$) is given by Eq. (4.2):

$$\overline{\Delta T} = T_v - (T_{w,in} + T_{w,out})/2 .$$

Therefore, with the information for run R-11-001 L,

$$\overline{\Delta T} = 94.08^\circ\text{F} - (83.41^\circ\text{F} + 84.14^\circ\text{F})/2 = 10.30^\circ\text{F} .$$

The outside surface area (A_o) of Tube L is listed in Table 2.1 as 0.1397 m² (1.504 ft²). Applying Eq. (4.1) and using the data from run R-11-001 L,

$$U = \frac{Q_c}{A_o \Delta T} = \frac{7843 \text{ Btu/h}}{(1.504 \text{ ft}^2)(10.30^\circ\text{F})} = 506 \text{ Btu/h}\cdot\text{ft}^2\cdot^\circ\text{F}.$$

The same calculations illustrated for run R-11-001 L can be used for the other three runs in Table A.1. The results of the calculations for all four runs are shown in Table A.2. The four heat rates can be averaged to obtain an average heat load for the series of runs so that

$$Q_{c,avg} = 7747 \text{ Btu/h},$$

$$Q_{w,avg} = 7607 \text{ Btu/h}.$$

Water velocities (v) in Table A.2 are calculated from

$$v = F_w/A_c, \quad (\text{A.7})$$

where A_c is the cross-sectional flow area. During experimental tests with Tube L, a 0.5-in. diam solid rod was inserted through the tube center as noted in Sect. 2.2. For Tube L, the cross-sectional flow area is

$$A_c = \frac{\pi}{4} (D_i^2 - D_r^2), \quad (\text{A.8})$$

where D_i is the inside diameter of the test tube and D_r is the outside diameter of the solid rod. Because Tube L has an inside diameter (D_i) of 0.87 in.,

$$\begin{aligned} A_c &= \frac{\pi}{4} \left[\left(\frac{0.87}{12} \right)^2 - \left(\frac{0.50}{12} \right)^2 \right] \\ &= 0.002765 \text{ ft}^2, \end{aligned}$$

Table A.2. Sample information for the Wilson plot — R-11 condensing on Tube L

Run No.	Condenser heat load			Overall mean temperature difference, ^c $\frac{\Delta T}{(^{\circ}\text{F})}$	Primary cooling water velocity, v (ft/s)	$1/v^{0.8}$	Overall coefficient, U (Btu/h·ft ² ·°F)	$1/U$ (h·ft ² ·°F/Btu)
	Q_c^a (Btu/h)	Q_w^b (Btu/h)	$\Delta\%$					
R-11-001 L	7843	7694	1.9	10.30	17.7	0.1004	506	1.98×10^{-3}
R-11-002 L	7741	7716	0.3	13.24	6.1	0.2354	389	2.57×10^{-3}
R-11-003 L	7746	7643	1.3	15.26	4.2	0.3172	337	2.98×10^{-3}
R-11-004 L	7660	7436	2.9	19.55	2.4	0.4964	260	3.85×10^{-3}

^a Calculated from condensate flow.

^b Calculated from temperature rise and flow of the primary cooling water.

^c Between condensing vapor and primary cooling flow.

and the water velocity for run R-11-001 L is

$$v = (22.0 \text{ gpm}) \frac{1 \text{ ft}^3}{7.481 \text{ gal}} \cdot \frac{1 \text{ min}}{60 \text{ s}} \cdot \frac{1}{0.002765 \text{ ft}^2}$$

$$= 17.7 \text{ ft/s} .$$

To generate the Wilson plot, the reciprocal of the overall coefficient must be taken and the water velocity must be raised to the negative 0.8 power. For example, with the values for run R-11-001 L,

$$\frac{1}{v^{0.8}} = (1/17.7 \text{ ft/s})^{0.8} = 0.1004$$

and

$$\frac{1}{U} = (1/506 \text{ Btu/h} \cdot \text{ft}^2 \cdot ^\circ\text{F}) = 1.98 \times 10^{-3} \frac{\text{h} \cdot \text{ft}^2 \cdot ^\circ\text{F}}{\text{Btu}} .$$

The values for $(v^{-0.8})$ and $(1/U)$ are given in Table A.2 and were used to construct the Wilson plot shown in Fig. A.1. The data points shown in Fig. A.1 were fitted by a least squares method of the first order to determine the best linear fit to satisfy the following relationship:

$$\frac{1}{U} = a_0 + a_1 v^{-0.8} ,$$

where a_1 is the slope of the straight line and a_0 is the y-intercept. The reciprocal $(1/a_0$ or $h_c)$ gives the composite heat transfer coefficient of the condensing film and tube wall.

For this particular run series, the values a_0 and h_c are:

$$a_0 = 1.48 \times 10^{-3} \text{ h} \cdot \text{ft}^2 \cdot ^\circ\text{F} / \text{Btu} ,$$

$$h_c = 677 \text{ Btu/h} \cdot \text{ft}^2 \cdot ^\circ\text{F} .$$

The data show good linearity and allow extrapolation, with some confidence, to infinite water velocity (zero water-side resistance) at the plot y-intercept (Fig. A.1).

Fig. A.1. Wilson-plot for R-11 condensing outside fluted Tube L - runs R-11-001 L to R-11-004 L.

The corresponding composite temperature difference is calculated using Eq. (4.9). Because the average heat load value for this series of runs is ~7747 Btu/h, then from Eq. (4.9):

$$\Delta T_c = \frac{Q_{c,avg}}{h_c A_o} = \frac{(7747 \text{ Btu/h})}{(677 \text{ Btu/h} \cdot \text{ft}^2 \cdot ^\circ\text{F})(1.504 \text{ ft}^2)} = 7.6 ^\circ\text{F} .$$

The computations outlined in this appendix were followed in reducing all of the experimental data. These Wilson-plot results are presented in graphic and tabular form, Sect. 5.0 and Appendix B, respectively.

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Appendix B

WILSON-PLOT RESULTS

Wilson-plot results from condensation experiments performed on single, vertical tubes in this study are summarized herein. Table B.1 (from Ref. 3) is presented for Tube A as a baseline comparison with the other tested tubes (Tables B.2 through B.12). The condenser heat load was taken as the average heat load based on the condensate flow ($Q_{c,avg}$) for a series of runs (see Appendix A for an example). Individual runs are documented in Appendix C.

Table B.1. Summary of experimental conditions and results from Wilson plots for R-11
condensing on vertical Tube A

Series of runs	Condenser heat load [W (Btu/h)]		Difference (%)	Vapor temperature range [K (°F)]	Condensing temperature difference [K (°F)]	Condensing heat transfer coefficient [W/m ² ·K (Btu/h·ft ² ·°F)]
	Q _c	Q _w				
R-11-037A to 040A	1271 (4336)	1286 (4388)	-1.2	315.7-318.5 (108.9-113.9)	14.1 (25.4)	923.3 (162.8)
R-11-047A to 044A	774 (2642)	797 (2722)	-3.0	309.9-311.3 (98.4-100.9)	8.1 (14.6)	981.8 (173.2)
R-11-045A to 048A	926 (3161)	947 (3231)	-2.2	311.5-313.3 (101.3-104.6)	10.0 (17.9)	955.1 (168.4)
R-11-049A to 052A	1638 (5589)	1644 (5611)	-0.4	319.3-323.1 (115.3-122.1)	18.5 (33.3)	909.5 (160.4)
R-11-053A to 056A	1874 (6394)	1892 (6457)	-1.0	322.4-327.1 (120.9-129.3)	21.6 (38.8)	891.9 (157.3)
R-11-057A to 060A	2219 (7572)	2200 (7507)	-0.9	325.3-330.8 (126.2-136.0)	25.2 (45.3)	905.6 (159.7)
R-11-061A to 064A	1112 (3795)	1145 (3908)	-3.0	313.3-315.6 (104.6-108.7)	12.2 (22.0)	935.2 (164.9)
R-11-065A to 068A	2066 (7051)	2063 (7040)	-0.2	322.1-327.5 (120.4-130.1)	23.8 (42.9)	889.6 (156.9)
R-11-069A to 072A	1495 (5101)	1531 (5226)	-2.4	316.3-320.7 (109.9-117.8)	16.9 (30.5)	906.6 (159.9)
R-11-073A to 076A	2402 (8197)	2425 (8276)	-1.0	323.1-329.1 (122.2-132.9)	27.4 (49.4)	899.3 (158.6)
R-11-077A to 080A	583 (1989)	605 (2064)	-3.8	307.7-308.8 (94.5-96.4)	6.2 (11.2)	958.6 (169.1)

Table B.2. Summary of experimental conditions and results from Wilson plots for R-11
condensing on vertical Tube A-1

Series of runs	Condenser heat load [W (Btu/h)]		Difference (%)	Vapor temperature range [K (°F)]	Condensing temperature difference [K (°F)]	Condensing heat transfer coefficient [W/m ² ·K (Btu/h·ft ² ·°F)]
	Q _c	Q _w				
R-11-001 to 004 A-1	938 (3203)	922 (3148)	1.7	310.5-313.0 (99.2-103.7)	8.4 (15.1)	1151.2 (203.0)
R-11-005 to 008 A-1	1972 (6729)	1939 (6618)	1.6	313.7-319.4 (104.9-115.3)	19.8 (35.7)	1021.9 (180.2)
R-11-009 to 012 A-1	1388 (4738)	1360 (4643)	2.0	315.5-320.1 (108.3-116.5)	13.3 (24.0)	1069.6 (188.6)
R-11-013 to 016 A-1	700 (2390)	684 (2335)	2.3	315.1-316.2 (107.6-109.5)	5.7 (10.3)	1255.7 (221.5)
R-11-017 to 020 A-1	1581 (5398)	1558 (5316)	1.5	314.8-320.3 (106.9-116.8)	15.6 (28.0)	1044.2 (184.2)
R-11-021 to 024 A-1	1185 (4043)	1176 (4014)	0.7	314.5-317.1 (106.4-111.2)	11.1 (20.0)	1095.2 (193.2)
R-11-025 to 028 A-1	1802 (6149)	1782 (6083)	1.1	313.7-319.6 (105.0-115.6)	18.2 (32.8)	1016.5 (179.3)
R-11-029 to 032 A-1	2188 (7469)	2129 (7265)	2.7	317.0-323.9 (111.0-123.3)	22.3 (40.2)	1006.3 (177.5)

Table B.3. Summary of experimental conditions and results from Wilson plots for R-11 condensing on vertical Tube L

Series of runs	Condenser heat load [W (Btu/h)]		Difference (%)	Vapor temperature range [K (°F)]	Condensing temperature difference [K (°F)]	Condensing heat transfer coefficient [W/m ² ·K (Btu/h·ft ² ·°F)]
	Q _c	Q _w				
R-11-001 L to 004 L	2270 (7747)	2229 (7607)	1.8	307.6-313.5 (94.1-104.7)	4.2 (7.6)	3837.1 (676.7)
R-11-005 L to 008 L	4077 (13913)	4026 (13740)	1.3	306.7-319.0 (92.3-114.6)	10.5 (18.9)	2774.4 (489.3)
R-11-009 L to 012 L	1123 (3831)	1108 (3783)	1.3	309.4-311.7 (97.3-101.4)	1.7 (3.0)	4846.7 (854.8)
R-11-013 L to 016 L	1119 (3818)	1125 (3841)	-0.6	309.3-311.9 (97.1-101.7)	1.7 (3.0)	4769.1 (841.12)
R-11-017 L to 020 L	1597 (5449)	1607 (5484)	-0.7	308.4-312.2 (95.4-102.3)	2.8 (5.0)	4141.0 (730.3)
R-11-021 L to 023 L	2956 (10089)	2918 (9959)	1.3	307.8-312 (94.4-102.0)	6.5 (11.6)	3269.9 (576.7)
R-11-024 L to 027 L	815 (2782)	843 (2876)	-3.4	309.7-311.9 (97.7- 99.9)	1.1 (2.0)	5350.5 (943.6)
R-11-028 L to 031 L	1270 (4334)	1254 (4281)	1.2	309.0-311.6 (96.5-101.2)	2.0 (3.7)	4444.1 (783.8)
R-11-032 L to 035 L	2551 (8705)	2521 (8604)	1.2	307.7-314.6 (94.1-106.6)	5.0 (9.0)	3634.1 (640.9)
R-11-036 L to 039 L	1955 (6672)	1944 (6635)	0.6	308.4-313.4 (95.4-104.4)	3.5 (6.3)	4001.1 (705.7)
R-11-040 L to 043 L	3430 (11707)	3367 (11492)	1.8	307.9-317.7 (94.5-112.3)	7.8 (14.1)	3136.2 (553.1)
R-11-044 L to 047 L	3755 (12817)	3675 (12543)	2.1	306.5-318.1 (92.0-112.8)	8.9 (16.0)	3012.4 (531.3)

Table B.4. Summary of experimental conditions and results from Wilson plots for R-11 condensing on vertical Tube L-1

Series of runs	Condenser heat load [W (Btu/h)]		Difference (%)	Vapor temperature range [K (°F)]	Condensing temperature difference [K (°F)]	Condensing heat transfer coefficient [W/m ² ·K (Btu/h·ft ² ·°F)]
	Q _c	Q _w				
R-11-001L1 to 004L1	1044 (3564)	1020 (3481)	2.3	309.9-312.4 (98.2-102.6)	1.3 (2.3)	5860.2 (1033.6)
R-11-005L1 to 008L1	3455 (11791)	3426 (11693)	0.8	307.2-317.0 (93.3-110.9)	6.3 (11.3)	3938.6 (694.6)
R-11-009L1 to 012L1	1369 (4672)	1338 (4570)	2.3	309.7-312.4 (97.8-102.6)	1.9 (3.4)	5181.5 (913.9)
R-11-013L1 to 016L1	3032 (10349)	3004 (10251)	1.0	307.0-315.6 (93.0-108.5)	5.4 (9.7)	4043.6 (713.2)
R-11-017L1 to 020L1	1714 (5850)	1682 (5742)	1.9	309.5-313.4 (97.4-104.5)	2.6 (4.6)	4783.6 (843.7)
R-11-021L1 to 024L1	2625 (8960)	2580 (8804)	1.7	307.3-314.4 (93.5-106.2)	4.5 (8.1)	4176.7 (736.6)
R-11-025L1 to 028L1	2205 (7527)	2200 (7507)	0.3	308.1-313.5 (94.9-104.7)	3.6 (6.4)	4430.1 (781.3)
R-11-029L1 to 032L1	4033 (13764)	3970 (13551)	1.6	306.6-318.7 (92.1-113.9)	8.1 (14.5)	3581.8 (631.7)
R-11-033L1 to 036L1	837 (2856)	854 (2913)	-2.0	310.7-312.4 (99.6-102.7)	1.0 (1.8)	5946.7 (1048.8)
R-11-037L1 to 040L1	3689 (12590)	3635 (12406)	1.5	306.6-317.2 (92.3-112.3)	7.1 (12.8)	3710.3 (654.4)

Table B.5. Summary of experimental conditions and results from Wilson plots for R-11
condensing on vertical Tube L-3

Series of runs	Condenser heat load [W (Btu/h)]		Difference (%)	Vapor temperature range [K (°F)]	Condensing temperature difference [K (°F)]	Condensing heat transfer coefficient [W/m ² ·K (Btu/h·ft ² ·°F)]
	Q _c	Q _w				
R-11-001 L3 to 004 L3	2169 (7303)	2148 (7332)	1.0	308.0–313.7 (94.8–105.1)	3.3 (5.9)	4761.6 (839.8)
R-11-005 L3 to 008 L3	1305 (4455)	1284 (4380)	1.7	309.6–312.0 (97.6–101.9)	1.7 (3.0)	5655.5 (997.24)
R-11-009 L3 to 012 L3	4040 (13788)	3992 (13623)	1.2	306.7–318.5 (92.4–113.6)	7.5 (13.5)	3854.0 (679.7)
R-11-013 L3 to 016 L3	2695 (9199)	2647 (9035)	1.8	307.4–314.4 (93.6–106.3)	4.4 (7.9)	4413.8 (778.5)
R-11-017 L3 to 020 L3	1068 (3644)	1047 (3573)	2.0	309.8–312.2 (98.0–102.3)	1.3 (2.3)	5971.4 (1053.2)
R-11-021 L3 to 024 L3	3483 (11887)	3402 (11611)	2.3	307.3–317.2 (93.4–111.2)	6.1 (11.0)	4081.0 (719.8)
R-11-025 L3 to 028 L3	1797 (6132)	1774 (6053)	1.3	305.2–313.7 (96.8–105.0)	2.6 (4.6)	5039.2 (888.8)
R-11-029 L3 to 032 L3	3102 (10589)	3054 (10424)	1.6	306.8–315.5 (92.6–108.2)	5.2 (9.4)	4247.8 (749.2)
R-11-033 L3 to 036 L3	852 (2909)	853 (2911)	-0.1	310.1–312.0 (98.6–101.8)	0.9 (1.6)	6560.6 (1157.1)
R-11-037 L3 to 040 L3	3720 (12696)	3646 (12443)	2.0	306.8–317.5 (92.6–111.9)	6.7 (12.0)	3985.2 (702.9)

