TWO PHASE PRESSURE DROP CHARACTERISTICSIN A HORIZONTAL SMOOTH PIPE REFRIGERATION AMMONIA (R717) SYSTEM

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ABSTRACT: This paper focused on comparison of pressure drop characteristics verses the vapour qualities and modeled of ammonia refrigeration system using the results of experiments and simulation results in a virtual environment. In this study two-phase ammonia fluid flow system with mass fluxes from 50 to 100 kg/s.m^2, vapour qualities between 0 and 1, and saturation temperatures from -20^{o}C to 30^{o}C were considered. The single-phase pressure drop equation with a modified fluid density was used to predict the two-phase pressure drop of the system. The results indicate that two phase pressure drop is dependent upon the average kinetic energy density of the flow, hydraulic diameter and friction factor of the pipe.

Keywords: Ammonia, Condenser, Evaporator, Pressure drop, Two phase flow

INTRODUCTION

In the field of vapour compression systems, environmental concerns regarding ozone depletion and global warming first ledto international agreements (Montreal protocol and its amendments).Because Chloro-Fluoro-Carbons(CFC) and Hydro-Chloro-Fluoro-Carbons (HCFC) synthetic refrigerants has high OzoneDepletion Potential (ODP). Then in the ninetiesHydro-Fluoro-Carbons (HFC) was introduced, since Hydro-Fluoro-Carbons (HFC) have azero ODP. But, they are powerful greenhouse gases identifiedby the Kyoto protocol in 1997. In Europe, HFC have been subjected to a restricted use since 2006 (European Union 2006). Thanks to its zero ODP and zero Global Warming Potential (GWP), the ‘‘old’’ ammonia refrigerant received a renewed interest as an alternativenatural working fluid for refrigeration systems.This refrigerant gained considerable attention as an alternative refrigerant in multistage refrigeration cycle and cascade systems due to excellent thermo physical properties in operating temperature range.(Granryd, 2001; Lorentzen, 1994, 1988; Cavallini, 1996).

In designing condensation and evaporation heat transfer equipments the prediction of pressure drop is as important as the prediction of heat transfer coefficients. Pressure drop during condensation and evaporation can be obtained from the two-phase flow momentum equation given below according to Cavallini and homogeneous two phase pressure drop (Collier and Thome1996). The total pressure drop of the system is given below by equation 01.

$$\frac{dp}{dz} = \left(\frac{dp}{dz}\right)_f + \left(\frac{dp}{dz}\right)_a + \left(\frac{dp}{dz}\right)_g \qquad 01$$

The pressure gradient consists of frictional gravitational and acceleration pressure gradients symbolized by subscripts f, g and a respectively. The axial coordinate z is oriented in the flow direction.

Pressure gradient for gravitation shown below in equation 02.

$$\left(\frac{dp}{dz}\right)_g = g.(\rho_v.\varepsilon - (1-\varepsilon).\rho_l).sin(\phi) \qquad 02$$

Pressure gradient foracceleration shown below in equation 03.

$$\left(\frac{dp}{dz}\right)_a = G^2\left\{\frac{x^2}{\rho_v.\varepsilon} + \frac{(1-x^2)}{[\rho_l(1-\varepsilon)]}\right\}.dz \qquad 03$$

*wheredp/dz*is the gradient of pressure in the direction of flow.

Acceleration and gravitational terms can be neglected because it is assumed adiabatic conditions and horizontal flow. Simplified equation shown in equation 04.

$$\frac{dp}{dz} = \left(\frac{dp}{dz}\right)_f \qquad 04$$

Frictional pressure drop in two-phase flow is due to the combination of friction between the fluid particles and the tube walls and between the liquid and vapor phases.

Martinelli and Nelson (1948) introduced two-phase multiplier (Φ) to utilize the two phase pressure drop correlations. Lockhart and Martinelli (1949) relates the two-phase frictional pressure drop in terms of either single phase liquid or vapor pressure drop.This is the acceptable most accurate horizontal tube correlation. For the purpose of this investigation, a vapor only multiplier is defined below in equation 05.

$$\left(\frac{dp}{dz}\right)_f = {\phi^2}_{vo}\left(\frac{dp}{dz}\right)_{vo} \qquad 05$$

where the subscript*"vo"*indicates that the entire flow in the pipe is made up of vapor only.

