Energy Conversion and Management 50 (2009) 3063–3070

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Dehumidification effects in the superheated region (SPR) of a direct expansion (DX) air cooling coil

Xia Liang, Ming-Yin Chan, Deng Shiming *, Xu Xiangguo

Department of Building Services Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong SAR, China

ARTICLE INFO

Article history:
Received 29 May 2008
Received in revised form 5 January 2009
Accepted 12 August 2009
Available online 15 September 2009

Keywords:
Superheated region
Dehumidification effect
DX air cooling coil
Air conditioning

ABSTRACT

A DX air cooling coil may normally be assumed to have two regions in its refrigerant side, according to refrigerant status, a two-phase region (TPR) and a superheated region (SPR). Dry air side surface of the SPR in a DX air cooling coil has been normally assumed in lumped-parameter mathematical models previously developed without however being validated. Therefore, an experimental study has been carried out to examine such an assumption under different operating conditions. The experimental results suggested that the air side surface of the SPR in a DX air cooling coil was either fully or partially wet under all experimental conditions and assuming dry air side of the SPR could lead to an underestimated total amount of water vapor condensed on the entire DX coil surface. Therefore, it is recommended that the assumption of dry air side in a SPR be no longer used in future lumped-parameter models to be developed for improved modeling accuracy.

1. Introduction

In small- to medium-scaled buildings, direct expansion (DX) air conditioning (A/C) units, such as split-type air conditioners and window-type air conditioners, are commonly used. For example, in the US, based on Department of Energy, packaged rooftop DX A/C systems accounted for about 60% of the total installed cooling capacity [1].

The key component in a DX A/C unit is its DX air cooling coil, where simultaneous air cooling and dehumidification takes place at its air side, if its surface temperature is below the dew point temperature of incoming air. At its refrigerant side, a DX cooling coil (evaporator) can be assumed to have two regions according to the status of refrigerant, a two-phase region (TPR) and a superheated region (SPR). Refrigerant enters the TPR in a coil as a mixture of vapor and liquid at evaporating pressure with a specific vapor fraction. When flowing through the cooling coil, liquid refrigerant absorbs the heat from the air and vaporizes. The TPR ends and the SPR commences at the point where all liquid refrigerant vaporizes and the vapor fraction becomes unity.

Mathematical models have been developed to describe the operating characteristics of DX cooling coils. These models can be generally divided into two categories: distributed parameter models and lumped-parameter models, respectively. Distributed parameter models [2–6] divide the whole coil into many micro-scale elements and the thermal performance within each element is individually evaluated. Consequently, these models require large computational effort and may potentially encounter numerical instabilities. However, in lumped-parameter models, TPR and SPR are analyzed separately. Wet air side in TPR and dry air side in SPR have been commonly assumed. For example, Fisher and Rice [7] developed an air-to-air heat pump model where dry air side in the SPR was assumed, i.e., no condensation occurring on the air side of the SPR. Mullen et al. [8] followed the above assumption and developed a room air-conditioner computer simulation model. Theerakulpisut and Priprem [9] presented a modeling procedure for DX cooling coils. Again the assumption of dry air side in SPR was used in the model.

Furthermore, dynamic or multi-variable mathematical models have been developed for DX air conditioning systems [10,11] more recently. Although these models were developed for the purpose of designing suitable controllers for DX air conditioners, dry air side in SPR was also assumed.

In all the models reported [7–11], nil condensate on the air side of SPR was assumed and hence no analysis of potential dehumidification effect on the air side of SPR included. Nonetheless, these models were claimed to have been experimentally validated and the assumption of a dry air side of SPR has been commonly accepted in most cases.

The fact that dehumidification effect on the air side of SPR in a DX cooling coil has been commonly ignored may well be due to that the air side surface area in a SPR only accounts for a small fraction of the entire air side coil surface area. However, as shown in Fig. 1, water droplets were clearly visible on the external surface of the refrigerant suction pipe of a DX cooling coil in an

* Corresponding author. Tel.: +852 27665859; fax: +852 27657198.
E-mail address: besmd@polyu.edu.hk (D. Shiming).