Table B.6. Summary of experimental conditions and results from Wilson plots for R-11 condensing on vertical Tube M

Series of runs	Condenser heat load [W (Btu/h)]		Difference (%)	Vapor temperature range [K (°F)]	Condensing temperature difference [K (°F)]	Condensing heat transfer coefficient [W/m ² ·K (Btu/h·ft ² ·°F)]
	Q _c	Q _w				
R-11-001 M to 004 M	1302 (4442)	1282 (4376)	1.5	311.5-313.7 (101.0-105.0)	14.0 (25.1)	950.4 (167.6)
R-11-005 M to 008 M	2057 (7021)	2050 (6998)	0.3	312.9-316.1 (103.5-109.4)	22.2 (39.9)	946.1 (166.9)
R-11-009 M to 012 M	690 (2354)	717 (2446)	3.9	314.2-315.8 (105.8-108.8)	6.4 (11.4)	1107.2 (195.3)
R-11-013 M to 016 M	689 (2351)	722 (2465)	4.8	314.2-316.0 (106.0-109.1)	6.5 (11.7)	1081.6 (190.8)
R-11-017 M to 020 M	1036 (3535)	1045 (3565)	0.9	313.0-313.8 (103.7-105.1)	10.9 (19.6)	968.8 (170.9)
R-11-021 M to 024 M	2429 (8289)	2371 (8093)	2.4	316.2-320.4 (109.5-117.0)	26.1 (47.0)	948.0 (167.2)
R-11-025 M to 028 M	1568 (5352)	1562 (5331)	0.4	312.1-314.6 (102.0-106.6)	17.0 (30.7)	938.2 (165.5)
R-11-029 M to 032 M	1792 (6115)	1783 (6087)	0.5	311.9-314.8 (101.7-106.9)	19.4 (34.9)	941.7 (166.08)

Table B.7. Summary of experimental conditions and results from Wilson plots for R-11
condensing on vertical Tube N

Series of runs	Condenser heat load [W (Btu/h)]		Difference (%)	Vapor temperature range [K (°F)]	Condensing temperature difference [K (°F)]	Condensing heat transfer coefficient [W/m ² ·K (Btu/h·ft ² ·°F)]
	Q _c	Q _w				
R-11-001 N to 004 N	680 (2322)	713 (2433)	4.78	311.2–312.1 (100.4–102.1)	6.5 (11.7)	1065.2 (187.9)
R-11-005 N to 008 N	680 (2321)	735 (2507)	8.04	311.3–312.3 (100.7–102.4)	6.6 (11.9)	1050.4 (185.3)
R-11-009 N to 012 N	1565 (5340)	1560 (5323)	0.3	311.1–313.4 (100.3–104.5)	17.1 (30.7)	932.9 (164.5)
R-11-013 N to 016 N	2428 (8285)	2377 (8112)	2.1	315.7–319.4 (108.6–115.3)	26.5 (47.7)	931.8 (164.3)
R-11-017 N to 020 N	984 (3358)	1002 (3420)	1.9	310.8–312.1 (99.8–102.1)	10.2 (18.4)	978.7 (172.6)
R-11-021 N to 024 N	2132 (7276)	2114 (7214)	0.8	312.4–315.6 (102.7–108.4)	23.6 (42.5)	918.9 (162.1)
R-11-025 N to 028 N	1259 (4297)	1251 (4268)	0.7	311.0–312.8 (100.2–103.3)	13.3 (24.0)	961.7 (169.6)
R-11-029 N to 032 N	1837 (6269)	1832 (6253)	0.3	311.7–314.0 (101.5–105.5)	20.3 (36.6)	919.1 (162.1)

Table B.8. Summary of experimental conditions and results from Wilson plots for R-11 condensing on vertical Tube O (no rod on water side)

Series of runs	Condenser heat load [W (Btu/h)]		Difference (%)	Vapor temperature range [K (°F)]	Condensing temperature difference [K (°F)]	Condensing heat transfer coefficient [W/m ² ·K (Btu/h·ft ² ·°F)]
	Q _c	Q _w				
R-11-001 O to 004 O	1721 (5873)	1728 (5898)	-0.4	308.7-310.9 (95.9-99.9)	10.2 (18.4)	1627.8 (287.1)
R-11-005 O to 008 O	2527 (8626)	2483 (8474)	1.8	309.1-313.2 (96.7-104.1)	15.7 (28.2)	1561.3 (275.4)
R-11-009 O to 012 O	955 (3260)	945 (3226)	1.1	309.7-310.8 (97.9-99.7)	5.0 (8.9)	1863.5 (328.7)
R-11-013 O to 016 O	2595 (8858)	2528 (8629)	2.6	311.8-315.8 (101.6-108.7)	16.1 (28.9)	1566.6 (276.3)
R-11-017 O to 020 O	794 (2710)	804 (2744)	-1.3	310.5-311.3 (99.3-100.6)	4.0 (7.2)	1912.6 (337.3)
R-11-021 O to 024 O	1972 (6729)	1956 (6676)	0.8	309.1-311.8 (96.7-101.6)	12.1 (21.7)	1583.5 (279.3)
R-11-025 O to 028 O	1178 (4021)	1170 (3993)	0.7	310.1-311.8 (98.4-101.6)	6.4 (11.5)	1790.1 (315.7)
R-11-029 O to 032 O	2176 (7428)	2141 (7307)	1.6	309.2-312.3 (96.8-102.4)	13.2 (23.8)	1594.2 (281.2)
R-11-033 O to 036 O	1471 (5022)	1464 (4996)	0.5	310.0-312.1 (98.4-102.1)	8.3 (15.0)	1711.1 (301.8)
R-11-037 O to 040 O	2373 (8100)	2308 (7877)	2.8	309.4-313.2 (97.3-104.1)	14.5 (26.2)	1580.9 (278.8)
R-11-041 O to 044 O	783 (2672)	750 (2560)	4.17	311.3-312.2 (100.6-102.3)	3.9 (7.1)	1927.1 (339.9)
R-11-045 O to 048 O	2880 (9828)	2726 (9305)	5.32	310.3-314.2 (98.9-105.9)	20.4 (36.8)	1365.8 (240.9)

Table B.9. Summary of experimental conditions and results from Wilson plots for R-11
condensing on vertical Tube R

Series of runs	Condenser heat load [W (Btu/h)]		Difference (%)	Vapor temperature range [K (°F)]	Condensing temperature difference [K (°F)]	Condensing heat transfer coefficient [W/m ² ·K (Btu/h·ft ² ·°F)]
	Q _c	Q _w				
R-11-001 R to 004 R	880 (3002)	850 (2901)	3.4	312.1-313.6 (102.0-104.8)	2.4 (4.4)	3421.0 (603.4)
R-11-005 R to 008 R	3479 (11873)	3402 (11612)	2.2	309.0-317.0 (96.6-111.0)	15.0 (27.0)	2202.0 (388.0)
R-11-009 R to 012 R	1128 (3850)	1122 (3828)	0.6	311.6-314.0 (101.2-105.5)	3.4 (6.0)	3190.0 (563.0)
R-11-013 R to 016 R	3205 (10938)	3143 (10729)	1.9	309.5-316.3 (97.4-109.7)	13.7 (24.7)	2217.0 (391.0)
R-11-017 R to 020 R	1480 (5051)	1476 (5037)	0.3	311.0-313.5 (100.1-104.7)	4.9 (8.8)	2863.0 (505.0)
R-11-021 R to 024 R	2810 (9589)	2779 (9483)	1.1	309.6-315.5 (97.6-108.3)	11.5 (20.7)	2317.0 (409.0)
R-11-025 R to 029 R	1771 (6046)	1766 (6027)	0.3	310.7-313.9 (99.6-105.3)	6.2 (11.1)	2718.4 (479.4)
R-11-030 R to 033 R	2480 (8463)	2449 (8359)	1.2	309.9-315.5 (98.2-108.2)	9.7 (17.4)	2432.1 (429.0)
R-11-034 R to 037 R	2143 (7314)	2124 (7249)	0.9	310.0-314.0 (98.3-105.5)	7.9 (14.3)	2557.4 (451.1)

Table B.10. Summary of experimental conditions and results from Wilson plots for R-11 condensing on vertical Tube S

Series of runs	Condenser heat load [W (Btu/h)]		Difference (%)	Vapor temperature range [K (°F)]	Condensing temperature difference [K (°F)]	Condensing heat transfer coefficient [W/m ² ·K (Btu/h·ft ² ·°F)]
	Q _c	Q _w				
R-11-001 S to 004 S	2119 (7231)	2105 (7185)	0.6	310.0-313.8 (98.4-105.2)	7.5 (13.5)	2856.7 (503.8)
R-11-005 S to 008 S	1003 (3423)	996 (3399)	0.7	311.6-312.9 (101.2-103.5)	2.6 (4.7)	3906.7 (689.0)
R-11-009 S to 012 S	3315 (11313)	3375 (11518)	-1.8	312.5-318.8 (102.7-114.1)	16.5 (29.7)	2036.7 (359.0)
R-11-013 S to 016 S	1554 (5304)	1560 (5324)	-0.4	310.2-312.6 (98.6-103.0)	4.8 (8.6)	3296.0 (581.0)
R-11-017 S to 020 S	3093 (10556)	3061 (10448)	1.0	310.2-315.9 (98.7-109.0)	14.0 (25.3)	2234.0 (394.0)
R-11-021 S to 024 S	1228 (4193)	1228 (4190)	0.1	310.8-312.6 (99.8-103.0)	3.5 (6.2)	3605.5 (635.9)
R-11-025 S to 028 S	2754 (9401)	2708 (9242)	-1.7	309.2-314.1 (97.0-105.7)	11.4 (20.6)	2442.8 (430.8)
R-11-029 S to 031 S	751 (2563)	759 (2591)	-1.1	311.2-311.4 (100.1-100.8)	1.8 (3.2)	4300.5 (758.5)
R-11-032 S to 035 S	1862 (6355)	1875 (6399)	-0.7	310.7-314.0 (99.6-105.6)	6.1 (10.7)	3101.8 (547.1)

Table B.11. Summary of experimental conditions and results from Wilson plots for R-11
condensing on vertical Tube T

Series of runs	Condenser heat load [W (Btu/h)]		Difference (%)	Vapor temperature range [K (°F)]	Condensing temperature difference [K (°F)]	Condensing heat transfer coefficient [W/m ² ·K (Btu/h·ft ² ·°F)]
	Q _c	Q _w				
R-11-001 T to 004 T	2109 (7199)	2136 (7289)	-1.3	311.1-316.9 (100.4-110.7)	3.7 (6.7)	3789.7 (668.4)
R-11-005 T to 008 T	3791 (12940)	3794 (12948)	-0.1	310.9-322.4 (99.9-120.7)	9.6 (17.3)	2649.1 (467.2)
R-11-009 T to 012 T	1419 (4842)	1429 (4875)	-0.7	312.6-316.3 (103.0-109.7)	2.2 (4.0)	4307.1 (759.6)
R-11-013 T to 016 T	2919 (9962)	2908 (9926)	0.4	310.1-318.4 (98.4-113.4)	6.1 (11.0)	3203.3 (565.0)
R-11-017 T to 020 T	1800 (6142)	1812 (6183)	-0.7	312.1-317.3 (102.1-111.5)	3.1 (5.5)	3947.6 (696.2)
R-11-021 T to 024 T	3447 (11763)	3426 (11693)	0.6	310.0-320.2 (98.3-116.7)	8.2 (14.7)	2827.8 (498.7)
R-11-025 T to 028 T	2497 (8522)	2498 (8524)	0.0	310.6-318.1 (99.5-112.9)	4.7 (8.5)	3558.2 (627.5)
R-11-029 T to 032 T	4047 (13813)	4036 (13773)	0.3	313.8-326.4 (105.2-127.9)	11.4 (20.4)	2389.5 (421.4)
R-11-033 T to 036 T	1004 (3425)	998 (3407)	0.5	312.9-315.2 (103.5-107.6)	1.4 (2.6)	4750.5 (837.8)
R-11-037 T to 040 T	1046 (3572)	1005 (3431)	3.9	312.9-315.8 (103.5-108.7)	1.4 (2.6)	4937.0 (870.7)

Table B.12. Summary of experimental conditions and results from Wilson plots for R-11 condensing on vertical Tube U

Series of runs	Condenser heat load [W (Btu/h)]		Difference (%)	Vapor temperature range [K (°F)]	Condensing temperature difference [K (°F)]	Condensing heat transfer coefficient [W/m ² ·K (Btu/h·ft ² ·°F)]
	Q _c	Q _w				
R-11-001 U to 004 U	2093 (7144)	2082 (7107)	0.5	310.7–315.3 (99.5–107.9)	7.1 (12.8)	2547.3 (449.3)
R-11-005 U to 008 U	856 (2920)	870 (2968)	–1.6	311.1–313.2 (100.4–104.0)	1.6 (2.9)	4574.0 (806.7)
R-11-009 U to 012 U	3114 (10628)	3098 (10573)	0.5	313.7–321.3 (105.0–118.8)	13.2 (23.8)	2047.1 (361.0)
R-11-013 U to 016 U	1089 (3717)	1095 (3737)	–0.5	311.4–313.6 (100.8–104.9)	2.3 (4.1)	4160.3 (733.7)
R-11-017 U to 020 U	2759 (9417)	2737 (9341)	0.8	310.6–317.3 (99.4–111.4)	11.0 (19.8)	2182.5 (384.9)
R-11-021 U to 024 U	1418 (4839)	1434 (4895)	–1.2	311.1–314.3 (100.4–106.2)	3.6 (6.4)	3439.9 (606.7)
R-11-025 U to 028 U	2407 (8216)	2368 (8082)	1.63	311.2–316.8 (100.5–110.6)	9.0 (16.1)	2330.8 (411.4)
R-11-029 U to 032 U	1766 (6026)	1760 (6006)	0.3	311.1–314.6 (100.2–106.5)	5.3 (9.6)	2870.6 (506.3)

Appendix C

EXPERIMENTAL DATA

Tables C.1 through C.13 document 124 runs that yielded 494 heat transfer data points. The tables summarize experimental data used in data reduction and for construction of Wilson plots. Table C.1 is taken from Ref. 3. The tables list overall heat transfer coefficients, in addition to saturation pressures and heat balance checks. Water velocities are presented with Reynolds numbers for the various water flow rates. The information was generated by a computer code used for data reduction, and the runs are grouped in series corresponding to Wilson plots.

