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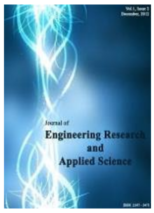

Experimental Investigation of the Pressure Drop of the Liquid Refrigerant in the Copper Tube Used in Air Conditioning Condensers

Gökçen Özkara Altıntop, Kemal Ermiş*, Alpaslan Alkan

Mechanical Engineering, Sakarya University of Applied Sciences, Sakarya, Türkiye

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Abstract
Air-conditioning systems used in vehicles are required to deliver higher performance than those used in residential or stationary building applications due to their dynamic operating environments, stringent thermal comfort requirements, and the limited space available for system installation. Pressure drop in the tubes used in condensers and evaporators of automotive Heating, Ventilation, and Air Conditioning (HVAC) systems significantly affects compressor sizing and overall system performance. In HVAC applications, minimizing pressure drop while maintaining a high heat transfer coefficient is essential for improving energy efficiency and reducing compressor power consumption. This study presents an experimental investigation of the pressure drop characteristics of liquid refrigerants R-134a and R-1234yf flowing through a smooth circular copper tube. The variations in pressure drop were analyzed as a function of refrigerant mass flux and Reynolds number. In addition, friction factors were determined from the experimental data and compared with the widely used Blasius correlation. The resulting coefficients were evaluated against those predicted by the Blasius equation. The results indicate that the frictional pressure drop increases with increasing refrigerant mass flux for both refrigerants. The findings contribute to a better understanding of refrigerant flow behavior in compact heat exchanger tubes and provide valuable data for the design and optimization of high-performance automotive HVAC systems.

Keywords: *Air condition, Pressure drop, Friction factor, R-134a, R-1234yf*

1. Introduction

In refrigeration and air-conditioning systems, refrigerant condensation in tubes (or condenser tubes) is the process where the refrigerant changes from a high-pressure vapor to a high-pressure liquid by rejecting heat to the surroundings. Single-phase liquid refrigerant flow in small-diameter tubes and compact heat exchangers is widely encountered in air-conditioning systems, automotive HVAC units, airborne vapor-compression systems, and power-generation applications. Accurate prediction of the associated pressure drop is essential for system design, as it directly influences compressor power consumption, system efficiency, and overall thermal performance [1, 2]. Single-phase liquid pressure drop in microchannels and minichannels plays a critical role in the design and optimization of compact thermal management systems. Owing to their high surface-area-to-volume ratio and compact geometry, these channels are widely employed in automotive and air-conditioning HVAC condensers and evaporators, heat pipes, thermosyphons, and other advanced thermal control devices. Accurate prediction of liquid-phase pressure drop is essential for minimizing pumping or compressor power requirements while maintaining high thermal performance and system efficiency [3]. Automotive air-conditioning systems are required to occupy minimal space within both the passenger compartment and the engine compartment while maintaining high thermal performance and low energy consumption. Since the compressor is mechanically driven by the vehicle engine, minimizing the power demand of the air-conditioning system is essential for improving overall vehicle efficiency. Among the major components of an automotive Heating, Ventilation, and Air Conditioning (HVAC) system, condensers and evaporators play a critical role in determining system performance. The pressure drop occurring in the tubes through which the refrigerant flows directly affects the sizing and power requirements of the compressor. Excessive pressure losses require larger compressor capacities and higher power consumption, thereby reducing the overall efficiency of the HVAC system. Consequently, minimizing pressure drop while maintaining a high heat transfer coefficient is a key objective in the design of automotive heat exchangers.

*Corresponding author: ermis@subu.edu.tr

The influence of hydraulic diameter on the performance of tubes used in evaporator and condenser units has been investigated by several researchers [4]. In particular, both single-phase and two-phase pressure drops are commonly evaluated in heat transfer studies involving tubes and channels used in automotive condensers and evaporators. Accurate determination of single-phase liquid pressure drop is especially important because these data are frequently employed in the prediction and analysis of two-phase (liquid-vapor) heat transfer and pressure drop characteristics [5–7]. The Blasius correlation has been widely accepted as a reliable reference for predicting friction factors in turbulent single-phase flow and is commonly used for comparison with experimental results reported in the literature [8–13].

In the present study, the pressure drop characteristics of liquid refrigerant R-134a and R-1234yf flowing through copper tube were investigated experimentally. The variation of pressure drop with refrigerant mass flux and Reynolds number was analyzed in detail. Friction factors obtained from the experimental data were compared with the well-known Blasius correlation. The agreement between the experimental results and the values predicted by the Blasius equation was evaluated, and the corresponding correlation coefficients were determined. The results demonstrated that the measured friction factors are in good agreement with the predictions of turbulent flow correlations.

