Energy and Buildings 75 (2014) 523–530

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Investigation of Heat Pump Condenser Performance in Heating Process of Buildings using a Steady-State Mathematical Model

Jozsef Nyers[a,*], Arpad Nyers[b]

[a] Subotica Tech. Serbia, Obuda University, Budapest, Hungary
[b] Subotica Tech. Serbia, Tera Term co. Subotica, Serbia

ARTICLE INFO

Article history:
Received 18 December 2013
Received in revised form 6 February 2014
Accepted 20 February 2014

Keywords:
Condenser
Heat pump
Appropriate
Circulation pump
Mathematical model
Lumped parameters

ABSTRACT

The general aim of the paper is the wide-range analysis of heat pump plate condenser performance depending on external impacts. The external impacts are the inlet temperature of hot water, the hydraulic resistance of the hot water circuit, the power of circulation pump and the surface of condenser. The additional goal is to find the appropriate power of circulation pump to obtain the near maximum condenser performance as a function of resistance to flow in the hot water circuit and dimension of condenser. The performance of condenser is the quantity of heat exchanged inside the condenser between the refrigerant and the hot water. The analysis of performance and appropriate power is done using the non-linear lumped parameter mathematical model. The mathematical model includes equations of heat transfer between the hot water and the refrigerant inside the condenser, the power of circulation pump and the hydraulic resistance in hot water circuit. The mathematical model of the condenser is divided into a section of superheated steam cooling and a section of saturation steam condensation of refrigerant. In order to solve the mathematical model, which comprises of nonlinear algebraic equation system, the Newton–Taylor linearization and Gauss elimination methods were applied.

1. Introduction

In scientific journals a lot of articles deal with the research of heat pumps in stationary regime using various lumped parameter mathematical models. Most of the mathematical models contain the main four components including the condenser, as well. Research of all reviewed articles focused on the behavior of a complete system rather than individual components, such as the condenser. Hatef and Madani et al. [1] examined the heating system with a heat pump in terms of capacity control for the entire heating season. For the study they developed a lumped parameter steady-state mathematical model for stationary regime. In the model the mathematical description of condenser is based on the energy and mass conservation. Enthalpy as the state parameter has been applied instead of the temperature, Kinab et al. [2]. Their aim was the investigation of optimal seasonal performance of reversible heat pumps. The mathematical model of condenser is created in the exponential series based on the data of existing condenser. The behavior of condenser was not specially investigated.

A smaller number of articles dealt with the study of condenser's behavior as a component of heat pump. The reviewed articles mainly investigated the processes in the condenser in terms of heat transfer. Qiao et al. [3] developed a new mathematical model for stationary heat transfer within the plate heat exchanger, which can be used for the condenser as well. The mathematical model is two-dimensional with distributed parameters. The finite difference scheme is used for discretization. The behavior of condenser was investigated in terms of the internal heat transfer. They investigated the influence of constructive details on the heat transfer within the plate condenser. The external influences on the condenser performance were not discussed. Cesar Pacio et al. [4] carried out review of published papers related to the plate evaporator and condenser, applied in refrigeration systems. The work classified the mathematical models and the procedures for solving the model. They gave an overview of possible negligence in the mathematical models. The work does not deal with the investigations of heat transfer within the evaporator and condenser as a function of external impacts.

A good selection of heat transfer coefficient of refrigerant as well as of the hot water is very important. In fact, the accuracy of results obtained by simulation mainly depended on the quality of heat transfer coefficients. There are thousands of authors and titles that deal with this topic; however, the problem is of a large dissipation of results obtained from the proposed models. This problem was

---

* Corresponding author. Tel.: +381 24 687175; fax: +381 24 687175.
E-mail addresses: jnyers@vts.su.ac.rs, nyarp@yahoo.com (J. Nyers).

http://dx.doi.org/10.1016/j.enbuild.2014.02.046
0378-7788/© 2014 Elsevier B.V. All rights reserved.