Table C.1. Experimental data for R-11 condensing on Tube A

Run No.	T _v (°F)	P (psia)	P _{sat} (psia)	F _c (gpm)	T _c (°F)	m _c (lb _m /h)	F _w (gpm)	v (ft/s)	Re	T _{w,in} (°F)	T _{w,out} (°F)	ΔT _w (°F)	ΔT (°F)	Q _c (Btu/h)	Q _w (Btu/h)	Δ (%)	U (Btu/h·ft ² ·°F)
R-11-037A	108.87	27.2	27.4	0.0807	97.63	58.56	21.8	17.6	59687.	81.80	82.27	0.47	26.84	4357.	4470.	-2.6	155.
R-11-038A	110.40	28.0	28.1	0.0807	99.78	58.44	7.6	6.1	20743.	81.18	82.38	1.18	28.63	4340.	4478.	-3.2	145.
R-11-039A	111.42	28.5	28.6	0.0815	101.54	58.90	5.2	4.2	14195.	80.93	82.65	1.70	29.63	4369.	4400.	-0.7	141.
R-11-040A	113.86	29.9	29.8	0.0803	104.02	57.88	3.0	2.4	8254.	81.01	83.86	2.81	31.42	4280.	4206.	1.7	130.
R-11-041A	98.40	23.0	22.8	0.0483	88.24	35.36	21.8	17.6	60307.	82.72	83.04	0.26	15.53	2665.	2806.	-5.3	164.
R-11-042A	99.07	23.4	23.1	0.0483	88.73	35.34	7.6	6.1	20971.	82.29	83.05	0.72	16.40	2662.	2749.	-3.3	155.
R-11-043A	99.47	23.7	23.2	0.0479	89.07	35.01	5.2	4.2	14338.	82.09	83.13	1.04	16.87	2636.	2698.	-2.3	149.
R-11-044A	100.88	24.0	23.8	0.0475	90.10	34.66	3.0	2.4	8292.	81.89	83.73	1.76	18.07	2605.	2634.	-1.1	138.
R-11-045A	101.33	24.0	24.0	0.0575	89.67	41.99	21.8	17.6	59997.	82.27	82.64	0.30	18.88	3154.	3317.	-5.2	160.
R-11-046A	102.12	24.4	24.3	0.0583	91.34	42.52	7.6	6.1	20762.	81.41	82.30	0.86	20.26	3191.	3257.	-2.1	150.
R-11-047A	102.79	24.7	24.6	0.0581	92.14	42.33	5.2	4.2	14191.	81.14	82.40	1.25	21.02	3174.	3232.	-1.8	144.
R-11-048A	104.57	25.4	25.4	0.0574	93.92	41.79	3.0	2.4	8231.	81.14	83.27	2.08	22.36	3127.	3118.	0.3	134.
R-11-049A	115.28	30.0	30.5	0.1054	105.88	75.86	21.8	17.6	58363.	79.92	80.51	0.53	35.07	5599.	5721.	-2.2	153.
R-11-050A	117.69	31.2	31.7	0.1064	109.06	76.33	7.6	6.1	20396.	79.63	81.18	1.52	37.28	5616.	5782.	-3.0	144.
R-11-051A	119.17	32.2	32.5	0.1064	110.79	76.20	5.2	4.2	13996.	79.54	81.76	2.17	38.52	5596.	5635.	-0.7	139.
R-11-052A	122.11	33.7	34.1	0.1062	113.57	75.84	3.0	2.4	8104.	79.64	82.23	2.55	41.17	5548.	5307.	4.3	129.
R-11-053A	120.86	32.9	33.4	0.1228	110.05	87.98	21.8	17.6	58313.	79.82	80.47	0.61	40.71	6447.	6613.	-2.6	151.
R-11-054A	123.40	34.2	34.8	0.1223	113.37	87.34	7.6	6.1	20419.	79.63	81.38	1.74	42.90	6378.	6613.	-3.7	142.
R-11-055A	125.42	35.4	36.0	0.1231	116.26	87.65	5.2	4.2	14075.	79.83	82.37	2.48	44.31	6384.	6447.	-1.0	138.
R-11-056A	129.34	37.7	38.3	0.1240	120.59	87.92	3.0	2.4	8248.	80.30	84.45	4.11	46.96	6370.	6157.	3.3	130.
R-11-057A	126.17	35.7	36.4	0.1482	119.35	105.24	21.5	17.3	56182.	77.90	78.67	0.71	47.88	7657.	7659.	-0.0	153.
R-11-058A	128.84	37.4	38.0	0.1474	121.87	104.39	7.6	6.1	19992.	77.78	79.84	2.00	50.03	7568.	7598.	-0.4	144.
R-11-059A	130.90	38.7	39.2	0.1478	124.07	104.49	5.2	4.2	13799.	78.04	80.98	2.90	51.40	7554.	7516.	0.5	140.
R-11-060A	135.99	41.9	42.4	0.1488	128.97	104.62	3.0	2.4	8127.	78.71	83.63	4.85	54.82	7512.	7259.	3.4	131.
R-11-061A	104.57	25.0	25.4	0.0698	92.99	50.81	21.8	17.6	59125.	81.05	81.48	0.36	23.30	3801.	3926.	-3.3	156.
R-11-062A	105.81	25.7	26.0	0.0700	94.67	50.88	7.6	6.1	20540.	80.44	81.52	1.03	24.83	3801.	3924.	-3.2	146.
R-11-063A	106.53	26.2	26.3	0.0702	95.63	51.00	5.2	4.2	14020.	80.03	81.54	1.51	25.75	3806.	3925.	-3.1	141.
R-11-064A	108.74	27.2	27.3	0.0700	98.04	50.72	3.0	2.4	8097.	79.57	82.18	2.58	27.87	3775.	3858.	-2.2	129.
R-11-065A	120.42	32.7	33.2	0.1349	111.38	96.55	21.8	17.6	54906.	75.03	75.77	0.67	45.02	7078.	7309.	-3.3	150.
R-11-066A	123.21	34.2	34.7	0.1355	114.67	96.64	7.6	6.1	19226.	74.79	76.69	1.87	47.47	7059.	7090.	-0.4	142.
R-11-067A	125.37	35.4	35.9	0.1362	117.41	96.94	5.2	4.2	13277.	75.08	77.84	2.72	48.91	7060.	7059.	0.0	138.
R-11-068A	130.13	38.2	38.7	0.1368	122.41	96.84	3.0	2.4	7824.	75.87	80.39	4.48	52.00	7009.	6704.	4.4	129.
R-11-069A	109.94	27.5	27.9	0.0945	98.40	68.50	21.8	17.6	56716.	77.66	78.20	0.48	32.01	5090.	5210.	-2.3	152.
R-11-070A	112.42	28.7	29.1	0.0958	102.26	69.19	7.6	6.1	19825.	77.42	78.86	1.39	34.28	5125.	5278.	-3.0	143.
R-11-071A	114.13	29.7	29.9	0.0962	104.63	69.31	5.2	4.2	13630.	77.50	79.56	2.00	35.61	5123.	5201.	-1.5	137.
R-11-072A	117.81	31.5	31.8	0.0960	108.39	68.88	3.0	2.4	7995.	78.11	81.59	3.48	37.97	5067.	5214.	-2.9	127.
R-11-073A	122.18	33.7	34.1	0.1570	113.72	112.10	21.8	17.6	51308.	69.72	70.55	0.77	52.04	8199.	8388.	-2.3	150.
R-11-074A	124.19	34.9	35.3	0.1577	116.42	112.34	7.6	6.1	17643.	67.99	70.25	2.20	55.07	8195.	8347.	-1.9	142.
R-11-075A	126.26	36.0	36.4	0.1582	118.70	112.39	5.2	4.2	12136.	67.92	71.11	3.14	56.75	8176.	8149.	0.3	138.
R-11-076A	132.93	39.9	40.5	0.1616	126.03	113.99	3.0	2.4	7148.	68.27	73.82	5.48	61.88	8218.	8222.	-0.1	127.
R-11-077A	94.54	21.0	21.3	0.0359	83.28	26.38	21.8	17.6	60257.	82.68	82.94	0.20	11.73	1998.	2175.	-8.9	163.
R-11-078A	94.90	21.4	21.4	0.0359	83.68	26.37	7.6	6.1	20925.	82.20	82.78	0.56	12.41	1997.	2131.	-6.7	154.
R-11-079A	95.27	21.4	21.6	0.0357	83.89	26.21	5.2	4.2	14338.	82.20	83.02	0.79	12.67	1983.	2039.	-2.8	150.
R-11-080A	96.43	21.9	22.0	0.0357	84.62	26.19	3.0	2.4	8311.	82.34	83.65	1.28	13.44	1979.	1911.	3.4	141.

Table C.2. Experimental data for R-11 condensing on Tube A-1

Run No.	T _v (°F)	P (psia)	P _{sat} (psia)	F _c (gpm)	T _c (°F)	m _c (lb _m /h)	F _w (gpm)	v (ft/s)	Re	T _{w,in} (°F)	T _{w,out} (°F)	ΔT _w (°F)	ΔT (°F)	Q _c (Btu/h)	Q _w (Btu/h)	Δ (%)	U (Btu/h-ft ² -°F)
R-11-001A1	99.23	22.7	23.1	0.0598	95.63	43.47	22.2	17.9	61406.	82.71	83.03	0.29	16.36	3274.	3212.	1.9	191.
R-11-002A1	100.40	23.3	23.6	0.0588	96.42	42.66	7.6	6.1	21054.	82.56	83.43	0.85	17.40	3208.	3234.	-0.8	176.
R-11-003A1	101.72	23.9	24.2	0.0588	97.42	42.62	5.2	4.2	14542.	83.16	84.38	1.21	17.95	3200.	3134.	2.1	170.
R-11-004A1	103.72	24.7	25.0	0.0577	98.69	41.79	3.0	2.4	8452.	83.37	85.40	2.03	19.34	3130.	3040.	2.9	155.
R-11-005A1	104.90	25.4	25.6	0.1268	102.33	91.58	22.0	17.7	48863.	65.58	66.23	0.64	39.00	6849.	7069.	-3.2	168.
R-11-006A1	108.33	26.9	27.1	0.1256	104.92	90.45	7.6	6.1	17137.	66.11	67.88	1.76	41.33	6735.	6680.	0.8	156.
R-11-007A1	110.66	27.9	28.2	0.1256	107.10	90.26	4.9	3.9	11102.	66.04	68.64	2.60	43.32	6701.	6366.	5.0	148.
R-11-008A1	115.32	30.4	30.5	0.1255	110.95	89.86	3.0	2.4	6862.	65.88	70.19	4.31	47.28	6632.	6457.	2.6	134.
R-11-009A1	108.31	26.9	27.1	0.0877	104.77	63.15	22.2	17.9	61347.	82.56	83.02	0.41	25.52	4702.	4585.	2.5	176.
R-11-010A1	110.35	27.9	28.1	0.0875	106.51	62.89	7.4	6.0	20534.	82.49	83.77	1.29	27.22	4671.	4766.	-2.0	164.
R-11-011A1	112.60	29.0	29.1	0.0889	108.23	63.80	5.2	4.2	14576.	83.07	84.86	1.80	28.64	4725.	4683.	0.9	158.
R-11-012A1	116.50	30.9	31.1	0.0900	111.78	64.39	3.0	2.4	8495.	83.27	86.35	3.06	31.69	4745.	4577.	3.5	143.
R-11-013A1	107.58	26.4	26.8	0.0443	102.18	31.97	22.2	17.9	71740.	96.44	96.67	0.19	11.02	2382.	2120.	11.0	206.
R-11-014A1	107.87	26.7	26.9	0.0443	102.63	31.95	7.6	6.1	24434.	95.63	96.26	0.63	11.92	2381.	2381.	-0.0	191.
R-11-015A1	108.53	26.9	27.2	0.0447	103.11	32.25	5.0	4.0	16036.	95.23	96.22	0.99	12.80	2401.	2466.	-2.7	179.
R-11-016A1	109.52	27.4	27.7	0.0447	103.78	32.23	3.0	2.4	9604.	94.77	96.35	1.59	13.96	2396.	2370.	1.1	164.
R-11-017A1	106.91	26.2	26.5	0.0990	103.92	71.39	22.2	17.9	57260.	77.00	77.51	0.47	29.66	5326.	5250.	1.4	172.
R-11-018A1	109.95	27.5	27.9	0.1008	106.21	72.52	7.6	6.1	19736.	77.08	78.49	1.40	32.16	5389.	5301.	1.6	160.
R-11-019A1	112.34	28.5	29.0	0.1023	108.50	73.43	5.2	4.2	13578.	77.17	79.28	2.09	34.11	5440.	5419.	0.4	152.
R-11-020A1	116.79	31.2	31.3	0.1032	112.45	73.82	3.0	2.4	7919.	77.29	80.88	3.57	37.71	5437.	5337.	1.8	138.
R-11-021A1	106.40	25.9	26.2	0.0761	103.04	54.94	22.2	17.9	62909.	84.66	85.07	0.36	21.53	4101.	4043.	1.4	182.
R-11-022A1	107.80	26.5	26.9	0.0751	104.25	54.11	7.6	6.1	21554.	84.40	85.47	1.09	22.86	4032.	4129.	-2.4	168.
R-11-023A1	108.89	26.9	27.4	0.0753	105.38	54.21	5.2	4.2	14756.	84.20	85.76	1.57	23.91	4034.	4078.	-1.1	161.
R-11-024A1	111.15	28.2	28.4	0.0751	106.89	53.97	3.0	2.4	8541.	83.97	86.55	2.57	25.89	4005.	3842.	4.1	148.
R-11-025A1	104.97	25.5	25.6	0.1144	102.50	82.59	22.2	17.9	51868.	69.30	69.89	0.55	35.38	6176.	6135.	0.7	167.
R-11-026A1	108.16	27.0	27.0	0.1144	104.90	82.37	7.6	6.1	17955.	69.61	71.22	1.61	37.74	6135.	6103.	0.5	155.
R-11-027A1	110.33	28.2	28.0	0.1152	107.20	82.79	5.2	4.2	12321.	69.45	71.81	2.35	39.69	6149.	6111.	0.6	148.
R-11-028A1	115.57	30.5	30.6	0.1163	112.02	83.18	3.0	2.4	7202.	69.59	73.65	4.05	43.96	6137.	6070.	1.1	133.
R-11-029A1	110.97	28.2	28.4	0.1410	108.33	101.21	22.2	17.9	50547.	67.35	68.05	0.68	43.27	7511.	7532.	-0.3	166.
R-11-030A1	114.44	30.0	30.1	0.1409	111.34	100.84	7.6	6.1	17490.	67.52	69.44	1.91	45.96	7451.	7269.	2.4	155.
R-11-031A1	117.12	31.5	31.4	0.1414	113.86	100.97	5.2	4.2	12045.	67.56	70.35	2.79	48.16	7435.	7242.	2.6	147.
R-11-032A1	123.34	34.4	34.8	0.1443	119.50	102.42	3.0	2.4	7047.	67.61	72.36	4.75	53.35	7480.	7127.	4.7	134.

Table C.3. Experimental data for R-11 condensing on Tube L.

