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Comprehensive investigation of numerical methods in simulating a steady-state vapor compression system

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ABSTRACT

Computer simulation has become a required tool in the design phase of vapor compression systems; however with relatively few exceptions most simulations focus on the basic four component systems. With an increasing focus being placed on energy efficiency, the simulation of multi-component vapor compression systems (having multiple evaporators, condenser or compressors) will become essential to assist in the design of these more complicated systems. The implementation of a component-based framework will facilitate the simulation of multi-component systems. This paper describes three algorithms used to simulate a component-based vapor compression system. A test matrix of 6174 sample runs covering a wide range of operating conditions was constructed to determine the robustness and speed of each method when using three different types of nonlinear equation solvers. Each method was tested by simulating a basic four component cycle and a more advanced multiple evaporator system. The results are presented in such a format as to describe the reasons that contribute to any instability of the solvers and the computational efficiency of each method is discussed.

Méthodes numériques utilisées afin de simuler un système à compression de vapeur en régime permanent

Mots clés : Système frigorifique ; Système à compression ; Enquête ; Modélisation ; Simulation

1. Introduction

A vapor compression system consists of a set of components; namely compressors, heat exchangers, and expansion devices. Each of these components can be individually modeled using a set of mathematical equations that describe the corresponding thermodynamic processes occurring within the component. A system solver is then used to adjust the state points to ensure that the system level conservation equations are satisfied. In a global solution scheme, the mathematical equations describing each component model are generally located within the system solver. When a global solution scheme has been implemented, the vapor compression system configuration is generally fixed and therefore additional components cannot be inserted with any ease into the original configuration. A global solution scheme can offer advantages

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Nomenclature

F	function
H	specific enthalpy (J kg^{-1})
$\dot{H}$	energy flow (J s^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
M	refrigerant charge (kg)
N_J	number of junctions
P	pressure (Pa)
r	mass flow rate ratio
$r_{\dot{m}}$	mass flow rate residual value
$r_{\dot{H}}$	energy flow residual value
r_P	pressure residual value
r_M	system charge residual value
r_{SC}	subcooling residual value
$\vec{r}$	vector of residual values
T	temperature (K)
$\vec{x}$	vector of unknown variables

Greek symbol

ε_x	equation solver tolerance in the x domain

Subscripts

Comp	compressor
Cond	condenser
Evap	evaporator
Exp	expansion device
HX	heat exchanger
i	index parameter, iteration
in	flow into a junction or component
J	junction
mix	mixing value of multiple streams
out	flow out of a junction or component
sat	saturation
SC	subcooling (K)

in the area of robustness since the system solver is directly evaluating all mathematical equations.

In a modular/component-based solution scheme, the component models are located outside the system solver. This approach can be extended to handle arbitrary system configurations since the solver requires only knowledge on how the component models have been connected. This increase in flexibility can lead to decreased robustness since the system solver cannot assume a functional form of the mathematical equations being solved by the component models.

The purpose of this paper is to describe and investigate the robustness and efficiency of three unique algorithms used to simulate a modular/component-based vapor compression system. The set of unknown variables and residual equations are derived for each of the three approaches. The robustness and efficiency of each algorithm are determined by running a series of numerical experiments. The two cycle configurations shown in Figs. 1 and 2 have been analyzed. All three approaches utilize a nonlinear equation solver to solve the resulting mass and energy balance equations. Three nonlinear equation solvers have been tested with each algorithm, which include the Newton–Raphson method (Press et al., 1992), Broyden's method (Press et al., 1992), and the Hybrid method (More et al., 1980). All three types of nonlinear equation solvers require a set of guess values to start the solution procedure. This paper proposes two different approaches used to formulate the set of guess values and presents the effect of each approach on the robustness and efficiency of each algorithm.

2. Literature review

The focus of this paper is on the solution technique to simulate a steady-state vapor compression system, and therefore dynamic modeling and dynamic modeling tools are not

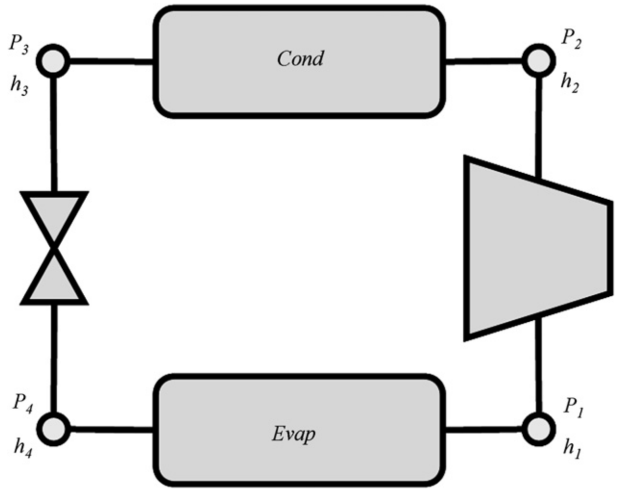

Fig. 1 – Basic vapor compression cycle.

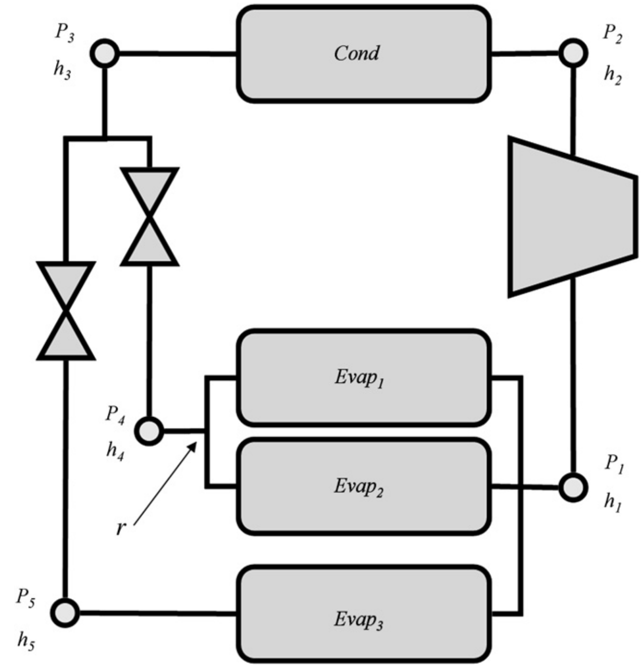

Fig. 2 – Advanced vapor compression cycle.