2. Materials and Methods

The experimental study of adiabatic liquid refrigerant pressure drop was carried out using the copper tube shown in Figure 1. Pressure drop measurements were performed for liquid refrigerant flow through the test tube under adiabatic operating conditions.

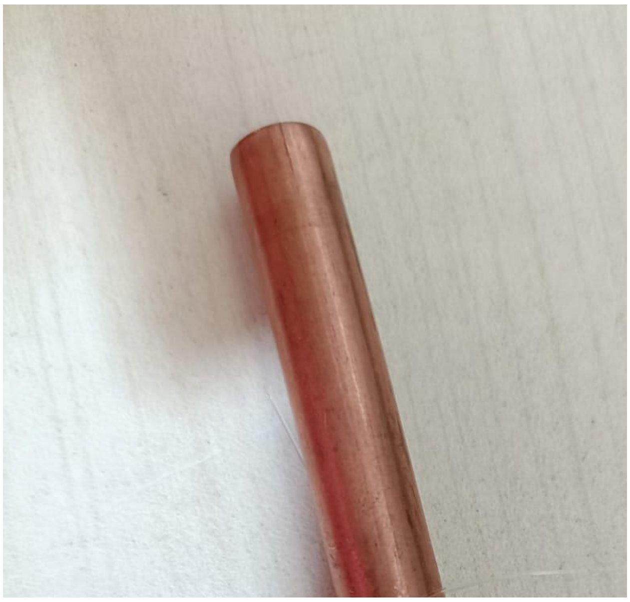

Figure 1. Photograph of the copper tube employed in the experimental study.

Table 1. Geometric dimensions of the copper tube.

Parameter	Value
Length (mm)	733
Wall thickness (mm)	1
Flow area (mm²)	28.27
Hydraulic diameter (mm)	6
Wetted perimeter (mm)	18.85

The experimental study of adiabatic liquid refrigerant pressure drop was performed in a copper tube having an internal hydraulic diameter of 6 mm, as illustrated in Figure 1. The obtained experimental data were subsequently compared with the values predicted by the Blasius equation presented below.

$$f_{blas} = 0.079 Re_{Dh}^{-0.25} \quad (1)$$

The geometric parameters and dimensions of the copper tube used in the experiments are presented in Table 1.

2.1. Experimental Setup

Photograph of the test facility is shown in Figure 2. The test facility consists of a test section, a refrigerant circulation loop, and a water loop. Inlet and outlet plenums were employed to measure the differential pressure across the test section. Pressure drop data for liquid-phase R-134a and R-1234yf refrigerants were obtained under adiabatic conditions in a horizontal tube with a length of 733 mm.

Figure 2. Photograph of the test facility.

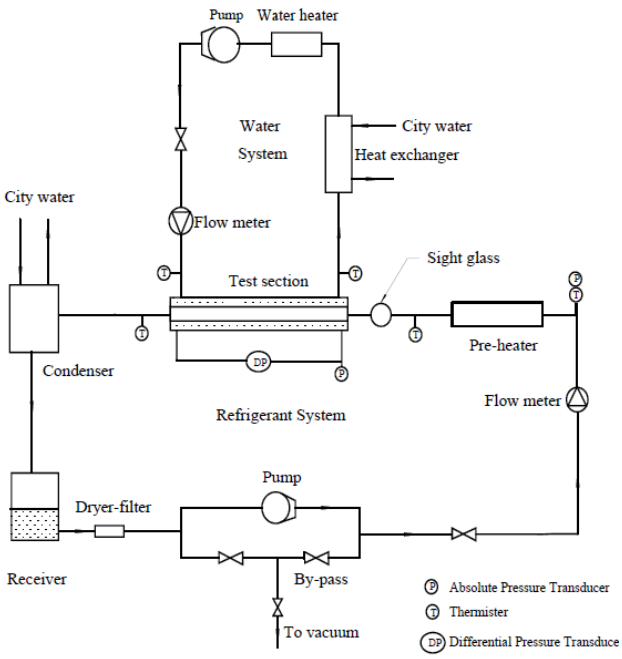

Figure 3. Schematic diagram of the experimental setup.