Run No.	T_v (°F)	P (psia)	P_{sat} (psia)	F_c (gpm)	T_c (°F)	$\dot{m}_c$ (lb _m /h)	F_w (gpm)	v (ft/s)	Re	$T_{w,in}$ (°F)	$T_{w,out}$ (°F)	ΔT_w (°F)	ΔT (°F)	Q_c (Btu/h)	Q_w (Btu/h)	Δ (%)	U (Btu/h·ft ² ·°F)
R-11-001L	94.08	21.0	21.1	0.1419	91.27	103.49	22.0	17.7	61528.	83.41	84.14	0.70	10.30	7843.	7694.	1.9	506.
R-11-002L	97.35	22.2	22.4	0.1410	94.44	102.55	7.6	6.1	21340.	83.08	85.13	2.03	13.24	7741.	7716.	0.3	389.
R-11-003L	99.65	23.2	23.3	0.1418	96.50	102.91	5.2	4.2	14650.	82.91	85.86	2.95	15.26	7746.	7643.	1.3	337.
R-11-004L	104.68	25.2	25.5	0.1417	101.05	102.40	3.0	2.4	8528.	82.64	87.61	4.97	19.55	7660.	7436.	2.9	260.
R-11-005L	92.30	20.4	20.4	0.2519	89.90	184.02	21.8	17.6	50082.	67.68	69.02	1.31	23.95	13976.	14227.	-1.8	388.
R-11-006L	99.83	23.4	23.4	0.2558	97.34	185.55	7.6	6.1	17881.	68.26	71.96	3.69	29.72	13964.	14025.	-0.4	312.
R-11-007L	103.88	24.9	25.1	0.2556	101.03	184.77	5.2	4.2	12353.	68.20	73.45	5.24	33.05	13836.	13621.	1.6	278.
R-11-008L	114.55	30.0	30.1	0.2626	111.57	187.91	3.0	2.4	7290.	68.21	77.08	8.86	41.90	13882.	13267.	4.4	220.
R-11-009L	97.33	22.0	22.4	0.0708	94.03	51.55	22.0	17.7	68518.	92.92	93.31	0.34	4.22	3891.	3770.	3.1	613.
R-11-010L	98.23	22.2	22.7	0.0700	94.90	50.89	7.6	6.1	23513.	92.00	93.05	1.03	5.71	3837.	3899.	-1.6	447.
R-11-011L	99.13	22.7	23.1	0.0696	95.72	50.54	5.2	4.2	16086.	91.77	93.25	1.47	6.62	3807.	3807.	-0.0	332.
R-11-012L	101.35	23.7	24.0	0.0696	97.59	50.45	3.0	2.4	9302.	91.49	93.95	2.45	8.63	3790.	3659.	3.4	292.
R-11-013L	97.14	21.9	22.3	0.0702	94.02	51.05	22.0	17.7	68352.	92.70	93.10	0.36	4.24	3855.	3923.	-1.8	604.
R-11-014L	98.23	22.2	22.7	0.0693	94.96	50.38	7.6	6.1	23513.	92.00	93.05	1.03	5.71	3799.	3899.	-2.6	443.
R-11-015L	99.09	22.7	23.1	0.0693	95.87	50.34	5.2	4.2	16075.	91.70	93.20	1.48	6.64	3792.	3844.	-1.4	380.
R-11-016L	101.68	23.7	24.2	0.0703	98.07	50.97	3.0	2.4	9319.	91.64	94.13	2.48	8.80	3827.	3700.	3.3	289.
R-11-017L	95.38	21.2	21.6	0.1000	92.70	72.89	22.0	17.7	65066.	88.34	88.89	0.50	6.77	5515.	5490.	0.5	542.
R-11-018L	97.46	22.2	22.4	0.0992	94.69	72.14	7.4	6.0	21864.	87.76	89.29	1.54	8.93	5445.	5695.	-4.6	405.
R-11-019L	98.82	22.7	23.0	0.0992	95.83	72.07	5.2	4.2	15389.	87.61	89.72	2.12	10.15	5430.	5499.	-1.3	356.
R-11-020L	102.25	24.2	24.4	0.0995	98.89	72.06	3.0	2.4	8923.	87.33	90.87	3.52	13.15	5407.	5266.	2.6	273.
R-11-021L	94.40	20.7	21.2	0.1833	92.55	133.60	22.0	17.7	58535.	79.23	80.20	0.93	14.68	10121.	10240.	-1.2	458.
R-11-022L	99.17	22.7	23.1	0.1842	97.04	133.68	7.4	6.0	19880.	79.15	81.84	2.68	18.68	10068.	9898.	1.7	358.
R-11-023L	101.93	23.9	24.3	0.1853	99.63	134.15	5.2	4.2	14039.	79.00	82.79	3.78	21.04	10069.	9798.	2.7	318.
R-11-024L	97.69	22.2	22.5	0.0513	93.56	37.36	22.0	17.7	69814.	94.62	94.93	0.26	2.92	2819.	2904.	-3.0	643.
R-11-025L	98.13	22.4	22.7	0.0507	93.54	36.89	7.6	6.1	23953.	93.78	94.55	0.77	3.97	2782.	2922.	-5.1	466.
R-11-026L	98.50	22.5	22.8	0.0505	93.75	36.73	5.2	4.2	16325.	93.26	94.38	1.11	4.69	2768.	2885.	-4.2	393.
R-11-027L	99.89	23.0	23.4	0.0505	94.90	36.69	3.0	2.4	9399.	92.70	94.57	1.87	6.26	2761.	2800.	-1.4	293.
R-11-028L	96.45	21.7	22.0	0.0790	93.49	57.52	22.0	17.7	67242.	91.24	91.68	0.39	4.99	4347.	4252.	2.2	579.
R-11-029L	97.77	22.2	22.5	0.0790	94.60	57.46	7.6	6.1	23127.	90.49	91.66	1.15	6.69	4335.	4361.	-0.6	431.
R-11-030L	98.90	22.7	23.0	0.0792	95.52	57.56	5.2	4.2	15823.	90.22	91.93	1.69	7.82	4337.	4382.	-1.1	369.
R-11-031L	101.24	23.7	24.0	0.0790	97.19	57.32	3.0	2.4	9145.	89.84	92.62	2.77	10.01	4306.	4136.	3.9	286.
R-11-032L	94.11	20.7	21.1	0.1584	92.29	115.43	22.0	17.7	60327.	81.74	82.57	0.80	11.96	8747.	8737.	0.1	486.
R-11-033L	98.08	22.4	22.7	0.1592	96.05	115.65	7.6	6.1	20958.	81.47	83.77	2.29	15.46	8722.	8675.	0.5	375.
R-11-034L	100.64	23.2	23.7	0.1592	98.32	115.36	5.2	4.2	14404.	81.31	84.66	3.34	17.66	8673.	8662.	0.1	327.
R-11-035L	106.61	26.0	26.3	0.1614	103.92	116.33	3.0	2.4	8405.	81.11	86.73	5.62	22.69	8681.	8408.	3.1	254.
R-11-036L	95.38	21.4	21.6	0.1222	93.34	88.97	22.0	17.7	63749.	86.54	87.21	0.62	8.51	6732.	6772.	-0.6	526.
R-11-037L	98.12	22.5	22.7	0.1219	95.68	88.59	7.6	6.1	22069.	86.18	87.93	1.77	11.06	6681.	6689.	-0.1	402.
R-11-038L	100.26	23.4	23.6	0.1223	97.74	88.69	5.2	4.2	15161.	86.10	88.69	2.59	12.86	6671.	6716.	-0.7	345.
R-11-039L	104.39	25.0	25.3	0.1222	101.30	88.29	3.0	2.4	8809.	85.86	90.14	4.26	16.39	6607.	6370.	3.6	268.
R-11-040L	94.48	21.0	21.3	0.2132	92.16	155.42	21.8	17.6	55492.	75.66	76.78	1.08	18.26	11772.	11789.	-0.1	429.
R-11-041L	100.26	23.2	23.6	0.2155	97.82	156.25	7.6	6.1	19608.	75.73	78.82	3.08	22.98	11752.	11674.	0.7	340.
R-11-042L	103.76	24.7	25.1	0.2157	101.43	155.84	5.2	4.2	13521.	75.68	80.09	4.39	25.88	11671.	11394.	2.4	300.
R-11-043L	112.26	28.7	29.0	0.2190	109.32	157.02	3.0	2.4	7941.	75.55	83.06	7.49	32.95	11634.	11206.	3.7	235.

Table C.3 (continued)

Run No.	T _v (°F)	P (psia)	P _{sat} (psia)	F _c (gpm)	T _c (°F)	m _c (lb _m /h)	F _w (gpm)	v (ft/s)	Re	T _{w,in} (°F)	T _{w,out} (°F)	ΔT _w (°F)	ΔT (°F)	Q _c (Btu/h)	Q _w (Btu/h)	Δ (%)	U (Btu/h·ft ² ·°F)
R-11-044L	92.03	20.0	20.3	0.2321	89.88	169.54	21.8	17.6	52046.	70.60	71.80	1.17	20.83	12880.	12778.	0.8	411.
R-11-045L	98.54	22.5	22.9	0.2343	96.13	170.14	7.6	6.1	18458.	70.92	74.30	3.37	25.93	12824.	12762.	0.5	329.
R-11-046L	102.61	24.2	24.6	0.2360	99.93	170.77	5.2	4.2	12748.	70.92	75.72	4.79	29.29	12807.	12429.	3.0	291.
R-11-047L	112.82	29.0	29.3	0.2404	109.97	172.31	3.0	2.4	7554.	71.26	79.50	8.24	37.44	12758.	12327.	3.4	227.

Table C.4. Experimental data for R-11 condensing on Tube L-1

Run No.	T _v (°F)	P (psia)	P _{sat} (psia)	F _c (gpm)	T _c (°F)	m _c (lb _m /h)	F _w (gpm)	v (ft/s)	Re	T _{w,in} (°F)	T _{w,out} (°F)	ΔT _w (°F)	ΔT (°F)	Q _c (Btu/h)	Q _w (Btu/h)	Δ (%)	U (Btu/h·ft ² ·°F)
R-11-001L1	98.21	22.2	22.7	0.0653	93.81	47.50	22.0	17.7	69835.	94.62	94.98	0.32	3.41	3581.	3496.	2.4	698.
R-11-002L1	99.45	22.9	23.2	0.0655	94.74	47.61	7.6	6.1	24090.	94.20	95.14	0.94	4.78	3584.	3574.	0.3	499.
R-11-003L1	100.48	23.2	23.7	0.0648	95.68	47.10	5.0	4.0	15866.	94.08	95.47	1.39	5.71	3542.	3469.	2.0	413.
R-11-004L1	102.61	24.2	24.6	0.0653	97.17	47.35	2.9	2.3	9219.	93.76	96.11	2.35	7.68	3551.	3394.	4.4	308.
R-11-005L1	93.28	20.5	20.8	0.2156	91.27	157.30	21.8	17.6	56409.	76.94	78.07	1.09	15.77	11933.	11887.	0.4	503.
R-11-006L1	98.80	22.7	23.0	0.2173	96.48	157.77	7.6	6.1	19841.	76.63	79.79	3.14	20.59	11888.	11925.	-0.3	384.
R-11-007L1	102.70	24.4	24.6	0.2158	100.19	156.14	5.0	4.0	13161.	76.52	81.19	4.65	23.84	11709.	11599.	0.9	327.
R-11-008L1	110.92	28.0	28.3	0.2184	107.92	156.80	3.0	2.4	8022.	76.28	83.96	7.66	30.79	11638.	11459.	1.5	251.
R-11-009L1	97.83	22.5	22.6	0.0853	94.12	62.04	22.0	17.7	68425.	92.76	93.22	0.41	4.84	4680.	4504.	3.8	644.
R-11-010L1	99.17	23.0	23.1	0.0859	95.36	62.43	7.6	6.1	23502.	91.85	93.12	1.25	6.69	4702.	4728.	-0.5	468.
R-11-011L1	99.97	23.4	23.4	0.0855	96.09	62.08	5.2	4.2	16032.	91.32	93.12	1.78	7.75	4671.	4605.	1.4	401.
R-11-012L1	102.57	24.5	24.5	0.0853	97.74	61.83	3.0	2.4	9264.	90.87	93.85	2.97	10.21	4637.	4432.	4.4	302.
R-11-013L1	92.97	20.5	20.7	0.1878	90.59	137.12	21.8	17.6	58030.	79.26	80.25	0.96	13.21	10406.	10430.	-0.2	524.
R-11-014L1	97.52	22.2	22.4	0.1877	94.81	136.45	7.6	6.1	20358.	78.89	81.63	2.73	17.26	10297.	10340.	-0.4	397.
R-11-015L1	100.87	23.7	23.8	0.1888	98.01	136.83	5.2	4.2	14024.	78.82	82.80	3.97	20.06	10284.	10307.	-0.2	341.
R-11-016L1	108.48	26.9	27.2	0.1942	105.86	139.84	3.0	2.4	8222.	78.77	85.46	6.69	26.36	10411.	10007.	3.9	263.
R-11-017L1	97.43	22.2	22.4	0.1069	94.30	77.79	22.0	17.7	66913.	90.75	91.31	0.51	6.39	5872.	5621.	4.3	611.
R-11-018L1	99.45	22.9	23.2	0.1069	95.92	77.67	7.6	6.1	23033.	89.93	91.51	1.56	8.73	5848.	5917.	-1.2	445.
R-11-019L1	101.01	23.7	23.9	0.1071	97.34	77.72	5.2	4.2	15773.	89.65	91.94	2.28	10.22	5840.	5911.	-1.2	380.
R-11-020L1	104.50	25.0	25.4	0.1080	100.52	78.10	3.0	2.4	9145.	89.36	93.08	3.70	13.27	5843.	5535.	5.3	293.
R-11-021L1	93.54	20.7	20.9	0.1631	91.41	118.97	22.0	17.7	60514.	81.98	82.84	0.83	11.13	9022.	9099.	-0.9	539.
R-11-022L1	97.43	22.2	22.4	0.1634	94.89	118.80	7.6	6.1	21006.	81.62	83.99	2.35	14.62	8967.	8925.	0.5	408.
R-11-023L1	100.17	23.2	23.5	0.1640	97.34	119.00	5.2	4.2	14453.	81.57	84.96	3.38	16.91	8951.	8761.	2.1	352.
R-11-024L1	106.16	25.9	26.1	0.1652	102.83	119.22	3.0	2.4	8430.	81.33	87.01	5.68	21.99	8902.	8503.	4.5	269.
R-11-025L1	94.91	21.0	21.4	0.1384	92.65	100.86	22.0	17.7	63117.	85.53	86.27	0.70	9.01	7636.	7672.	-0.5	563.
R-11-026L1	97.90	22.2	22.6	0.1370	95.41	99.55	7.6	6.1	21842.	85.06	87.07	2.03	11.84	7509.	7669.	-2.1	422.
R-11-027L1	99.95	23.0	23.4	0.1374	96.91	99.68	5.2	4.2	14950.	84.76	87.66	2.91	13.74	7500.	7535.	-0.5	363.
R-11-028L1	104.68	25.4	25.5	0.1380	101.13	99.77	3.0	2.4	8672.	84.26	89.08	4.80	18.01	7463.	7173.	3.9	276.
R-11-029L1	92.13	20.0	20.4	0.2493	90.43	182.01	21.8	17.6	52973.	72.00	73.30	1.27	19.48	13826.	13834.	-0.1	472.
R-11-030L1	98.84	22.7	23.0	0.2507	96.55	182.02	7.6	6.1	18776.	72.11	75.71	3.59	24.92	13715.	13631.	0.6	366.
R-11-031L1	103.59	24.7	25.0	0.2543	101.09	183.83	5.2	4.2	13002.	72.20	77.46	5.25	28.76	13770.	13617.	1.1	318.
R-11-032L1	113.91	29.7	29.8	0.2598	111.08	185.96	3.0	2.4	7675.	72.18	81.03	8.84	37.30	13749.	13234.	3.7	245.
R-11-033L1	99.63	22.9	23.3	0.0523	94.81	38.05	22.0	17.7	71404.	96.79	97.10	0.27	2.68	2864.	2965.	-3.5	710.
R-11-034L1	100.46	23.4	23.6	0.0523	95.65	38.02	7.6	6.1	24586.	96.25	97.05	0.79	3.81	2859.	2990.	-4.6	499.
R-11-035L1	101.12	23.7	23.9	0.0523	96.24	38.00	5.2	4.2	16812.	96.03	97.16	1.13	4.52	2855.	2912.	-2.0	420.
R-11-036L1	102.68	24.2	24.6	0.0523	97.50	37.95	3.0	2.4	9707.	95.74	97.60	1.86	6.01	2846.	2770.	2.7	315.
R-11-037L1	92.29	20.2	20.4	0.2297	90.70	167.68	21.8	17.6	54566.	74.31	75.52	1.17	17.37	12735.	12757.	-0.2	488.
R-11-038L1	98.21	22.5	22.7	0.2301	96.09	167.11	7.6	6.1	19267.	74.24	77.57	3.32	22.31	12601.	12584.	0.1	376.
R-11-039L1	102.66	24.2	24.6	0.2316	100.45	167.49	5.2	4.2	13339.	74.41	79.24	4.82	25.83	12560.	12494.	0.5	323.
R-11-040L1	111.25	28.2	28.5	0.2341	108.67	168.01	3.0	2.4	7831.	74.21	82.19	7.95	33.05	12464.	11897.	4.5	251.

