Review of predicting heat transfer coefficient for condensation of refrigerant in mini/micro channel

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ABSTRACT

This study aims to develop a generalized condensation model to determine the condensation heat transfer coefficient. The proposed correlation was validated by constructing a comprehensive database comprising data for eight refrigerants (R22, R32, R134a, R290, R410A, R600a, R1234yf, and R1270). The database includes hydraulic diameters ranging from 0.96 to 9.43 mm, mass fluxes from 75 to 1400 kg/m²s, round and rectangular geometries, single and multi-channel configurations, as well as both horizontal and vertical flow orientations. A total of 995 data points were collected from nine different sources for comparison and validation purposes.

KEY WORDS

Condensation, heat transfer, correlation, mini/micro-channel

1. INTRODUCTION

In the past, most condensers utilized large-diameter circular tubes; however, there has been a recent trend towards a variety of small-diameter channel configurations. These smaller channels provide higher heat transfer coefficients, minimize the required surface area, and reduce refrigerant charge within refrigeration systems. Typically, Microchannel Heat Exchangers (MCHX) reduce refrigerant charge by approximately 10% and pressure drop by up to 84% compared to Fin-and-Tube Heat Exchangers (FTHX) under similar operating conditions. Additionally, MCHX can increase the Coefficient of Performance (COP) by 6–10%, thereby enhancing overall system efficiency[1] Consequently, heat transfer prediction methods are now needed not only for large diameter tubes but also for mini/micro channels. The Montreal Protocol amendments, mandate a substantial reduction in the Global Warming Potential (GWP) weighting for refrigerants used in air conditioning and refrigeration equipment. This requirement has accelerated the phase-out of HCFCs, and with the subsequent Kigali Amendment introducing further restrictions on HFCs, the development of environmentally friendly refrigerants has become increasingly critical.[2] However, the development of condensation correlations for these eco-friendly refrigerants remains limited. Therefore, there is a need to establish universally applicable correlations that encompass both conventional and eco-friendly refrigerants, which is essential for efficient heat exchanger design. This study evaluates models using existing data to enhance the predictive accuracy of heat transfer models across a range of refrigerants and hydraulic diameters.

2. EVALUATION OF EXISTING CONDESATION MODELS

2.1 Data decription

In order to validate existing condensation heat transfer models, data were gathered from published papers, resulting in a total of 995 data points from nine different sources, forming a new integrated database. TABLE 1 summarizes the information included in this consolidated database. The data evaluation method was conducted using Mean Absolute Percentage Error (MAPE). The definition of MAPE is as follows

$$MAPE = \frac{1}{N}\sum_N \left|\frac{h_{prediction}-h_{experiment}}{h_{experiment}}\right| \times 100\% \quad (1)$$

Table 1: Condensation heat transfer database.

Authors	Geometry	D_h(mm)	Fluid	G($\frac{kg}{m^2s}$)	Data points
Hu et al.[3]	C, single, H	3.4	R32,	150-350	30
Oh and Son [4]	C, single, H	1.77	R22, R410, R134a	450-1050	108
Davide Del Col et al.[5]	S, single, H	1.23 0.96 0.96	R134a, R1234yf, R290	200-1000	387
Matkovic et al.[6]	C, single, H	0.96	R32, R134a	100-1200	161
Huang et al.[7]	C, single, H	1.6 4.18	R410	200-600	35
Cavallini et al.[8]	R,multi,H	1.4	R134a, R410	200-1400	36
Murphy et al.[9]	C, multi, H	0.96	R290	75-150	27
Belchi et al.[10]	R, multi, H	1.16	R134a, R290	200-1400	136
Moreira et al.[11]	C, single, H	9.43	R290, R600a, R1270	50-250	11

*C: circular, R: rectangular, S: square, H: horizontal, V: vertical

2.1 Heat transfer coefficient models

The database correlation evaluation was conducted using a total of three methods. The data were evaluated using the Shah[12], Koyama et al.[13], and Bohdal et al.[14] correlations.

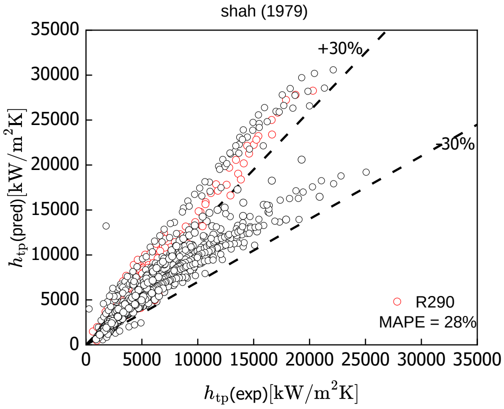

Fig. 1. Comparison of 955 pint consolidated database of shah correlation

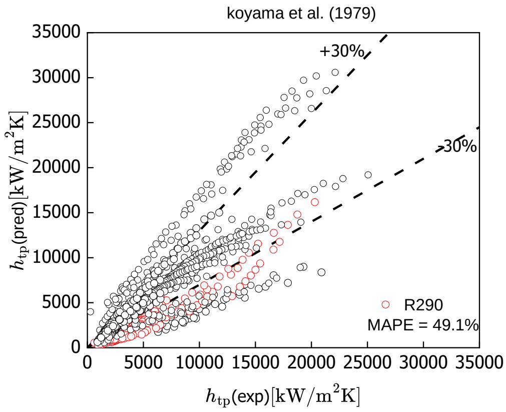

Fig. 2. Comparison of 955 point consolidated database of koyama et al. correlation

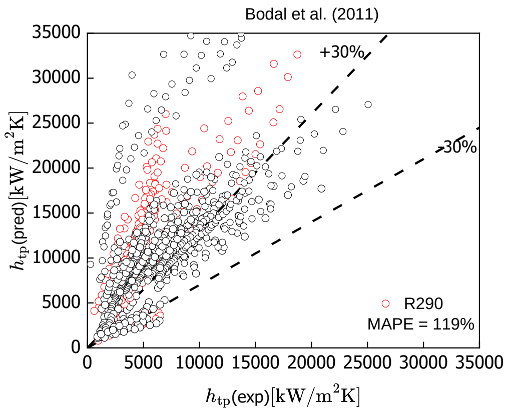

Fig. 3. Comparsion of 955 point consolidated database of Bodal et al. correlation

3. Results

Among the three correlations compared, the SHAH[12] correlation exhibited the lowest MAPE at 28%, whereas the Bohdal et al.[13] correlation showed the highest MAPE at 119%. Figures 1, 2, and 3 illustrate the data, with red markers indicate R290 data. All three correlations exhibit prediction errors outside the ±30% margin for R290 data, indicating a critical need for further refinement of correlation accuracy. Accurate predictive correlations for R290 refrigerant are essential, particularly as the use of low GWP refrigerants is expected to increase. Furthermore, such correlations are crucial for the efficient design of heat exchangers. Consequently, future research will prioritize the development of universally applicable correlations that address these needs and are suitable for use across both mini/micro channels and large-diameter heat exchangers.

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