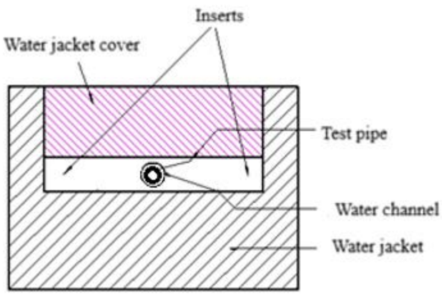

Figure 4. Cross-sectional view of the test section.

Schematic diagram of the experimental setup is presented in Figure 3.

The cross-sectional view of the test section is presented in Figure 4. As shown in the figure, the refrigerant tube is installed between two PVC inserts, while an annular channel surrounding the tube allows water to circulate around the outer surface of the copper tube.

The experimental database covers liquid refrigerant flow conditions corresponding to Reynolds numbers in the range of 11,000 < ReDh < 58,000. Pressure drop data for R-134a and R-1234yf were acquired at refrigerant temperatures respectively 20 °C and 19 °C and mass fluxes ranging from 380 to 1802 kg m^{-2} s^{-1}. Differential pressure measurements were performed using a calibrated pressure transducer with an uncertainty of ±2% of the measured value.

2.2. Governing Equations

The pressure drop data were obtained under adiabatic conditions. Therefore, the acceleration and gravitational components (for horizontal flow) were neglected and were not included in the measured pressure drop. The total measured pressure drop, (ΔP_{exp}), consists of three components: the frictional pressure drop (ΔP_f), the inlet pressure drop (ΔP_i), and the outlet pressure drop (ΔP_e).

$$\Delta P_{exp} = \Delta P_f + \Delta P_i + \Delta P_e \quad (2)$$

$$\Delta P_i = \frac{G^2}{2\rho_l}(1 - \sigma^2 + K_c) \quad (3)$$

$$\Delta P_e = \frac{G^2}{2\rho_l}(1 - \sigma^2 + K_e) \quad (4)$$

where G is the mass flux, ρ is the liquid refrigerant density, and σ is the ratio of the test tube cross-sectional area to the frontal area of the inlet and outlet plenums. The coefficients K_c and K_e, are functions of σ and the Reynolds number. Kays and London [14] provided charts for determining σ, Kc and Ke for various cross-sectional geometries.

The ratio (ΔP_i + (ΔP_e) / (ΔP_{exp}) ranges from 0.10 to 0.30, whereas the ratio (ΔP_f / ΔP_{exp}) varies between 0.80 and 0.95 depending on the test conditions. Therefore, the uncertainties associated with the evaluation of inlet and outlet losses are relatively small.

For single-phase flow, the friction factor, (f), is defined by the following equation:

$$f = \frac{\Delta P_f}{G^2/2\rho_l}\frac{D_h}{4L} \quad (5)$$

Where D_h is the hydraulic diameter and L is the length of the tube.

3. Results

The variation of the frictional pressure drop (ΔP_f) of liquid refrigerants R-134a and R-1234yf with refrigerant mass flux is shown in Figure 5.

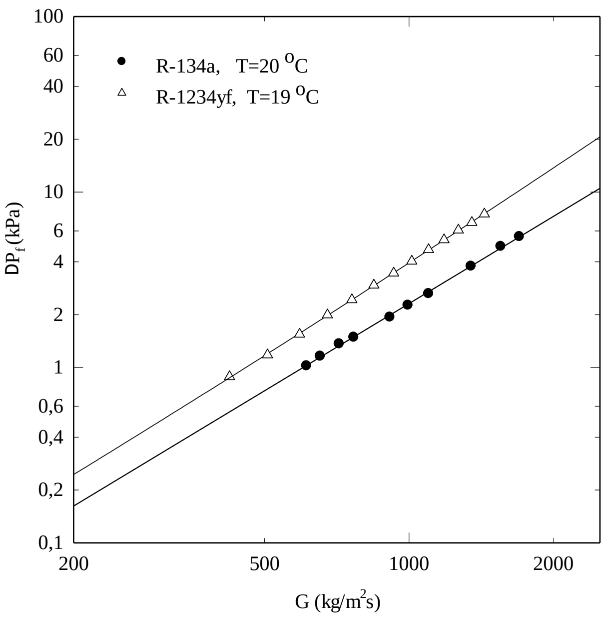

Figure 5. Variation of the frictional pressure drop of liquid R-134a and R-1234yf with refrigerant mass flow rate in the test tube.