Table C.5. Experimental data for R-11 condensing on Tube L-3

Run No.	T_v (°F)	P (psia)	P_{sat} (psia)	F_c (gpm)	T_c (°F)	m_c (lb _m /h)	F_w (gpm)	v (ft/s)	Re	$T_{w,in}$ (°F)	$T_{w,out}$ (°F)	ΔT_w (°F)	ΔT (°F)	Q_c (Btu/h)	Q_w (Btu/h)	Δ (%)	U (Btu/h·ft ² ·°F)
R-11-001L3	98.79	20.9	21.4	0.1350	92.51	98.37	22.0	17.7	63438.	86.10	86.82	0.67	8.33	7449.	7320.	1.7	595.
R-11-002L3	97.90	22.2	22.6	0.1352	95.23	98.28	7.5	6.0	21652.	85.56	87.57	2.02	11.34	7414.	7557.	-1.9	435.
R-11-003L3	100.17	23.0	23.5	0.1357	97.46	98.46	5.2	4.2	15100.	85.64	88.47	2.84	13.12	7406.	7353.	0.7	375.
R-11-004L3	105.06	25.2	25.6	0.1360	101.76	98.25	3.0	2.4	8787.	85.40	90.17	4.75	17.28	7346.	7105.	3.3	283.
R-11-005L3	97.62	22.2	22.5	0.0827	94.07	60.16	22.2	17.9	69148.	92.90	93.34	0.40	4.50	4540.	4379.	3.5	671.
R-11-006L3	98.92	22.7	23.0	0.0822	94.44	59.82	7.6	6.1	23575.	92.15	93.36	1.19	6.16	4507.	4505.	0.1	487.
R-11-007L3	99.81	23.0	23.4	0.0813	94.99	59.10	5.2	4.2	16108.	91.77	93.50	1.71	7.18	4447.	4437.	0.2	412.
R-11-008L3	101.89	23.9	24.2	0.0794	96.48	57.66	3.0	2.4	9270.	91.00	93.83	2.82	9.48	4328.	4211.	2.7	304.
R-11-009L3	92.44	20.0	20.5	0.2507	90.52	183.03	22.0	17.7	54439.	73.39	78.68	1.26	18.40	13898.	13829.	0.5	502.
R-11-010L3	99.57	22.9	23.3	0.2526	97.27	183.22	7.6	6.1	19172.	73.69	77.36	3.66	24.05	13793.	13862.	-0.5	381.
R-11-011L3	104.07	24.9	25.2	0.2549	101.61	184.17	5.2	4.2	13237.	73.57	78.88	5.30	27.85	13787.	13752.	0.3	329.
R-11-012L3	113.58	29.2	29.6	0.2581	110.43	184.92	3.0	2.4	7779.	73.26	82.08	8.80	35.91	13678.	13168.	3.7	253.
R-11-013L3	93.64	20.5	20.9	0.1692	92.02	123.33	22.0	17.7	60677.	82.19	83.07	0.85	11.01	9352.	9318.	0.4	565.
R-11-014L3	97.69	22.2	22.5	0.1684	95.63	122.32	7.6	6.1	21083.	81.89	84.33	2.43	14.59	9229.	9202.	0.3	421.
R-11-015L3	100.44	23.2	23.6	0.1683	98.13	121.97	5.2	4.2	14505.	81.81	85.32	3.50	16.88	9172.	9077.	1.0	361.
R-11-016L3	106.30	25.9	26.2	0.1680	103.39	121.15	3.0	2.4	8467.	81.65	87.42	5.76	21.77	9044.	8622.	4.7	276.
R-11-017L3	98.00	22.2	22.6	0.0673	94.55	48.96	22.2	17.9	70288.	94.39	94.75	0.32	3.43	3693.	3494.	5.4	716.
R-11-018L3	99.13	21.5	23.1	0.0669	95.34	48.62	7.6	6.1	23994.	93.83	94.80	0.97	4.82	3662.	3672.	-0.3	506.
R-11-019L3	100.13	23.2	23.5	0.0660	96.37	47.95	5.2	4.2	16435.	93.71	95.13	1.42	5.72	3607.	3668.	-1.7	420.
R-11-020L3	102.27	24.0	24.4	0.0665	98.09	48.18	3.0	2.4	9513.	93.55	95.87	2.32	7.56	3615.	3465.	4.1	318.
R-11-021L3	93.40	20.4	20.8	0.2173	91.87	158.41	22.0	17.7	57514.	77.76	78.87	1.07	15.08	12015.	11777.	2.0	530.
R-11-022L3	99.19	22.7	23.1	0.2179	97.15	158.06	7.6	6.1	20135.	77.81	80.94	3.12	19.81	11904.	11830.	0.6	399.
R-11-023L3	103.33	24.5	24.9	0.2188	101.18	158.17	5.2	4.2	13949.	78.11	82.64	4.52	22.95	11852.	11734.	1.0	343.
R-11-024L3	111.20	28.0	28.5	0.2212	108.43	158.76	3.0	2.4	8170.	77.86	85.35	7.48	29.60	11779.	11200.	4.9	265.
R-11-025L3	96.80	21.7	22.2	0.1124	94.39	81.74	22.2	17.9	66913.	89.95	90.54	0.55	6.56	6175.	6049.	2.0	626.
R-11-026L3	99.05	22.7	23.1	0.1123	96.33	81.57	7.6	6.1	22876.	89.30	90.95	1.63	8.93	6144.	6185.	-0.7	458.
R-11-027L3	101.01	23.5	23.9	0.1123	98.11	81.40	5.2	4.2	15723.	89.33	91.71	2.36	10.49	6117.	6120.	-0.1	388.
R-11-028L3	104.97	25.2	25.6	0.1128	101.72	81.51	3.0	2.4	9140.	89.21	93.15	3.93	13.79	6095.	5871.	3.7	294.
R-11-029L3	92.61	20.2	20.5	0.1932	90.78	141.04	22.0	17.7	58340.	78.95	79.95	0.96	13.16	10708.	10570.	1.3	541.
R-11-030L3	97.67	22.0	22.5	0.1936	95.46	140.68	7.6	6.1	20362.	78.87	81.68	2.80	17.40	10615.	10632.	-0.2	406.
R-11-031L3	100.87	23.4	23.8	0.1939	98.34	140.55	5.2	4.2	14033.	78.84	82.87	4.02	20.01	10563.	10418.	1.4	351.
R-11-032L3	108.18	26.5	27.0	0.1952	105.04	140.59	3.0	2.4	8208.	78.58	85.37	6.79	26.21	10471.	10167.	2.9	266.
R-11-033L3	98.56	22.4	22.9	0.0533	93.56	38.82	22.2	17.9	71387.	95.81	96.11	0.26	2.68	2926.	2875.	1.7	749.
R-11-034L3	99.37	22.7	23.2	0.0531	94.02	38.64	7.6	6.1	24352.	95.25	96.04	0.79	3.73	2970.	2979.	-2.4	519.
R-11-035L3	100.15	22.9	23.5	0.0531	94.96	38.61	5.2	4.2	16675.	95.14	96.28	1.14	4.44	2905.	2942.	-1.3	435.
R-11-036L3	101.85	23.9	24.2	0.0531	96.35	38.56	3.0	2.4	9631.	94.86	96.77	1.91	6.04	2895.	2851.	1.5	319.
R-11-037L3	92.57	20.2	20.5	0.2315	90.86	168.94	22.0	17.7	55977.	75.59	76.78	1.15	16.39	12826.	12633.	1.5	520.
R-11-038L3	99.09	22.7	23.1	0.2323	96.87	168.61	7.6	6.1	19676.	75.86	79.23	3.35	21.55	12700.	12698.	0.0	392.
R-11-039L3	103.50	24.7	24.9	0.2346	101.18	169.57	5.2	4.2	13626.	76.06	80.94	4.87	25.00	12703.	12642.	0.5	338.
R-11-040L3	111.88	28.4	28.8	0.2362	109.04	169.43	3.0	2.4	8000.	75.91	83.88	7.95	31.99	12559.	11897.	5.3	261.

Table C.6. Experimental data for R-11 condensing on Tube L*

Run No.	T _y (°F)	P (psia)	P _{sat} (psia)	F _c (gpm)	T _c (°F)	m _c (lb _m /h)	F _w (gpm)	v (ft/s)	Re	T _{w,in} (°F)	T _{w,out} (°F)	ΔT _w (°F)	ΔT (°F)	Q _c (Btu/h)	Q _w (Btu/h)	Δ (%)	U (Btu/h·ft ² ·°F)
R-11-001L*	99.99	23.0	23.5	0.1310	97.17	95.04	22.2	19.9	69450.	91.21	91.88	0.62	8.45	7151.	6867.	4.0	563.
R-11-002L*	103.22	24.4	24.8	0.1310	100.31	94.73	7.6	6.8	24023.	91.51	93.39	1.89	10.77	7099.	7158.	-0.8	438.
R-11-003L*	105.36	25.3	25.8	0.1310	102.42	94.54	5.2	4.7	16552.	91.72	94.41	2.69	12.29	7066.	6975.	1.3	382.
R-11-004L*	110.10	27.4	27.9	0.1303	106.49	93.69	3.0	2.7	9634.	91.54	96.15	4.62	16.25	6961.	6898.	0.9	285.
R-11-005L*	99.85	23.2	23.4	0.0489	94.69	35.56	22.2	19.9	74055.	97.28	97.54	0.22	2.44	2676.	2429.	9.2	729.
R-11-006L*	100.19	23.4	23.5	0.0487	94.89	35.40	7.6	6.8	25200.	96.51	97.22	0.70	3.33	2663.	2657.	0.2	532.
R-11-007L*	100.46	23.4	23.6	0.0483	95.23	35.08	5.2	4.7	17180.	96.03	97.05	1.01	3.92	2638.	2620.	0.7	448.
R-11-008L*	101.81	23.9	24.2	0.0487	96.89	35.33	3.0	2.7	9908.	95.67	97.35	1.70	5.30	2653.	2536.	4.4	333.
R-11-009L*	100.15	23.5	23.5	0.0877	96.53	63.65	22.2	19.9	72240.	94.80	95.25	0.41	5.13	4788.	4556.	4.9	621.
R-11-010L*	101.43	24.0	24.1	0.0881	97.55	63.89	7.6	6.8	24653.	94.11	95.38	1.27	6.68	4799.	4796.	0.1	477.
R-11-011L*	102.48	24.5	24.5	0.0879	98.42	63.69	5.2	4.7	16862.	93.80	95.64	1.84	7.77	4777.	4758.	0.4	409.
R-11-012L*	105.26	25.7	25.7	0.0883	100.99	63.82	3.0	2.7	9745.	93.35	96.39	3.06	10.40	4771.	4575.	4.1	305.
R-11-013L*	101.62	24.2	24.1	0.2545	100.17	184.09	22.0	19.7	59671.	78.83	80.11	1.25	22.15	13823.	13676.	1.1	415.
R-11-014L*	107.60	26.4	26.8	0.2535	105.70	182.41	7.6	6.8	21084.	79.49	83.09	3.58	26.31	13595.	13578.	0.1	344.
R-11-015L*	112.10	28.4	28.9	0.2566	110.00	183.89	5.2	4.7	14597.	79.65	84.85	5.19	29.85	13628.	13472.	1.1	304.
R-11-016L*	121.87	33.5	34.0	0.2620	119.60	186.01	3.0	2.7	8609.	79.72	88.41	8.68	37.81	13611.	12993.	4.5	239.
R-11-017L*	100.42	23.6	23.6	0.1100	97.65	79.77	22.2	19.9	70971.	93.16	93.74	0.54	6.97	5999.	6026.	-0.5	572.
R-11-018L*	102.42	24.5	24.5	0.1094	99.41	79.19	7.6	6.8	24322.	92.75	94.34	1.59	8.88	5940.	6027.	-1.5	445.
R-11-019L*	104.03	25.2	25.2	0.1093	100.82	79.05	5.2	4.7	16691.	92.64	94.96	2.32	10.23	5918.	6006.	-1.5	385.
R-11-020L*	107.92	26.6	26.9	0.1097	104.18	79.07	3.0	2.7	9701.	92.54	96.39	3.86	13.45	5891.	5775.	2.0	291.
R-11-021L*	94.89	21.4	21.4	0.2134	93.77	155.29	22.0	19.7	58522.	77.38	78.47	1.05	16.97	11757.	11481.	2.4	461.
R-11-022L*	100.15	23.6	23.5	0.2120	98.62	153.59	7.6	6.8	20633.	78.03	81.06	3.01	20.61	11554.	11420.	1.2	373.
R-11-023L*	103.63	25.1	25.0	0.2125	101.82	153.47	5.2	4.7	14258.	78.18	82.51	4.33	23.29	11495.	11228.	2.3	328.
R-11-024L*	112.44	28.7	29.1	0.2135	109.92	153.03	3.0	2.7	8396.	78.29	85.72	7.42	30.44	11336.	11108.	2.0	248.
R-11-025L*	98.06	22.7	22.7	0.1544	96.25	112.13	22.0	19.7	65538.	86.94	87.72	0.75	10.73	8457.	8208.	3.0	524.
R-11-026L*	101.39	24.1	24.0	0.1528	99.41	110.61	7.6	6.8	22812.	86.87	89.08	2.21	13.42	8308.	8362.	-0.7	412.
R-11-027L*	103.96	25.1	25.1	0.1538	101.70	111.07	5.2	4.7	15708.	86.91	90.12	3.21	15.45	8316.	8317.	-0.0	358.
R-11-028L*	109.39	27.2	27.6	0.1544	106.75	111.02	3.0	2.7	9144.	86.59	91.98	5.39	20.11	8256.	8051.	2.5	273.
R-11-029L*	99.73	23.4	23.3	0.0655	95.45	47.58	22.2	19.9	73043.	96.00	96.34	0.30	3.56	3581.	3312.	7.5	668.
R-11-030L*	100.79	23.8	23.8	0.0644	96.22	46.77	7.6	6.8	24989.	95.63	96.58	0.94	4.68	3516.	3572.	-1.6	499.
R-11-031L*	101.62	24.2	24.1	0.0644	96.72	46.75	5.2	4.7	17116.	95.52	96.88	1.35	5.42	3510.	3501.	0.3	431.
R-11-032L*	103.81	25.1	25.1	0.0648	98.67	46.97	3.0	2.7	9896.	95.25	97.54	2.31	7.41	3518.	3442.	2.2	316.
R-11-033L*	96.73	22.2	22.1	0.1841	95.25	133.77	22.0	19.7	62408.	82.64	83.58	0.91	13.62	10106.	9977.	1.3	493.
R-11-034L*	100.99	23.9	23.9	0.1822	98.99	131.99	7.6	6.8	21831.	82.81	85.47	2.66	16.85	9919.	10089.	-1.7	391.
R-11-035L*	104.21	25.4	25.2	0.1844	101.95	133.16	5.2	4.7	15058.	82.88	86.74	3.86	19.40	9967.	10024.	-0.6	342.
R-11-036L*	111.15	28.1	28.4	0.1840	108.50	132.05	3.0	2.7	8827.	83.07	89.50	6.43	24.87	9798.	9608.	1.9	262.