0196-8904/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enconman.2009.08.011

Nomenclature

A_f	overall fin surface area of a DX cooling coil, m^2
A_i	refrigerant side surface area of SPR in a DX cooling coil, m^2
A_o	overall airside area in the SPR of a DX cooling coil, m^2
C_1	a ratio defined by Eq. (3)
C_{pa}	specific heat of air, kJ/(kg K)
C_{pa}'	specific heat of moist air, kJ/(kg K)
C_{pr}	specific heat of refrigerant, kJ/(kg K)
h_{fg}	latent heat of vaporization of water, kJ/kg
Le	Lewis number
m_a	mass flow rate of air, kg/s
m_r	mass flow rate of refrigerant, kg/s
m_{cond}	water vapor condensing rate in the SPR, kg/s
M_{cond}	water vapor condensing rate in the entire DX cooling coil surface, kg/s
P_a	atmospheric pressure, kPa
q	heat transfer rate, W
RH	relative humidity of air
Sp_a	ratio of supply air fan speed to its maximum speed, (%)
Sp_c	ratio of compressor speed to its maximum speed, (%)
T_a	air temperature, °C
T_{adp}	air dew point temperature, °C
T_r	refrigerant evaporating temperature, °C
U_o	overall heat transfer coefficient of a DX air cooling coil, W/(m^2 K)
w_a	moisture content of air, kg/kg
w_r	equivalent moisture content of saturated moist air at refrigerant temperature in a DX air cooling coil, kg/kg

Greek symbols

η_o	overall fin efficiency
η_f	fin efficiency
α_a	air side heat transfer coefficient, W/m^2K
α_m	air side mass transfer coefficient, kg/m^2s
α_r	refrigerant side heat transfer coefficient, W/m^2K

Subscripts

1	inlet to a SPR
2	outlet from a SPR
3	turning point
d	dry or dry-bulb
w	wet or wet-bulb
out	outlet from the entire DX cooling coil
sf	air side surface of a DX cooling coil
l	latent heat transfer
s	sensible heat transfer

experimental observation, when the coil inlet air temperature and relative humidity (RH) were 24°C and 60%, respectively. A refrigerant suction pipe has been commonly regarded as SPR. Therefore the experimental observation suggested that there is a need to re-evaluate the assumption of dry air side in a SPR.

This paper reports on a study on the dehumidification effect on the air side of a SPR in a DX cooling coil through a series of experiments under different operating conditions carried out in an experimental DX air conditioning system. Firstly, the DX A/C system and experimental conditions are described. This is followed by reporting a Calculation Procedure specifically developed to process experimental data. With the Calculation Procedure, the surface condition and water vapor condensing rate on the air side of SPR of the DX cooling coil under different operating conditions may be evaluated and are presented.

2. Experimental DX A/C system and experimental conditions

2.1. Experimental DX A/C system

The experimental DX A/C system was mainly composed of two parts, i.e., a DX refrigeration plant and an air-distribution sub-system. Its detailed schematic diagram is shown in Fig. 2. The major components in the DX refrigeration plant included a variable speed rotor compressor, an electronic expansion valve (EEV), a high-efficiency louver-finned tube DX cooling coil (evaporator) and an air-cooled plate-finned tube condenser. The evaporator was placed inside the supply air duct to work as a DX air cooling and dehumidifying coil.

The air-distribution sub-system included an air-distribution ductwork with return air dampers, an air filter, a variable-speed centrifugal supply air fan and a conditioned space. The size of the conditioned space was 7.8 m (L) × 3.8 m (W) × 2.8 m (H). Inside the space there were sensible heat and moisture load generating units (LGUs) for simulating space cooling loads.

The experimental DX A/C system was equipped with a data-logging and control supervisory program, which was implemented in a personal computer (PC), so that all measured parameters real-time monitored, curve-data displayed, recorded and processed. It also enabled the PC to act as a central supervisory control unit for different low-level control loops, such as changing compressor and fan speeds, adjusting the outputs of LGUs to simulate different levels of indoor cooling load.

2.2. Specification of sensors/measuring devices

The experimental system was fully instrumented for measuring all of its operating parameters, which might be categorized into three types: temperature, pressure and flow rate. The locations of all the measuring sensors can be seen in Fig. 2. All measurements were computerized and operating data recorded for subsequent analysis.

All the temperature sensors were of platinum Resistance Temperature Device (RTDs) type, using three-wire Wheatstone bridge connection and with the pre-calibrated accuracy of ±0.1 °C. Air relative humidity was indirectly measured via measuring air dry-bulb and wet-bulb temperatures. Refrigerant temperature sensors were in direct contact with the refrigerant to ensure fast response. The atmospheric pressure was measured with a barometer with an accuracy of ±0.05 kPa. The air flow rate measuring apparatus were constructed in accordance with ANSI/ASHRAE Standards 41.2 with an accuracy of ±0.1% of the full scale reading (0.71 kg/s). Refrigerant mass flow rate passing through the EEV was measured by a Coriolis mass flow meter with an accuracy of ±.25% of full scale reading (0.3 kg/s).

2.3. Experimental conditions and procedures

In order to evaluate the dehumidifying performance on the air side of the SPR in the DX air cooling coil under various operating conditions, two types of experimental work were designed and carried out, as follows:

Type 1: The experimental operating conditions are shown in Table 1. In this type of experiments, inlet air temperature and