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Transient modeling of a flash tank vapor injection heat pump system – Part II: Simulation results and experimental validation

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ABSTRACT

This two-part article investigates the transient characteristics of a flash tank vapor injection system through modeling and experimental validation. The first part describes the detailed modeling techniques for each component, and the second part describes the transient simulations that are carried out for the overall system under start-up and shut-down operations and presents the results. After comparing the predictions of the proposed model with the experimental data, it was concluded that the proposed model can adequately capture the transient heat transfer and flow phenomena of the system. The dynamic system response when subjected to a step change in the opening of the upper-stage EEV (electronic expansion valve) was also investigated. It was found that EEV opening has a significant impact on the system performance and the liquid level in the flash tank, but exhibits little effect on the suction pressure. These findings were corroborated through experiments.

Modélisation transitoire d'un systéme de pompe à chaleur à injection de vapeur au niveau du réservoir intermédiaire – Partie II: résultats de la simulation et validation expérimentale

Mots clés : Transitoire ; Modélisation ; Injection de vapeur ; Ecoulement diphasique ; Réservoir intermédiaire ; Modelica

1. Introduction

The evaluation of the steady-state, full-load performance of vapor compression systems is often used to determine the capacity requirement and the size of the unit. However, vapor compression systems rarely operate under steady-state conditions. Examples of transient operation include: (1) start-up and shut-down surges; (2) part-load operation with capacity control measures; (3) frost accumulation on coil surfaces which gradually degrades system performance; and (4) defrosting processes

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Nomenclature

Symbols

ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
EB	energy balance [–]
EEV	electronic expansion valve
NPT	National Pipe Thread
$\dot{Q}$	heat transfer rate [W]
t	time [s]
TXV	thermostatic expansion valve
u	velocity [m s^{-1}]

Greek letters

γ	void fraction [–]
τ	time constant [s]
ω	compressor speed [min^{-1}]

Subscripts

a	air
hom	homogeneous
nom	nominal
r	refrigerant

needed to be initiated periodically in order to remove frost buildup and free coil surfaces before the equipment can return to normal operation, etc. Taking these circumstances into account, a transient simulation is expected to capture the overall system performance more accurately (Murphy and Goldschmidt, 1985; 1986; Yasuda et al., 1990; Liu et al., 2003; Zhang and Zhang, 2011). Moreover, in order to investigate the effects of integrated control on the operation of vapor compression systems, it is important to predict the transient response and stability characteristics of the overall systems as well as its components (Yasuda et al., 1983; He et al., 1998; Shah et al., 2004; Li et al., 2010).

Part I of this two-part article presents a first-principles dynamic model for a flash tank vapor injection (FTVI) heat pump system. This system includes the indoor coil, outdoor coil, flash tank, piping, reversing valve, expansion device, and vapor injection scroll compressor. In this part, the model presented in Part I is validated using experimental data. The system response to a step increase in the opening of the upper-stage electronic expansion valve (EEV) is investigated with the objective of developing a control algorithm for the degree of injection superheat. The remainder of this article is organized into four other sections: Section 2 describes the test facility of a FTVI system. Section 3 presents all the pertinent simulation results and compares the results to the experimental data, and Section 4 discusses the critical modeling challenges that were encountered in this study. Finally, the paper ends with a conclusion section.

2. Experimental facility

2.1. *Experimental facility layout*

Fig. 1 shows the schematic of the test facility of a FTVI cycle, utilizing R-410A as the working fluid. The indoor unit is located within a closed psychrometric loop, and the air is driven by the blower of the air-handling unit. The air flows through the nozzle, which measures the air volume flow rate, and then enters the indoor unit. At the inlet and outlet of the indoor unit, two thermocouple grids, with nine thermocouples each, were installed to measure the inlet and outlet air temperature. Relative humidity sensors were installed to measure the relative humidity of the inlet and outlet air. The outdoor unit was located inside an environmental chamber, where temperature and humidity could be controlled according to ASHRAE Standard 116 (2010). Thermocouples and dew point sensors were installed to measure the outdoor unit inlet and outlet air temperatures and dew points, respectively. Pressure transducers and in-stream thermocouples were installed in the vapor compression system to measure the refrigerant-side pressures and temperatures. Mass flow meters were installed to measure the refrigerant mass flow rates of the injected vapor and liquid through the condenser. Two mass flow meters were installed in the liquid line, and only one mass flow meter was in use during either cooling or heating mode operations because the mass flow meters were only calibrated with one flow direction. Finally, a watt meter was installed to measure the outdoor unit power consumption.

The heat pump system could be operated in both cooling and heating mode. In the cooling mode, refrigerant was discharged from the compressor and entered the outdoor unit for condensing. After being throttled through the upper-stage expansion valve (2), the refrigerant entered the flash tank; the vapor refrigerant was injected into the compressor whereas the liquid refrigerant entered the lower-stage expansion valve (4), and circulated through the indoor unit. After evaporating from the indoor unit, the refrigerant then entered the suction port of the compressor to complete the closed-loop cycle. In the heating mode, the electrical coil of the four way valve was energized, and therefore, the valve reversed the refrigerant flow direction. The refrigerant exiting the compressor circulated through the indoor unit for condensing, then expanded through the upper-stage expansion valve (2), and entered the flash tank. The vapor refrigerant was injected into the compressor; meanwhile the liquid refrigerant circulated through the lower-stage expansion valve (3), evaporated in the outdoor coil, and then entered the compressor to complete the cycle.

2.2. *Major component description*

The compressor used in the experimental study was a vapor-injected scroll compressor. It had a constant speed of 3500 RPM with a displacement of 29.5 cm^3. The system could be operated either with or without vapor injection by controlling an injection control valve (1) located in the vapor injection line. The vapor injection control valve was installed close to the compressor in order to minimize the re-expansion of compressed vapor trapped between the control valve and injection port of the compressor. The specifications of the outdoor and indoor heat exchangers are shown in Table 1. The upper-stage expansion valve utilized in the system was an EEV controlled by an electric stepper motor with 500 steps from closed to fully open, and the lower-stage expansion