Table C.7. Experimental data for R-11 condensing on Tube M

Run No.	T_v (°F)	P (psia)	P_{sat} (psia)	F_c (gpm)	T_c (°F)	m_c (lb _m /h)	F_w (gpm)	v (ft/s)	Re	$T_{w,in}$ (°F)	$T_{w,out}$ (°F)	ΔT_w (°F)	ΔT (°F)	Q_c (Btu/h)	Q_w (Btu/h)	Δ (%)	U (Btu/h·ft ² ·°F)
R-11-001H	101.01	23.9	23.9	0.0814	97.29	59.07	21.0	14.9	5135.	75.06	75.52	0.43	25.72	4439.	4463.	-0.5	164.
R-11-002H	102.02	24.4	24.3	0.0814	97.96	59.03	7.6	5.4	1865.	74.97	76.16	1.17	26.45	4431.	4451.	-0.5	159.
R-11-003H	102.94	24.7	24.7	0.0814	98.77	58.99	5.2	3.7	1283.	75.17	76.85	1.67	26.93	4422.	4327.	2.1	156.
R-11-004H	104.99	25.5	25.6	0.0828	100.70	59.88	3.0	2.1	750.	75.26	78.79	2.87	27.97	4478.	4300.	4.0	152.
R-11-005H	103.55	24.7	25.0	0.1310	100.64	94.71	21.0	14.9	4283.	61.51	62.24	0.71	41.67	7094.	7492.	-5.6	161.
R-11-006H	105.42	25.4	25.8	0.1303	102.12	94.12	7.6	5.4	1565.	61.62	63.45	1.83	42.89	7034.	6935.	1.4	155.
R-11-007H	106.49	25.9	26.3	0.1303	102.93	94.05	5.2	3.7	1075.	61.51	64.14	2.63	43.66	7020.	6821.	2.8	152.
R-11-008H	109.37	27.2	27.6	0.1296	105.47	93.31	3.0	2.1	629.	61.56	66.13	4.57	45.52	6939.	6846.	1.3	144.
R-11-009H	105.84	26.0	26.0	0.0437	98.11	31.66	21.3	15.1	6515.	93.87	94.14	0.24	11.83	2365.	2536.	-7.2	189.
R-11-010H	106.14	26.2	26.1	0.0435	98.56	31.49	7.6	5.4	2323.	93.62	94.29	0.66	12.18	2351.	2506.	-6.6	183.
R-11-011H	107.27	26.7	26.6	0.0435	99.95	31.45	5.2	3.7	1605.	94.36	95.31	0.95	12.44	2345.	2455.	-4.7	179.
R-11-012H	108.75	27.4	27.3	0.0438	101.55	31.67	3.0	2.1	935.	94.89	96.43	1.54	13.09	2357.	2295.	2.6	171.
R-11-013H	105.98	26.0	26.0	0.0434	98.52	31.48	21.3	15.1	6514.	93.85	94.13	0.24	11.99	2351.	2525.	-7.4	186.
R-11-014H	106.96	26.4	26.5	0.0437	99.81	31.60	7.6	5.4	2338.	94.16	94.84	0.67	12.46	2357.	2548.	-8.1	179.
R-11-015H	107.80	26.9	26.9	0.0437	100.68	31.57	5.2	3.7	1610.	94.62	95.58	0.95	12.69	2352.	2474.	-5.2	176.
R-11-016H	109.12	27.5	27.5	0.0437	102.35	31.52	3.0	2.1	938.	95.18	96.73	1.55	13.16	2345.	2312.	1.4	169.
R-11-017H	103.74	24.9	25.0	0.0658	98.93	47.66	21.0	14.9	5684.	83.20	83.59	0.35	20.35	3569.	3677.	-3.0	166.
R-11-018H	103.92	25.0	25.1	0.0656	98.89	47.50	7.6	5.4	2049.	82.61	83.58	0.95	20.82	3557.	3606.	-1.4	162.
R-11-019H	104.12	25.2	25.2	0.0647	98.91	46.88	5.2	3.7	1401.	82.31	83.70	1.38	21.11	3510.	3588.	-2.2	158.
R-11-020H	105.08	25.5	25.6	0.0647	99.55	46.86	3.0	2.1	810.	82.10	84.38	2.28	21.84	3503.	3414.	2.5	152.
R-11-021H	109.54	27.4	27.7	0.1557	106.35	111.99	20.7	14.7	4165.	60.53	61.35	0.80	48.60	8326.	8327.	-0.0	162.
R-11-022H	112.26	28.7	29.0	0.1559	108.72	111.84	7.6	5.4	1552.	60.88	63.03	2.15	50.30	8287.	8150.	1.7	156.
R-11-023H	113.80	29.5	29.7	0.1565	110.28	112.12	5.2	3.7	1068.	60.82	63.93	3.11	51.43	8291.	8094.	2.4	153.
R-11-024H	116.97	31.2	31.3	0.1568	112.93	112.08	3.0	2.1	626.	60.82	66.10	5.28	53.51	8254.	7915.	4.1	146.
R-11-025H	102.04	24.2	24.3	0.0986	98.38	71.44	21.0	14.9	4814.	70.00	70.56	0.53	31.76	5361.	5551.	-3.5	160.
R-11-026H	103.59	24.9	25.0	0.0988	99.65	71.50	7.6	5.4	1758.	70.25	71.67	1.41	32.63	5356.	5366.	-0.2	156.
R-11-027H	104.54	25.4	25.4	0.0994	100.37	71.91	5.2	3.7	1207.	70.18	72.23	2.04	33.34	5380.	5293.	1.6	153.
R-11-028H	106.63	26.4	26.3	0.0986	102.50	71.16	3.0	2.1	703.	70.14	73.61	3.46	34.75	5310.	5190.	2.3	145.
R-11-029H	101.68	24.2	24.2	0.1121	98.48	81.23	21.0	14.9	4540.	65.68	66.31	0.61	35.69	6099.	6401.	-4.9	162.
R-11-030H	103.48	24.9	24.9	0.1121	99.45	81.16	7.6	5.4	1657.	65.80	67.41	1.61	36.87	6080.	6126.	-0.7	156.
R-11-031H	104.70	25.4	25.5	0.1136	100.25	82.16	5.2	3.7	1138.	65.72	68.06	2.34	37.81	6146.	6080.	1.1	154.
R-11-032H	106.91	26.5	26.5	0.1139	102.25	82.27	3.0	2.1	663.	65.59	69.49	3.89	39.37	6137.	5833.	5.0	148.

Table C.8. Experimental data for R-11 condensing on Tube N

Run No.	T _v (°F)	P (psia)	P _{sat} (psia)	F _c (gpm)	T _c (°F)	m _c (lb _m /h)	F _w (gpm)	v (ft/s)	Re	T _{w,in} (°F)	T _{w,out} (°F)	ΔT _w (°F)	ΔT (°F)	Q _c (Btu/h)	Q _w (Btu/h)	Δ (%)	U (Btu/h-ft ² -°F)
R-11-001N	100.40	23.4	23.6	0.0424	92.84	30.92	19.0	16.9	57172.	88.22	88.53	0.27	12.02	2325.	2517.	-8.3	183.
R-11-002N	100.87	23.5	23.8	0.0424	93.13	30.91	7.6	6.7	22933.	88.28	88.95	0.66	12.25	2323.	2487.	-7.0	179.
R-11-003N	101.22	23.7	24.0	0.0424	93.39	30.91	5.2	4.6	15723.	88.33	89.25	0.91	12.43	2322.	2354.	-1.4	177.
R-11-004N	102.06	24.0	24.3	0.0424	93.93	30.89	3.0	2.7	9109.	88.34	89.95	1.59	12.92	2318.	2377.	-2.5	170.
R-11-005N	100.73	23.5	23.8	0.0425	93.20	30.98	19.0	16.9	57259.	88.34	88.67	0.28	12.22	2329.	2678.	-15.0	180.
R-11-006N	101.08	23.7	23.9	0.0423	93.42	30.83	7.6	6.7	22939.	88.30	88.98	0.67	12.44	2316.	2548.	-10.0	176.
R-11-007N	101.51	23.9	24.1	0.0423	93.81	30.81	5.2	4.6	15733.	88.37	89.31	0.93	12.67	2314.	2398.	-3.6	173.
R-11-008N	102.44	24.2	24.5	0.0425	94.46	30.95	3.0	2.7	9119.	88.43	90.06	1.61	13.20	2322.	2407.	-3.7	166.
R-11-009N	100.30	23.2	23.6	0.0975	96.59	70.79	18.6	16.5	43941.	68.61	69.24	0.60	31.37	5324.	5539.	-4.0	161.
R-11-010N	101.81	23.9	24.2	0.0983	98.03	71.28	7.6	6.7	18094.	68.78	70.21	1.42	32.31	5351.	5389.	-0.7	157.
R-11-011N	102.89	24.4	24.7	0.0985	99.05	71.36	5.1	4.5	12205.	68.83	70.93	2.09	33.01	5350.	5321.	0.5	153.
R-11-012N	104.47	25.2	25.4	0.0985	100.35	71.27	3.0	2.7	7244.	68.83	72.26	3.42	33.93	5333.	5124.	3.9	149.
R-11-013N	108.60	26.9	27.2	0.1553	105.36	111.77	18.4	16.3	38058.	59.05	60.00	0.93	49.07	8320.	8532.	-2.6	160.
R-11-014N	111.25	28.2	28.5	0.1554	107.94	111.60	7.4	6.6	15527.	59.40	61.61	2.20	50.75	8279.	8135.	1.7	154.
R-11-015N	112.42	28.7	29.1	0.1560	108.97	111.93	5.2	4.6	10972.	59.34	62.44	3.10	51.52	8291.	8060.	2.8	152.
R-11-016N	115.26	30.2	30.5	0.1562	111.50	111.80	3.0	2.7	6437.	59.44	64.66	5.22	53.21	8252.	7833.	5.1	147.
R-11-017N	99.79	23.2	23.4	0.0617	95.56	44.82	18.8	16.7	51759.	80.65	81.06	0.38	18.94	3373.	3545.	-5.1	168.
R-11-018N	100.24	23.4	23.6	0.0610	95.61	44.34	6.8	6.0	18762.	80.57	81.49	0.90	19.21	3335.	3070.	7.9	164.
R-11-019N	100.97	23.7	23.9	0.0617	96.18	44.79	5.2	4.6	14395.	80.63	81.96	1.32	19.68	3366.	3417.	-1.5	162.
R-11-020N	102.06	24.2	24.3	0.0617	97.15	44.75	3.0	2.7	8347.	80.59	82.82	2.21	20.35	3358.	3315.	1.3	156.
R-11-021N	102.66	24.4	24.6	0.1343	99.79	97.16	18.6	16.5	38076.	58.51	59.35	0.83	43.72	7287.	7683.	-5.4	158.
R-11-022N	104.52	25.2	25.4	0.1350	101.24	97.56	7.6	6.7	15749.	58.70	60.60	1.90	44.87	7299.	7204.	1.3	154.
R-11-023N	105.79	25.7	26.0	0.1350	102.42	97.45	5.2	4.6	10857.	58.80	61.54	2.74	45.62	7279.	7122.	2.2	151.
R-11-024N	108.38	26.9	27.1	0.1350	104.83	97.22	3.0	2.7	6362.	58.92	63.55	4.63	47.14	7239.	6945.	4.1	145.
R-11-025N	100.19	23.5	23.5	0.0788	95.54	57.24	18.6	16.5	47904.	75.31	75.83	0.48	24.62	4306.	4417.	-2.6	165.
R-11-026N	100.91	21.6	23.8	0.0786	95.83	57.07	7.6	6.7	19632.	75.22	76.38	1.14	25.11	4289.	4311.	-0.5	162.
R-11-027N	101.81	24.2	24.2	0.0788	96.65	57.18	5.2	4.6	13499.	75.36	77.01	1.64	25.62	4293.	4260.	0.8	159.
R-11-028N	103.35	24.9	24.9	0.0792	97.94	57.40	3.0	2.7	7848.	75.40	78.18	2.75	26.56	4301.	4119.	4.2	153.
R-11-029N	101.45	23.7	24.1	0.1157	98.13	83.90	18.4	16.3	40496.	63.45	64.20	0.73	37.62	6301.	6758.	-7.2	158.
R-11-030N	102.79	24.2	24.6	0.1153	99.07	83.52	7.6	6.7	16873.	63.63	65.26	1.63	38.34	6262.	6186.	1.2	155.
R-11-031N	103.68	24.7	25.0	0.1155	99.81	83.61	5.2	4.6	11568.	63.40	65.78	2.39	39.09	6263.	6200.	1.0	152.
R-11-032N	105.49	25.7	25.8	0.1157	101.28	83.65	3.0	2.7	6741.	63.31	67.29	3.98	40.20	6251.	5965.	4.6	147.

Table C.9. Experimental data for R-11 condensing on Tube O (no rod on water side)

Run No.	T _v (°F)	P (psia)	P _{sat} (psia)	F _c (gpm)	T _c (°F)	m _c (lb _m /h)	F _w (gpm)	v (ft/s)	Re	T _{w,in} (°F)	T _{w,out} (°F)	ΔT _w (°F)	ΔT (°F)	Q _c (Btu/h)	Q _w (Btu/h)	Δ (%)	U (Btu/h-ft ² -°F)
R-11-0010	95.91	21.7	21.8	0.1073	93.70	78.08	20.2	21.5	114290.	76.34	76.98	0.59	19.25	5904.	5956.	-0.9	276.
R-11-0020	97.41	22.2	22.4	0.1076	95.05	78.25	7.6	8.1	43190.	76.20	77.81	1.59	20.40	5907.	6032.	-2.1	261.
R-11-0030	98.37	22.7	22.8	0.1074	95.89	78.05	5.2	5.5	29698.	76.24	78.55	2.30	20.97	5884.	5967.	-1.4	253.
R-11-0040	99.95	23.5	23.4	0.1062	96.93	77.09	3.0	3.2	17293.	76.22	80.04	3.80	21.82	5800.	5687.	1.9	239.
R-11-0050	96.73	22.2	22.1	0.1582	95.08	114.99	20.2	21.5	100876.	66.69	67.59	0.86	29.59	8687.	8671.	0.2	265.
R-11-0060	99.45	23.2	23.2	0.1575	97.50	114.24	7.6	8.1	38729.	67.49	69.74	2.23	30.84	8601.	8476.	1.4	251.
R-11-0070	101.18	23.9	23.9	0.1586	99.01	114.85	5.2	5.5	26749.	67.67	70.94	3.25	31.87	8629.	8437.	2.2	244.
R-11-0080	104.14	25.2	25.2	0.1588	101.53	114.75	3.0	3.2	15687.	67.69	73.35	5.63	33.62	8590.	8434.	1.8	230.
R-11-0090	97.86	22.0	22.6	0.0593	94.19	43.13	20.2	21.5	131947.	88.37	88.73	0.32	9.31	3254.	3189.	2.0	315.
R-11-0100	98.29	22.2	22.8	0.0597	94.87	43.42	7.6	8.1	49471.	87.81	88.70	0.88	10.04	3274.	3324.	-1.5	294.
R-11-0110	98.56	22.4	22.9	0.0591	95.07	42.95	5.2	5.5	33831.	87.58	88.84	1.24	10.35	3237.	3222.	0.5	282.
R-11-0120	99.69	22.7	23.3	0.0599	95.90	43.53	3.0	3.2	19612.	87.55	89.69	2.12	11.07	3276.	3174.	3.1	267.
R-11-0130	101.64	23.9	24.1	0.1647	99.89	119.17	20.2	21.5	106725.	70.83	71.75	0.88	30.35	8948.	8883.	0.7	266.
R-11-0140	103.88	24.9	25.1	0.1625	101.70	117.37	7.6	8.1	40662.	71.22	73.51	2.27	31.51	8788.	8626.	1.8	251.
R-11-0150	105.63	25.5	25.9	0.1642	103.41	118.43	5.2	5.5	28043.	71.29	74.64	3.33	32.67	8849.	8652.	2.2	244.
R-11-0160	108.70	26.9	27.3	0.1653	106.33	118.90	3.0	3.2	16421.	71.27	76.93	5.64	34.60	8850.	8441.	4.6	230.
R-11-0170	99.31	22.7	23.2	0.0490	95.57	35.60	20.2	21.5	137043.	91.67	91.99	0.28	7.48	2680.	2787.	-4.0	323.
R-11-0180	99.67	22.9	23.3	0.0496	95.74	36.06	7.6	8.1	51415.	91.21	91.96	0.74	8.09	2714.	2797.	-3.1	302.
R-11-0190	99.95	23.0	23.4	0.0501	96.20	36.36	5.2	5.5	35136.	90.95	92.01	1.05	8.47	2736.	2722.	0.5	291.
R-11-0200	100.60	23.4	23.7	0.0496	96.63	36.03	3.0	3.2	20324.	90.82	92.60	1.79	8.89	2709.	2673.	1.3	274.
R-11-0210	96.69	21.9	22.1	0.1231	95.23	89.51	20.2	21.5	110449.	73.65	74.38	0.67	22.68	6762.	6792.	-0.5	269.
R-11-0220	98.45	22.5	22.8	0.1233	96.66	89.51	7.6	8.1	41896.	73.74	75.54	1.79	23.80	6748.	6798.	-0.8	255.
R-11-0230	99.57	23.0	23.3	0.1231	97.71	89.27	5.2	5.5	28856.	73.86	76.44	2.57	24.42	6720.	6675.	0.7	248.
R-11-0240	101.60	23.7	24.1	0.1230	99.27	89.07	3.0	3.2	16809.	73.72	78.08	4.34	25.70	6689.	6497.	2.9	234.
R-11-0250	98.43	22.4	22.8	0.0729	95.16	53.02	20.2	21.5	128917.	86.35	86.80	0.41	11.85	3997.	4105.	-2.7	304.
R-11-0260	99.67	22.9	23.3	0.0737	96.29	53.55	7.6	8.1	48658.	86.31	87.39	1.06	12.82	4031.	4028.	0.1	283.
R-11-0270	100.38	23.2	23.6	0.0739	96.93	53.65	5.2	5.5	33426.	86.41	87.96	1.54	13.19	4035.	3981.	1.3	276.
R-11-0280	101.62	23.9	24.1	0.0739	98.25	53.58	3.0	3.2	19397.	86.38	88.98	2.59	13.94	4023.	3864.	4.0	260.
R-11-0290	96.82	21.9	22.2	0.1363	95.30	99.09	20.2	21.5	107559.	71.49	72.27	0.74	24.94	7484.	7510.	-0.3	270.
R-11-0300	98.60	22.7	22.9	0.1361	96.98	98.74	7.8	8.3	41700.	71.35	73.26	1.90	26.30	7442.	7386.	0.8	255.
R-11-0310	99.57	23.0	23.3	0.1357	97.74	98.37	5.2	5.5	27920.	71.24	74.02	2.77	26.94	7406.	7191.	2.9	248.
R-11-0320	102.44	24.2	24.5	0.1360	100.27	98.40	3.0	3.2	16390.	71.53	76.38	4.82	28.49	7381.	7214.	2.3	233.
R-11-0330	98.41	22.5	22.8	0.0920	95.68	66.81	20.2	21.5	123396.	82.53	83.07	0.50	15.60	5037.	5079.	-0.8	291.
R-11-0340	99.71	23.0	23.3	0.0917	97.15	66.56	7.6	8.1	46582.	82.40	83.76	1.35	16.63	5010.	5103.	-1.9	271.
R-11-0350	100.54	23.4	23.7	0.0921	97.82	66.80	5.2	5.5	31985.	82.40	84.34	1.93	17.17	5023.	5004.	0.4	264.
R-11-0360	102.10	24.0	24.3	0.0923	99.21	66.87	3.0	3.2	18590.	82.36	85.60	3.23	18.12	5018.	4839.	3.6	250.
R-11-0370	97.25	22.2	22.3	0.1481	95.92	107.60	2.0	2.1	10367.	69.44	70.30	0.82	27.38	8123.	818.	89.9	267.
R-11-0380	99.49	23.0	23.2	0.1477	97.65	107.08	7.6	8.1	39975.	69.91	72.01	2.09	28.53	8062.	7922.	1.7	255.
R-11-0390	101.81	23.9	24.2	0.1498	100.05	108.38	4.9	5.2	26053.	70.16	73.38	3.20	30.04	8136.	7830.	3.8	244.
R-11-0400	104.14	25.0	25.2	0.1495	102.14	107.97	3.0	3.2	16137.	70.21	75.32	5.08	31.38	8082.	7602.	5.9	232.
R-11-0410	100.62	24.2	23.7	0.0489	94.26	35.59	20.5	21.8	141321.	93.09	93.39	0.26	7.38	2676.	2706.	-1.1	327.
R-11-0420	101.14	24.3	23.9	0.0491	94.55	35.73	7.4	7.9	51029.	92.92	93.62	0.70	7.87	2685.	2580.	3.9	307.
R-11-0430	101.58	24.5	24.1	0.0487	94.83	35.41	5.0	5.3	34544.	92.93	93.93	1.02	8.14	2659.	2530.	4.8	294.
R-11-0440	102.31	24.8	24.4	0.0489	95.36	35.55	2.9	3.1	20100.	92.88	94.55	1.67	8.60	2667.	2414.	9.5	280.