Nomenclature

$\dot{m}$	mass flow rate (kg/s)
α	convective heat transfer coefficient (W/(m^2 K))
λ	conductive heat transfer coefficient (W/(m^2 K))
k	overall heat transfer coefficient (W/(m^2 K))
C_p	specific heat, p = const (J/(kg K))
t	temperature (°C, K)
Δt	temperature difference (°C, K)
Δp	pressure drop (N/m^2)
F,f	surface (m^2)
A	cross section area of flow (m^2)
di	latent heat (J/kg)
q	heat flux (W)
P	performance or power (W)
Re	Reynolds number
Pr	Prandlt number
ρ	density (kg/m^3)
δ	thickness (m)
d	diameter (m)
ξ	coefficient of resistance to flow
$k1$	coefficient (1/(kg m))
$k2$	coefficient (m^2/kg^2)

Subscripts and superscripts

v	water
f	refrigerant (Freon)
i	input
o	output
m	middle
1	vapor cooling section
2	condensation section
p	pressure
circ	circulation pump
comp	compressor

pointed out in the work of Sánta [5]. He used the mathematical models of several authors, and calculated and compared the results of condensing heat transfer coefficients as a function of the vapor quality. Coefficients were presented graphically as a function of the vapor quality and showed significant differences in values as well as the tendency in relation to the arithmetic mean value. According to his research the best characteristics are shown in Shah's model. The values of coefficients by Shah are in the nearest of arithmetic mean value of all coefficients.

In our work, we used a model of heat transfer coefficient of Yan et al. [6]. They developed a new mathematical model of convective heat transfer coefficient of plate condenser. They made the model verification on the performed refrigeration system. The advantage of the model is that it verified and supplied a complete mathematical model for refrigerant and especially for hot water. The condensing heat transfer coefficient of condensation depends on the vapor quality and only for R134a was made, Djordjević et al. [7]. They also studied the modeling of convective heat transfer coefficient of condensation plate condensers, but the article did not contain applicable mathematical model for the calculation.

Nyers et al. [8–10], in their earlier reported articles presented and explained in detail the applied numerical mathematic method for solving the proposed and used mathematical model. Zhang et al. [11] dealt with various heat pump driven liquid desiccant dehumidification (HPLD) systems and they found that to effectively exhaust the extra heat of condenser is the key issue for performance improvement. COP$_{\mathrm{sys}}$ of HPLD with water-cooled assistant condenser is 35% higher than Basis system [12]. A new model of water to water heat pump is implemented in IDA-ICE environment. The model includes the available heat pump manufactory data as input parameter. The model is validated by graphical and statistical methods. Garbai et al. [13–15] dealt with the problems of modeling of the geothermal heat pumps with geo-tube exchangers and optimization of mathematical models.

In this article, the research was focused on investigating the condenser performance as a function of external impacts. The condenser performance represents the efficiency and the quantity of heat transferred between the hot water and the refrigerant inside the condenser. In the analyzed system the external impacts are the circulation pump power, the inlet temperature of hot water, the hydraulic resistance in hot water circuit and the surface dimension of condenser. The hydraulic resistance of hot water circuit is expressed in measurable parameter of the system, in the pressure drop.

The general aim of the investigation is to comprehensively analyze the behavior of performance of heat pump's plate condenser. The proposed procedure provides the analysis of the influence of above-mentioned four external impacts on the condenser performance.

The most influential external impact on the condenser performance is the inlet temperature of hot water. If the inlet temperature is changed in the range of 21–50 °C it causes the increment of condenser performance for 17 kW. The least impact on the condenser performance produces the hydraulic characteristics of hot water circuit. Increasing the circulation pump power from 21 to 310 W hardly enhances the condenser performance, for 1 kW only.

From the above data it follows that the best improvement of condenser performance is achieved with increasing the surface of heating bodies in the hot water circuit. It is recommended to apply panel heating bodies instead of radiators. Panels consist of pipe packages in the floor, wall and ceiling and have significantly higher heating surfaces from the radiators, with that the inlet hot water temperature for heating decreases and increases the condenser performance. Increasing the circulation pump power enhances the condenser performance very poorly.

The additional practical goal is to find the appropriate circulation pump power. The appropriate power provides the near maximum condenser performance at the defined hydraulic resistance of the hot water circuit and the defined dimension of condenser. The theoretical optimum circulation pump power is in infinity.

The above statement can confirm the results of attached simulations. By increasing the power of the circulation pump, at the beginning condenser performance increases exponentially but later the increases are monotonical and reach maximum in the infinity.

In practice, by the end of the exponential increase in the performance it makes sense to increase the circulation pump power. In this point are the appropriate circulation pump power and the near maximum condenser performance. After this interval the circulation pump power linearly but the condenser performance only minimally increases and is nearly constant. In the attached simulation, based on the obtained graphics the optimum of circulation pump power is about 110 W.

The proposed procedure consists of the accurate mathematical model, an appropriate numerical procedure and two- and three-dimensional graphics. The created mathematical model describes the stationary behavior of the condenser, the circulation pump and the hot water circuits in terms of hydraulics. The condenser is plate and divided into sections for cooling and for condensing the refrigerant vapor. The circulating pump is described by power. The hydraulic characteristic of the hot water circuit is expressed by the pressure drop.