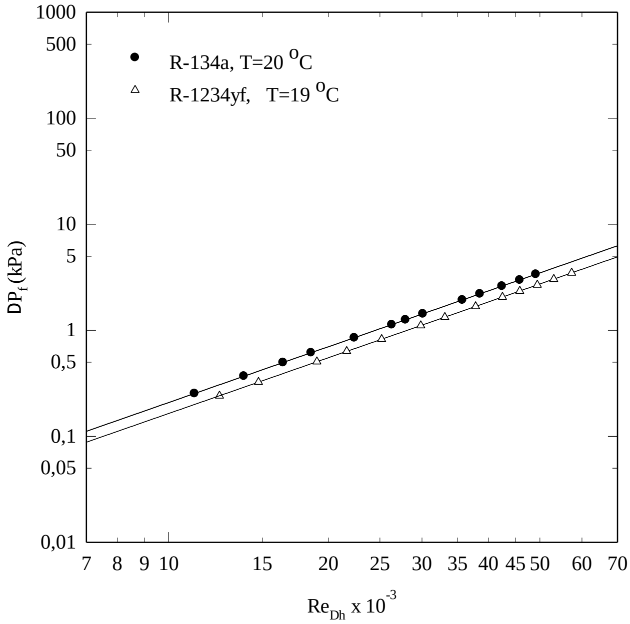

Figure 6. Frictional pressure drop of liquid R-134a and R-1234yf as a function of Reynolds number in the tube.

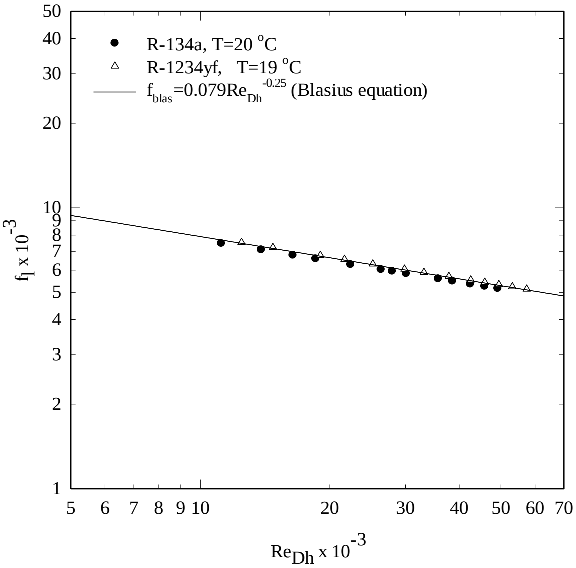

Figure 7. Variation of the friction factor of liquid R-134a and R-1234yf with Reynolds number in the test the copper pipe.

As can be seen from the figure, the frictional pressure drop in the tube increases with increasing refrigerant mass flux. The variation of the frictional pressure drop (ΔP_f) of liquid R-134a and R-1234yf with Reynolds number is presented in Figure 6. As expected, the frictional pressure drop in the copper tube exhibits an increasing trend with increasing Reynolds number for both R-134a and R-1234yf refrigerants.

The Blasius equation, presented in Equation (1), is among the most commonly used correlations for predicting the pressure drop of liquid R-134a and R-1234yf in copper tubes. It is also widely employed to evaluate the consistency and agreement of experimental data with established turbulent-flow correlations [8–13]. A comparison between the experimental data for both R-134a and R-1234yf refrigerants and the predictions of the Blasius equation is presented in Figure 7. Figure 7 also includes the Blasius friction factor correlation, ($0.079Re_{Dh}^{-0.25}$), represented by a solid line. The experimentally measured friction factors for R-134a and R-1234yf show good agreement with the Blasius prediction, with deviations generally remaining within ±10%. These results demonstrate that the Blasius correlation can accurately predict the friction factor for liquid refrigerant flow in the copper tube under the investigated operating conditions.

4. Conclusions

This study presents the experimental investigation of the pressure drop characteristics of liquid refrigerants R-134a and R-1234yf flowing through a 6 mm diameter circular copper tube. The results indicate that the frictional pressure drop increases with increasing refrigerant mass flux for both R-134a and R-1234yf. Friction factors were determined from the experimental pressure drop data and compared with the widely used Blasius correlation.

The experimental results show that the friction factor can be reasonably predicted by the conventional turbulent-flow Blasius equation based on the hydraulic diameter. For both refrigerants, the experimentally obtained friction factors were found to be within ±10% of the values predicted by the Blasius correlation. Overall, the measured friction factor data exhibit good agreement with classical turbulent-flow correlations, demonstrating that the Blasius equation provides a reliable method for predicting frictional pressure losses of liquid R-134a and R-1234yf flowing in a circular copper tube.

Acknowledgment

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