Table C.9 (continued)

Run No.	T_v (°F)	P (psia)	P_{sat} (psia)	F_c (gpm)	T_c (°F)	m_c (lb _m /h)	F_w (gpm)	v (ft/s)	Re	$T_{w,in}$ (°F)	$T_{w,out}$ (°F)	ΔT_w (°F)	ΔT (°F)	Q_c (Btu/h)	Q_w (Btu/h)	Δ (%)	U (Btu/h-ft ² -°F)
R-11-0450	98.90	23.9	23.0	0.1793	96.81	130.12	20.3	21.6	93111.	60.61	61.65	0.99	37.77	9804.	10012.	-2.1	234.
R-11-0460	101.37	24.4	24.0	0.1808	99.13	130.98	7.4	7.9	34546.	61.10	63.61	2.49	39.01	9835.	9204.	6.4	227.
R-11-0470	102.79	25.0	24.6	0.1812	100.29	131.05	5.0	5.3	23589.	61.31	64.87	3.56	39.70	9826.	8892.	9.5	223.
R-11-0480	105.86	26.1	26.0	0.1828	103.22	131.83	2.9	3.1	13887.	61.01	67.27	6.26	41.73	9847.	9069.	7.9	213.

Table C.10. Experimental data for R-11 condensing on Tube R

Run No.	T_v (°F)	P (psia)	P_{sat} (psia)	F_c (gpm)	T_c (°F)	m_c (lb _m /h)	F_w (gpm)	v (ft/s)	Re	$T_{w,in}$ (°F)	$T_{w,out}$ (°F)	ΔT_w (°F)	ΔT (°F)	Q_c (Btu/h)	Q_w (Btu/h)	Δ (%)	U (Btu/h·ft ² ·°F)
R-11-001R	102.04	24.6	24.3	0.0559	97.19	40.59	20.8	20.1	57720.	97.09	97.41	0.28	4.79	3046.	2865.	5.9	561.
R-11-002R	103.44	25.0	24.9	0.0551	98.21	39.93	7.6	7.3	21228.	97.45	98.23	0.78	5.59	2991.	2948.	1.5	471.
R-11-003R	103.76	25.1	25.1	0.0551	98.62	39.91	5.2	5.0	14499.	97.13	98.23	1.10	6.08	2989.	2855.	4.5	433.
R-11-004R	104.79	25.5	25.5	0.0551	99.33	39.89	3.0	2.9	8364.	96.70	98.64	1.96	7.12	2983.	2929.	1.8	369.
R-11-005R	96.58	22.3	22.1	0.2174	95.32	158.01	20.6	19.9	39466.	66.17	67.39	1.17	29.80	11939.	12064.	-1.1	353.
R-11-006R	102.12	24.4	24.3	0.2194	100.25	158.68	7.6	7.3	14869.	66.75	69.86	3.09	33.82	11908.	11727.	1.5	310.
R-11-007R	105.15	25.6	25.7	0.2198	103.02	158.59	5.2	5.0	10285.	66.87	71.33	4.44	36.05	11857.	11532.	2.7	290.
R-11-008R	110.97	28.2	28.4	0.2213	108.45	158.87	3.0	2.9	6064.	66.94	74.50	7.54	40.25	11790.	11299.	4.2	258.
R-11-009R	101.22	24.1	24.0	0.0701	96.96	50.84	20.8	20.1	56046.	94.25	94.66	0.37	6.76	3819.	3833.	-0.4	497.
R-11-010R	103.20	24.8	24.8	0.0721	99.35	52.21	7.6	7.3	20631.	94.61	95.64	1.03	8.08	3913.	3891.	0.6	427.
R-11-011R	103.94	25.1	25.1	0.0713	99.83	51.58	5.2	5.0	14138.	94.52	96.00	1.49	8.68	3862.	3849.	0.3	392.
R-11-012R	105.54	25.7	25.8	0.0704	100.91	50.92	3.0	2.9	8197.	94.46	96.95	2.51	9.83	3805.	3746.	1.6	341.
R-11-013R	97.39	21.5	22.4	0.2033	96.22	147.65	20.6	19.9	41098.	69.18	70.30	1.08	27.64	11144.	11086.	0.5	355.
R-11-014R	101.70	24.1	24.2	0.2007	99.97	145.21	7.6	7.3	15425.	69.58	72.46	2.87	30.68	10902.	10907.	-0.0	313.
R-11-015R	104.47	25.2	25.4	0.2015	102.59	145.43	5.1	4.9	10413.	69.35	73.59	4.23	33.00	10882.	10780.	0.9	290.
R-11-016R	109.69	27.4	27.7	0.2027	107.36	145.64	3.0	2.9	6242.	69.57	76.46	6.87	36.68	10826.	10282.	5.0	260.
R-11-017R	100.13	23.5	23.5	0.0937	96.63	68.00	20.8	20.1	53389.	89.92	90.46	0.50	9.94	5115.	5180.	-1.3	453.
R-11-018R	101.62	24.1	24.1	0.0930	97.97	67.46	7.5	7.2	19249.	89.49	90.87	1.38	11.44	5065.	5159.	-1.9	390.
R-11-019R	102.46	24.4	24.5	0.0926	98.62	67.11	5.2	5.0	13363.	89.33	91.24	1.91	12.17	5034.	4960.	1.5	364.
R-11-020R	104.68	25.4	25.5	0.0922	100.45	66.69	3.0	2.9	7765.	89.30	92.53	3.25	13.76	4989.	4859.	2.6	319.
R-11-021R	97.63	22.8	22.5	0.1770	96.07	128.58	20.6	19.9	43744.	74.08	75.06	0.94	23.06	9702.	9671.	0.3	371.
R-11-022R	101.24	23.9	24.0	0.1754	99.41	126.99	7.6	7.3	16319.	74.15	76.71	2.55	25.81	9540.	9661.	-1.3	326.
R-11-023R	104.01	25.1	25.2	0.1779	102.14	128.49	5.2	5.0	11269.	74.31	77.99	3.66	27.86	9620.	9498.	1.3	304.
R-11-024R	108.26	26.9	27.1	0.1773	106.02	127.54	3.0	2.9	6595.	74.19	80.34	6.14	30.99	9498.	9185.	3.3	270.
R-11-025R	99.55	23.0	23.3	0.1115	96.38	80.93	20.7	20.0	51208.	86.72	87.34	0.58	12.52	6093.	5949.	2.4	429.
R-11-026R	101.26	23.7	24.0	0.1106	98.01	80.20	7.6	7.3	18781.	86.13	87.75	1.61	14.32	6025.	6106.	-1.4	371.
R-11-027R	102.53	24.3	24.5	0.1114	99.13	80.69	5.2	5.0	12866.	85.89	88.21	2.32	15.48	6052.	6006.	0.8	344.
R-11-028R	105.29	25.5	25.7	0.1114	101.55	80.48	3.0	2.9	7480.	85.67	89.72	4.05	17.59	6016.	6053.	-0.6	301.
R-11-029R	98.15	22.7	22.7	0.1557	96.07	113.05	20.7	20.0	46389.	78.36	79.21	0.82	19.37	8525.	8479.	0.5	388.
R-11-030R	101.08	24.0	23.9	0.1544	98.67	111.88	7.6	7.3	17147.	78.21	80.43	2.22	21.75	8407.	8414.	-0.1	340.
R-11-031R	103.85	25.2	25.1	0.1568	101.22	113.32	5.2	5.0	11880.	78.71	81.95	3.24	23.52	8486.	8408.	0.9	318.
R-11-032R	108.21	26.7	27.1	0.1573	105.22	113.29	3.0	2.9	6976.	79.01	84.49	5.48	26.45	8437.	8206.	2.7	281.
R-11-033R	98.25	22.7	22.7	0.1355	96.09	98.43	20.7	20.0	48386.	81.81	82.56	0.72	16.07	7422.	7405.	0.2	407.
R-11-034R	100.60	23.7	23.7	0.1345	98.09	97.50	7.6	7.3	17831.	81.52	83.45	1.94	18.12	7331.	7341.	-0.1	357.
R-11-035R	102.10	24.4	24.3	0.1339	99.39	96.93	5.2	5.0	12241.	81.36	84.16	2.80	19.34	7274.	7254.	0.3	331.
R-11-036R	105.49	25.9	25.8	0.1340	102.44	96.77	3.0	2.9	7148.	81.40	86.11	4.71	21.74	7231.	7051.	2.5	293.

Table C.11. Experimental data for R-11 condensing on Tube S

Run No.	T _v (°F)	P (psia)	P _{sat} (psia)	F _c (gpm)	T _c (°F)	m _c (lb _m /h)	F _w (gpm)	v (ft/s)	Re	T _{w,in} (°F)	T _{w,out} (°F)	ΔT _w (°F)	ΔT (°F)	Q _c (Btu/h)	Q _w (Btu/h)	Δ (%)	U (Btu/h·ft ² ·°F)
R-11-001S	98.41	22.7	22.8	0.1337	96.46	97.03	18.9	19.1	46360.	82.95	83.78	0.79	15.04	7315.	7468.	-2.1	459.
R-11-002S	101.28	23.9	24.0	0.1330	98.95	96.35	7.6	7.7	18962.	83.82	85.73	1.92	16.51	7238.	7268.	-0.4	414.
R-11-003S	102.57	24.5	24.5	0.1326	100.13	95.95	5.2	5.3	13037.	83.79	86.57	2.78	17.39	7196.	7204.	-0.1	390.
R-11-004S	105.24	25.7	25.7	0.1330	102.29	96.02	3.0	3.0	7579.	83.53	86.11	4.58	19.42	7177.	6862.	4.4	349.
R-11-005S	101.20	24.0	24.0	0.0634	96.76	46.00	19.0	19.2	53766.	95.61	96.02	0.37	5.38	3456.	3511.	-1.6	606.
R-11-006S	101.72	24.2	24.2	0.0627	97.08	45.52	7.6	7.7	21470.	95.21	96.11	0.90	6.06	3418.	3396.	0.6	532.
R-11-007S	102.27	24.5	24.4	0.0627	97.59	45.50	5.2	5.3	14702.	95.09	96.39	1.30	6.53	3414.	3370.	1.3	493.
R-11-008S	103.48	25.0	24.9	0.0627	98.56	45.46	3.0	3.0	8503.	94.86	97.07	2.23	7.52	3406.	3328.	2.3	427.
R-11-009S	102.74	24.7	24.6	0.2123	100.91	153.51	18.7	18.9	38677.	69.25	70.57	1.27	32.83	11511.	11849.	-2.9	331.
R-11-010S	106.68	26.4	26.4	0.2112	104.50	152.20	7.6	7.7	16025.	69.80	72.89	3.08	35.33	11357.	11689.	-2.9	303.
R-11-011S	109.04	27.4	27.4	0.2110	106.77	151.67	5.2	5.3	11045.	69.71	74.08	4.35	37.15	11284.	11298.	-0.1	287.
R-11-012S	114.13	29.5	29.9	0.2099	111.52	150.24	3.0	3.0	6524.	70.00	77.62	7.61	40.33	11105.	11388.	-2.6	260.
R-11-013S	98.64	23.0	22.9	0.0982	95.43	71.37	19.0	19.2	49716.	88.62	89.25	0.59	9.71	5379.	5555.	-3.3	523.
R-11-014S	99.75	23.4	23.4	0.0970	96.40	70.41	7.6	7.7	19908.	88.31	89.74	1.41	10.73	5299.	5356.	-1.1	466.
R-11-015S	100.70	23.9	23.7	0.0968	97.27	70.20	5.2	5.3	13659.	88.25	90.28	2.04	11.44	5277.	5276.	0.0	435.
R-11-016S	102.98	24.8	24.7	0.0969	99.45	70.19	3.0	3.0	7957.	88.39	91.81	3.43	12.88	5261.	5119.	2.7	385.
R-11-017S	98.70	23.0	22.9	0.1953	97.27	141.68	18.7	18.9	39220.	70.35	71.55	1.15	27.75	10677.	10746.	-0.6	363.
R-11-018S	102.14	24.5	24.4	0.1943	100.35	140.53	7.6	7.7	16201.	70.90	73.68	2.76	29.85	10546.	10484.	0.6	333.
R-11-019S	104.61	25.6	25.4	0.1958	102.63	141.35	5.2	5.3	11183.	70.92	74.99	4.05	31.65	10575.	10509.	0.6	315.
R-11-020S	108.99	27.5	27.4	0.1950	106.65	140.18	3.0	3.0	6589.	71.16	77.96	6.79	34.43	10429.	10156.	2.6	286.
R-11-021S	99.79	23.4	23.4	0.0777	96.01	56.45	19.0	19.2	51963.	92.53	93.03	0.47	7.01	4249.	4410.	-3.8	572.
R-11-022S	100.66	23.8	23.7	0.0765	96.80	55.49	7.6	7.7	20790.	92.24	93.36	1.12	7.87	4172.	4228.	-1.4	500.
R-11-023S	101.45	24.2	24.1	0.0769	97.44	55.76	5.2	5.3	14265.	92.26	93.85	1.59	8.40	4188.	4113.	1.8	470.
R-11-024S	103.00	24.9	24.7	0.0767	98.91	55.53	3.0	3.0	8274.	92.19	94.86	2.68	9.48	4163.	4011.	3.7	414.
R-11-025S	96.95	22.3	22.2	0.1734	95.54	125.97	18.7	18.9	40931.	73.78	74.83	1.02	22.65	9513.	9507.	0.1	396.
R-11-026S	99.93	23.5	23.4	0.1723	98.19	124.87	7.6	7.7	16867.	74.14	76.61	2.46	24.56	9396.	9312.	0.9	361.
R-11-027S	101.85	24.3	24.2	0.1728	99.93	125.02	5.2	5.3	11609.	74.03	77.63	3.58	26.02	9385.	9298.	0.9	340.
R-11-028S	105.70	26.0	25.9	0.1728	103.39	124.61	3.0	3.0	6818.	74.22	80.22	5.97	28.48	9310.	8929.	4.1	308.
R-11-029S	100.13	23.5	23.5	0.0473	95.05	34.36	19.0	19.2	54038.	96.25	96.58	0.29	3.72	2585.	2702.	-4.5	656.
R-11-030S	100.52	23.7	23.7	0.0466	95.43	33.88	7.6	7.7	21584.	95.94	96.63	0.69	4.23	2547.	2612.	-2.5	568.
R-11-031S	100.81	23.9	23.8	0.0468	95.76	34.02	5.2	5.3	14756.	95.74	96.69	0.95	4.59	2557.	2451.	4.1	525.
R-11-032S	99.61	23.3	23.3	0.1167	97.38	84.62	19.0	19.2	48842.	87.06	87.78	0.67	12.19	6370.	6388.	-0.3	493.
R-11-033S	101.62	24.2	24.1	0.1172	98.93	84.92	7.6	7.7	19627.	86.96	88.67	1.71	13.81	6377.	6488.	-1.7	436.
R-11-034S	102.85	24.7	24.7	0.1168	100.19	84.51	5.2	5.3	13495.	87.00	89.45	2.45	14.62	6336.	6353.	-0.3	409.
R-11-035S	105.56	25.9	25.8	0.1175	102.65	84.83	3.0	3.0	7859.	86.90	91.16	4.27	16.53	6339.	6375.	-0.6	362.