The reason for choosing the vapor only basis is due to Niño (2002) finding that "liquid only" based correlations often fail when applied to small channels due to the Reynolds number dropping to levels below the laminar-turbulent transition range (Re ~ 2300). For typical mass flux ranges, the vapor only basis keeps the Reynolds number above the transition region, resulting in a more consistent reference level for the multiplier. This vapour only basis equation shown in equation 06.

$$\left(\frac{dp}{dz}\right)_{vo} = f_{vo}\left(\frac{G^2}{2\rho_v D_h}\right) \qquad 06$$

where$D_h$is the hydraulic diameter, *G* is the mass flux, $\rho_v$is the vapor density, and $f_{vo}$is the single phase.

Turbulent Darcy friction factor determined using the Blausius formula and Reynolds number in equations 07 and 08respectively shown below.

$$f_{vo} = \frac{0.316}{Re^{0.25}} \qquad 07$$

$$Re = \frac{GD_h}{\mu_{tp}} \quad 08$$

whereμ_{tp} is the viscosity of the fluid.
The viscosity of the fluid is defined in equation 09 below.

$$\mu_{tp} = x\mu_v + (1-x)\mu_l \quad 09$$

An important physical interpretation for pressure drop equation can be realized by defining the average kinetic energy density equation (10) and two phase density shown in equation 11 respectively given below

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$$Ke_{avg} = \frac{G^2}{2\rho_{tp}} \quad 10$$

$$\rho_{tp} = \left(\frac{x}{\rho_v} + \frac{(1-x)}{\rho_l}\right)^{-1} \quad 11$$

The equation 11 indicates that pressure drop is directly proportional to the inertial forces of the fluid flow and vapour quality x.

Ammonia is examined in two-phase pressure drop experiments and peak pressure drop was determined to be inversely related to vapour density from two phase pressure drop experiment by David C. Adams at el (2006).

Two phase fluid flow pressure drop equation for evaporation and condensation is given in the equation 12below.

$$\left(\frac{dp}{dz}\right)_{tp} = {\phi_{vo}}^2 \left(f_{vo} \cdot \frac{G^2}{2.D_h.\rho_v}\right) \quad 12$$

METHODOLOGY

To simulate the results of the pressure drop in two phase flow Engineering Equation Solver (EES) Academic Version is used as a platform. Which is a combination of NIST - REFPROP and FORTRAN software. All the properties of ammonia is calculated by using EES software.

In the developed software we applied same conditions for simulation which that experiment were done before, form that evaporation pressure drop and condensation pressure drop were simulated.Heat flux, mass flux, internal and external diameters of tubes, operating temperatures are the conditions that applied for simulated model.Simulated model consists exactly same condition of the experimental condition in the software because of that programmed mathematical model mentioned as virtual environment. Then simulated results compared with experimental results. From that pressure drop variation obtained as a results for changing vapour qualities.

RESULTS AND DISCUSSION

Pressure drop of Ammonia Condenser model is validated by using an Experimental Investigation of Pressure Drop and Heat Transfer in an In-Tube Condensation System of Pure Ammonia experimental results which done by Vollrath et al (2006). When heat flux is 100 kW/ m^2, internal diameter of 9.8mm, external diameter of 10.5mm, 30^o C operating temperature and when mass flux 80 kg/ m^2s both pressure drop results are obtained. Simulated results are shown in Figure 1. Experimental results are shown in Figure 2. Calculated deviation results are shown in Table 1.

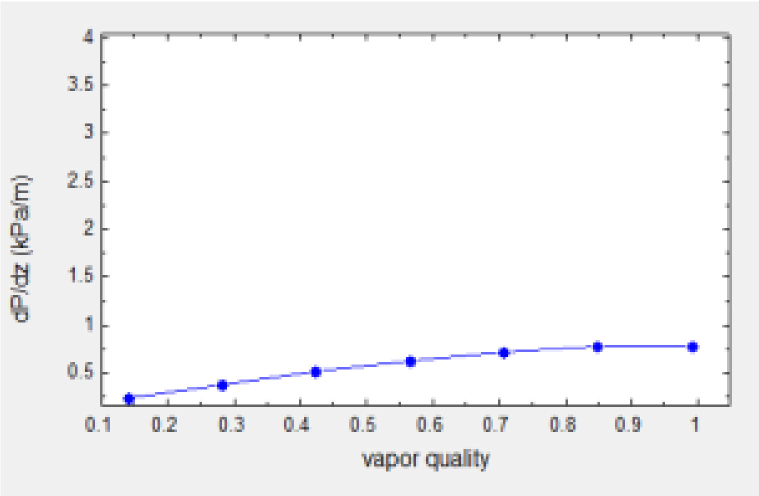

Figure 1: Simulated pressure drop result for condenser

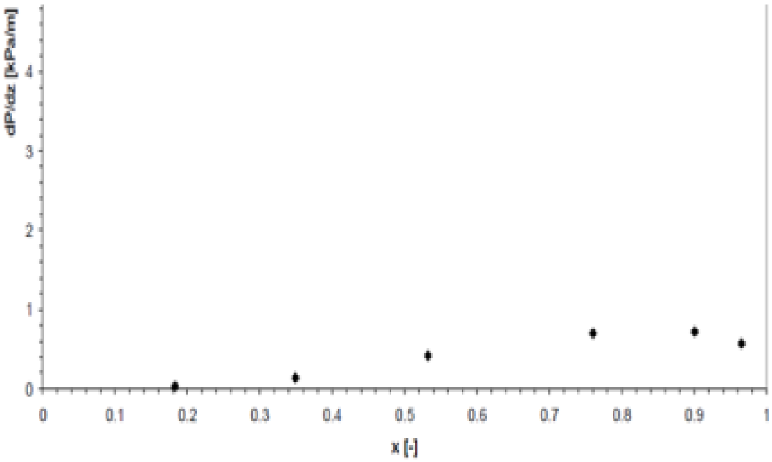

Figure 2: Experiment pressure drop result for condenser

Table 1: comparison deviation for simulated results and experiment results in evaporator and condenser

Type of process	**Average deviation (%)**	**Absolute average deviation (%)**
Condensation	3.19	3.56
Evaporation	4.06	3.82

Pressure drop of Ammonia evaporator model is validated by using an Experimental Investigation ofPressure Drop experimental results which done by Vollrath et al (2006). When heat flux is 70 kW/ m^2, internal diameter of 8.1mm, external diameter of 9.5mm, -20^oC operating temperature and when massflux 100 kg/ m^2s both pressure drop results are obtained. Experimental results are shown in figure 3.

Simulated results are shown in figure 4. Calculated deviation results are shown in Table 1.

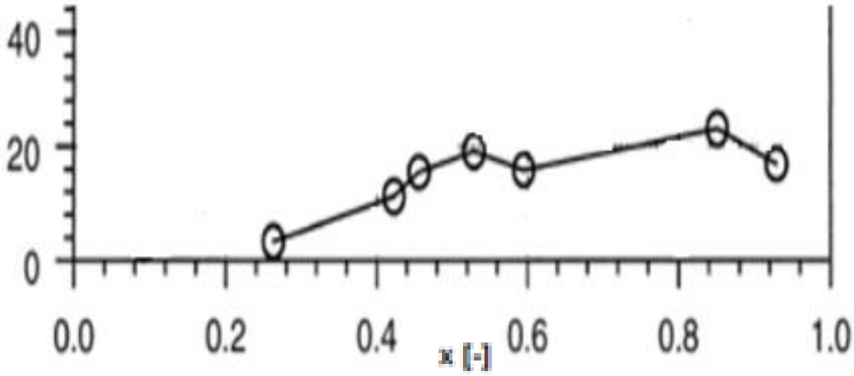

Figure 3: Experimental pressure drop result for evaporator

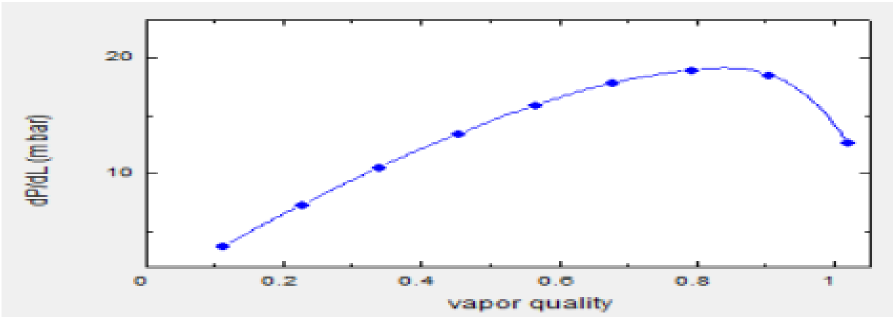

Figure 4: Simulated pressure drop result for evaporator

The results show that the developed simulation tool can use for the ammonia refrigeration system to design the evaporator and condenser of refrigeration system.

CONCLUSION

Ammonia is an important natural refrigerant and it has excellent thermo physical properties. Two phase pressure drop is depends on mass flux, internal diameter, type of pipe material, type of flow and fluid. Simulation and experiment results shows that two phase pressure drop increased with vapour quality and dropped significantly at 0.9 vapour quality for turbulent flow. Accurate two phase pressure drop correlation for ammonia is suggested and it is simulated in adiabatic condition and compared with drafted experiments and validated. This developed software can be used in designing length of the evaporator and condenser.

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