Table C.12. Experimental data for R-11 condensing on Tube T

Run No.	T_v (°F)	P (psia)	P_{sat} (psia)	F_c (gpm)	T_c (°F)	m_c (lb _m /h)	F_w (gpm)	v (ft/s)	Re	$T_{w,in}$ (°F)	$T_{w,out}$ (°F)	ΔT_w (°F)	ΔT (°F)	Q_c (Btu/h)	Q_w (Btu/h)	Δ (%)	U (Btu/h·ft ² ·°F)
R-11-001T	100.36	24.3	23.6	0.1348	97.88	97.74	22.0	17.7	66845.	90.59	91.29	0.67	9.41	7351.	7386.	-0.5	486.
R-11-002T	103.44	25.4	24.9	0.1326	100.45	95.92	7.5	6.0	22795.	89.98	91.96	1.97	12.46	7186.	7344.	-2.2	359.
R-11-003T	105.58	26.3	25.9	0.1329	102.31	95.95	5.2	4.2	15843.	89.77	92.58	2.80	14.40	7169.	7244.	-1.0	310.
R-11-004T	110.74	28.2	28.2	0.1330	107.20	95.55	3.0	2.4	9242.	89.74	94.55	4.81	18.59	7093.	7195.	-1.4	238.
R-11-005T	99.87	23.9	23.4	0.2426	98.11	175.87	22.0	17.7	56842.	76.77	78.01	1.21	22.48	13234.	13248.	-0.1	367.
R-11-006T	107.13	26.6	26.6	0.2425	104.79	174.67	7.6	6.1	20089.	77.47	80.92	3.44	27.93	13026.	13032.	-0.0	291.
R-11-007T	111.67	28.7	28.7	0.2423	109.12	173.82	5.2	4.2	13886.	77.53	82.49	4.95	31.66	12888.	12854.	0.3	254.
R-11-008T	120.73	33.3	33.3	0.2420	117.52	172.14	3.0	2.4	8195.	77.57	86.13	8.53	38.88	12615.	12765.	-1.2	202.
R-11-009T	103.02	25.1	24.7	0.0900	98.93	65.22	22.0	17.7	71709.	97.09	97.58	0.46	5.69	4889.	5087.	-4.1	536.
R-11-010T	105.08	25.9	25.6	0.0900	100.60	65.10	7.6	6.1	24794.	96.77	98.06	1.28	7.67	4867.	4845.	0.5	396.
R-11-011T	106.63	26.6	26.3	0.0898	102.14	64.85	5.2	4.2	16989.	96.61	98.49	1.88	9.08	4839.	4856.	-0.4	332.
R-11-012T	109.69	27.8	27.7	0.0891	104.81	64.21	3.0	2.4	9847.	96.40	99.54	3.15	11.72	4773.	4695.	1.6	254.
R-11-013T	98.45	23.3	22.8	0.1855	96.48	134.64	22.0	17.7	61534.	83.30	84.27	0.93	14.66	10150.	10240.	-0.9	431.
R-11-014T	103.46	25.2	24.9	0.1840	101.05	132.98	7.6	6.1	21468.	83.28	85.92	2.62	18.85	9963.	9949.	0.1	329.
R-11-015T	106.96	26.5	26.5	0.1854	104.38	133.60	5.2	4.2	14792.	83.27	87.10	3.82	21.77	9966.	9905.	0.6	285.
R-11-016T	113.44	28.5	29.6	0.1843	110.23	132.08	3.0	2.4	8636.	83.08	89.56	6.47	27.12	9772.	9668.	1.1	224.
R-11-017T	102.10	24.6	24.3	0.1146	99.21	82.99	22.0	17.7	69544.	94.13	94.73	0.58	7.67	6228.	6367.	-2.2	506.
R-11-018T	104.90	25.7	25.6	0.1144	101.47	82.64	7.6	6.1	24072.	93.78	95.44	1.65	10.29	6180.	6254.	-1.2	374.
R-11-019T	107.10	26.6	26.5	0.1137	103.52	82.02	5.2	4.2	16555.	93.87	96.26	2.39	12.04	6117.	6195.	-1.3	317.
R-11-020T	111.49	27.7	28.6	0.1134	107.48	81.50	3.0	2.4	9650.	94.16	98.12	3.97	15.35	6045.	5921.	2.0	245.
R-11-021T	98.33	23.7	22.8	0.2194	96.48	159.26	22.0	17.7	58246.	78.76	79.89	1.09	19.01	12007.	11996.	0.1	394.
R-11-022T	104.86	25.9	25.5	0.2182	102.48	157.51	7.6	6.1	20470.	79.14	82.27	3.12	24.16	11780.	11822.	-0.4	304.
R-11-023T	109.22	27.7	27.5	0.2196	106.61	157.89	5.2	4.2	14165.	79.33	83.91	4.56	27.60	11744.	11843.	-0.8	265.
R-11-024T	116.71	31.2	31.2	0.2190	113.59	156.43	3.0	2.4	8314.	79.27	86.77	7.49	33.68	11524.	11213.	2.7	213.
R-11-025T	99.47	23.7	23.2	0.1583	96.98	114.86	22.0	17.7	64365.	87.28	88.10	0.79	11.78	8648.	8635.	0.2	457.
R-11-026T	103.70	25.3	25.0	0.1576	100.84	113.95	7.6	6.1	22357.	87.01	89.29	2.27	15.54	8535.	8582.	-0.5	342.
R-11-027T	106.63	26.4	26.3	0.1581	103.65	114.02	5.2	4.2	15383.	87.00	90.27	3.25	18.00	8508.	8428.	0.9	295.
R-11-028T	112.87	29.2	29.3	0.1582	109.39	113.46	3.0	2.4	8980.	86.82	92.48	5.67	23.22	8400.	8467.	-0.8	225.
R-11-029T	105.20	26.0	25.7	0.2607	103.00	188.10	22.0	17.7	58198.	78.59	79.93	1.30	25.94	14062.	14268.	-1.5	338.
R-11-030T	112.79	29.2	29.2	0.2614	110.13	187.31	7.6	6.1	20572.	79.26	82.95	3.68	31.69	13869.	13949.	-0.6	273.
R-11-031T	117.27	31.3	31.5	0.2610	114.25	186.31	5.2	4.2	14237.	79.42	84.65	5.22	35.24	13715.	13539.	1.3	243.
R-11-032T	127.91	37.0	37.4	0.2655	124.66	187.50	3.0	2.4	8427.	79.64	88.64	8.99	43.77	13611.	13449.	1.2	194.
R-11-033T	103.52	25.1	25.0	0.0638	98.79	46.21	22.0	17.7	73681.	99.65	100.00	0.32	3.70	3462.	3512.	-1.5	583.
R-11-034T	104.52	25.5	25.4	0.0640	99.75	46.32	7.6	6.1	25320.	98.88	99.80	0.91	5.18	3466.	3451.	0.4	417.
R-11-035T	105.29	25.8	25.7	0.0636	100.70	45.97	5.2	4.2	17302.	98.57	99.88	1.31	6.06	3436.	3380.	1.6	353.
R-11-036T	107.63	26.6	26.8	0.0621	102.55	44.81	3.0	2.4	10049.	98.76	100.92	2.19	7.79	3340.	3270.	2.1	267.
R-11-037T	103.50	25.1	24.9	0.0669	98.91	48.43	22.0	17.7	73634.	99.59	99.94	0.32	3.74	3628.	3512.	3.2	605.
R-11-038T	104.54	25.5	25.4	0.0666	99.93	48.22	7.6	6.1	25314.	98.86	99.78	0.91	5.22	3608.	3451.	4.4	430.
R-11-039T	105.42	25.9	25.8	0.0660	100.89	47.71	5.2	4.2	17308.	98.59	99.92	1.33	6.17	3566.	3431.	3.8	360.
R-11-040T	108.72	27.1	27.3	0.0649	103.28	46.83	3.0	2.4	10156.	99.73	101.92	2.22	7.89	3486.	3318.	4.8	275.

Table C.13. Experimental data for R-11 condensing on Tube U

Run No.	T_v (°F)	P (psia)	P_{sat} (psia)	F_c (gpm)	T_c (°F)	m_c (lb _m /h)	F_w (gpm)	v (ft/s)	Re	$T_{w,in}$ (°F)	$T_{w,out}$ (°F)	ΔT_w (°F)	ΔT (°F)	Q_c (Btu/h)	Q_w (Btu/h)	Δ (%)	U (Btu/h·ft ² ·°F)
R-11-001U	99.51	23.2	23.3	0.1334	97.00	96.83	23.0	17.5	64186.	84.25	84.92	0.64	14.93	7290.	7355.	-0.9	394.
R-11-002U	101.95	24.3	24.3	0.1312	98.56	95.07	7.6	5.8	21279.	83.91	85.79	1.88	17.10	7136.	7113.	0.3	337.
R-11-003U	104.10	25.2	25.2	0.1312	100.89	94.86	5.2	4.0	14644.	83.98	86.70	2.71	18.76	7101.	7043.	0.8	306.
R-11-004U	107.89	27.0	26.9	0.1313	104.14	94.65	3.0	2.3	8524.	83.90	88.55	4.66	21.67	7052.	6962.	1.3	263.
R-11-005U	100.38	23.6	23.6	0.0539	95.48	39.15	23.0	17.5	73593.	96.59	96.88	0.27	3.64	2944.	3065.	-4.1	653.
R-11-006U	101.51	24.1	24.1	0.0534	96.09	38.82	7.6	5.8	24356.	96.49	97.26	0.78	4.64	2915.	2937.	-0.7	508.
R-11-007U	102.38	24.5	24.5	0.0534	96.61	38.80	5.2	4.0	16707.	96.53	97.68	1.16	5.27	2911.	3000.	-3.1	446.
R-11-008U	104.01	25.2	25.2	0.0537	98.62	38.88	3.0	2.3	9682.	96.57	98.45	1.91	6.50	2911.	2855.	1.9	362.
R-11-009U	104.97	25.6	25.6	0.2011	102.91	145.10	23.0	17.5	59001.	77.27	78.25	0.96	27.21	10850.	10993.	-1.3	322.
R-11-010U	109.47	27.4	27.6	0.1990	106.89	143.03	7.6	5.8	19786.	77.54	80.32	2.78	30.54	10635.	10533.	1.0	281.
R-11-011U	112.12	28.5	28.9	0.1988	109.27	142.61	5.2	4.0	13614.	77.38	81.37	3.98	32.75	10568.	10333.	2.2	261.
R-11-012U	118.75	31.8	32.3	0.1997	115.49	142.37	3.0	2.3	8034.	77.68	84.72	7.03	37.55	10460.	10516.	-0.5	225.
R-11-013U	100.79	23.7	23.8	0.0689	96.16	50.07	23.0	17.5	72886.	95.54	95.89	0.33	5.07	3764.	3781.	-0.4	600.
R-11-014U	102.02	24.3	24.3	0.0685	96.83	49.73	7.6	5.8	24070.	95.18	96.15	0.99	6.35	3732.	3740.	-0.2	475.
R-11-015U	103.00	24.7	24.7	0.0679	97.92	49.21	5.2	4.0	16502.	95.13	96.56	1.45	7.16	3689.	3758.	-1.9	416.
R-11-016U	104.86	25.5	25.5	0.0681	99.69	49.28	3.0	2.3	9534.	94.91	97.33	2.46	8.74	3686.	3666.	0.5	341.
R-11-017U	99.41	23.2	23.2	0.1761	97.57	127.68	23.0	17.5	58287.	76.36	77.24	0.85	22.61	9614.	9730.	-1.2	343.
R-11-018U	103.57	25.0	25.0	0.1738	100.99	125.64	7.6	5.8	19535.	76.66	79.17	2.50	25.65	9411.	9483.	-0.8	296.
R-11-019U	106.19	26.2	26.1	0.1740	103.22	125.53	5.2	4.0	13461.	76.69	80.27	3.58	27.71	9373.	9277.	1.0	273.
R-11-020U	111.39	28.2	28.6	0.1741	107.82	125.00	3.0	2.3	7892.	76.77	82.76	5.98	31.62	9272.	8952.	3.5	237.
R-11-021U	100.36	23.5	23.6	0.0893	96.55	64.85	23.0	17.5	70371.	92.36	92.82	0.44	7.77	4877.	5018.	-2.9	507.
R-11-022U	102.06	24.2	24.3	0.0891	97.82	64.62	7.6	5.8	23263.	91.99	93.27	1.29	9.43	4849.	4876.	-0.5	415.
R-11-023U	103.33	24.8	24.9	0.0889	98.95	64.39	5.2	4.0	15949.	91.87	93.74	1.87	10.52	4825.	4854.	-0.6	370.
R-11-024U	106.16	26.0	26.1	0.0891	101.45	64.35	3.0	2.3	9270.	91.85	95.07	3.24	12.70	4805.	4840.	-0.7	306.
R-11-025U	100.46	23.6	23.6	0.1526	98.19	110.59	23.0	17.5	62244.	81.68	82.43	0.71	18.41	8316.	8170.	1.8	365.
R-11-026U	103.79	25.1	25.1	0.1515	101.07	109.54	7.6	5.8	20714.	81.55	83.71	2.16	21.16	8203.	8175.	0.4	313.
R-11-027U	106.14	26.1	26.1	0.1521	103.26	109.72	5.2	4.0	14259.	81.56	84.71	3.15	23.01	8192.	8161.	0.4	288.
R-11-028U	110.63	27.7	28.2	0.1528	107.32	109.81	3.0	2.3	8326.	81.49	86.76	5.27	26.51	8153.	7883.	3.3	248.
R-11-029U	100.24	23.5	23.6	0.1116	97.63	80.96	23.0	17.5	67514.	88.71	89.26	0.52	11.25	6090.	6003.	1.4	437.
R-11-030U	102.46	24.4	24.5	0.1108	99.39	80.22	7.6	5.8	22366.	88.40	90.01	1.61	13.26	6017.	6098.	-1.4	367.
R-11-031U	103.72	25.0	25.0	0.1116	100.48	80.71	5.2	4.0	15274.	87.88	90.20	2.32	14.68	6045.	6014.	0.5	333.
R-11-032U	106.51	26.2	26.3	0.1105	102.91	79.77	3.0	2.3	8846.	87.40	91.34	3.96	17.14	5953.	5920.	0.6	281.

Appendix D

SI CONVERSION FACTORS

An attempt has been made to present all key tables and figures in dual units (ACU and SI). The following conversion factors may be used to convert from ACU to SI units:

<u>To convert from</u>	<u>To</u>	<u>Multiply by</u>
Btu/h	W	0.2929
Btu/h·ft ²	W/m ²	3.152
Btu/h·ft·°F	W/m·K	1.730
Btu/h·ft ² ·°F	W/m ² ·K	5.675
Btu/lb _m	J/kg	2.324×10^3
Btu/lb _m ·°F	J/kg·K	4.184×10^3
ft	m	0.3048
ft ²	m ²	0.0929
ft/h ²	m/s ²	2.35×10^{-8}
ft/s	m/s	0.3048
gpm	m ³ /s	6.309×10^{-5}
in.	cm	2.54
lb _f /ft	N/m	14.59
lb _m /ft ³	kg/m ³	16.02
lb _m /h·ft	Pa·s	4.134×10^{-4}
lb _m /h·ft ²	Pa·s/m	1.356×10^{-3}
psia	Pa	6.895×10^3
Δ(°F)	Δ(K) or Δ(°C)	0.5556

Temperature conversion: $T(K) = 5/9 \times [T(^{\circ}F) - 32] + 273.15$

$T(^{\circ}C) = 5/9 \times [T(^{\circ}F) - 32]$

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