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Condensate as a water source from vapor compression systems in hot and humid regions

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HIGHLIGHTS

- Air conditioner condensate serves as an additional water source.
- Condensate increases with air humidity and temperature increase.
- Analytical model agrees well with experimental results.
- Every 50 °C rise in inlet air temperature increases condensate by 0.5 kg/h.
- Chemical analysis confirms that the condensate is safe for human use.

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ABSTRACT

Water is one of the basic necessities in life and its preservation is essential, particularly in hot and humid regions. Air conditioning systems operating in these regions usually produce a considerable amount of condensate. In this paper, analytical and experimental investigations in determining the condensate from a vapor compression air conditioning system as an additional water source are presented. A split type air conditioning system (1.5 tons) located in Dhahran, Saudi Arabia, where the dry bulb temperatures and relative humidity range from 25 to 50 °C and from 15 to 90%, respectively, is used for the study during summer months. Based on the hourly data, the monthly condensate yields during June, July, August and September are 1.26, 1.29, 2.50 and 2.33 kg/ton per CDD, respectively. The condensate is dominantly affected by the air humidity and temperature. The variation pattern of the condensate extraction is similar to that of the relative humidity. The collected condensate can be used as an additional water source. The chemical analysis of the condensate indicates that the water can be used for human consumption. The analytical model predictions of the condensate correlate well with the experimental data with a correlation factor of more than 90%.

1. Introduction

Shortage of fresh water still exists in many developing and arid countries across the globe. The shortage in fresh water supply is attributed to the rapid increase in population, industrialization and the development of urban areas. Moreover, the demand for water is high during summer seasons. For example, the water demand in the Kingdom of Saudi Arabia has increased from 502 million m^3 in 1980 to 2350 million m^3 in 2000 and is expected to increase to 6450 million m^3 in 2025 [1]. Currently, many countries rely on ground water and seawater resources through desalination technology for fresh water supply. For example, Saudi Arabia, the largest producer of desalted water, is developing desalination plants along with other technologies to insure continuous supply of water. The process of seawater desalination is very costly and consumes huge amounts of energy that is mainly generated from burning fossil fuel which produces harmful carbon emissions. In addition, the seawater has the tendency for scale formation problems due to dissolved salts and finely suspended solids. Therefore, new water sources with low cost and clean technology are needed. One such promising method for obtaining fresh water is to use condensate collected from air conditioning systems. Air conditioning systems are considered a necessity during summer seasons and are installed in almost every building.

Significant research efforts have been made towards water and energy sustainability in the last decade. The air conditioning market is growing rapidly throughout the world. For example, a recent published report by TechSci Research [2] indicates that the air conditioner market in Saudi Arabia is expected to grow at the annual rate of 8.7% during the next five years due to its hot climate, high per capita income and rapid population growth. Therefore, Saudi Arabia becomes one of the promising

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places to implement the new method for producing fresh water from air conditioning systems.

Condensation of atmospheric water vapor occurs in different ways. Surface cooling, such as that occurring in the evaporators of air conditioning systems, is one of the common ways of water vapor condensation. When the evaporator coil surface temperature becomes lower than the dew point temperature of the inlet air stream, condensation occurs over the surface of the coils. For climate conditions similar to those of Dhahran area, a theoretical study on air-cooling and dehumidification process where the controlling parameters of heat and mass transfer rate are optimized has been presented [3]. An experimental study is carried out to obtain water from vapor condensation over three different surfaces for irrigation in Bahrain [4]. The hourly average quantities of condensate collected from these surfaces are reported. A theoretical study of water production from evaporator coils indicates that the daily variation pattern of water yield is similar to that of relative humidity for climatic conditions in Jeddah, Saudi Arabia [5]. The maximum water yield occurs during night hours when the humidity is high. Another study is carried out on a combined heat pump–dehumidification system in Jeddah for water production [6]. The water yield from the combined system is 0.62 m^3/day in January and 2.23 m^3/day in September. Water recovery from atmospheric air using a packaged unit air conditioner and tilted solar absorption/desorption system is measured experimentally producing an average rate of condensed water of about 7.2 l/day per kW of cooling [7]. Brayant and Ahmad [8] reported that over 660,000 gal of water is captured within 140 days from condensate drains of a 600 ton air conditioning unit in a commercial building in Doha, Qatar.

Normally, large capacity air conditioning systems operating in hot and humid areas generate huge quantities of condensate. Moreover, the amount of condensate depends on the capacity of the cooling coil as well as the humidity and inlet temperatures of the air entering the coil. Hourly condensate production rates from a typical building in San Antonio are between 0.1 and 0.3 gal of water per ton of cooling as reported by Guz [9]. More than 2600 l of condensate is produced from the cooling coils of air handling units when the exit cooling coil air temperature is fixed at 12.77 °C for the climatic conditions in Dubai, UAE [10].

A recent study is carried out to investigate the quantity and chemical quality of condensate collected from air conditioners operating in Bandar Abbas, Iran during the months of March to December [11]. The study reports that split-type air conditioners generate more water than window air conditioners of the same capacity and each air conditioner produced an average of 36 l of water per day. Furthermore, it is mentioned that the collected condensate has no adverse effects on consumer health after undergoing the required disinfection process.

The greatest potential regions in the world for condensate collection, with a special consideration to areas having water scarcity are reported [12]. The quality of the condensate collected is close to that of distilled water .

This paper presents an analytical and experimental investigation of the rate of condensate extraction from a split type air conditioning system using hourly climate data of Dhahran, Saudi Arabia during summer seasons. The presented analytical model considers the variations of the evaporator inlet air temperatures and humidity in addition to the exit air temperatures. Moreover, the paper reports on the quality of the collected condensate.

2. Description of the air conditioning system

The base air conditioning system used for the study is a 1.5 ton, conventional split-type vapor compression system consisting of four basic components: a compressor, a condenser, an expansion valve and an evaporator connected to the air duct as shown in Fig. 1. In an ideal cycle operation, the refrigerant mixture absorbs heat from the warm air that is passing through the evaporator and exits as a saturated vapor (state 1). When the evaporator coil surface temperature is below the dew point of the air, condensation of water vapor occurs. The refrigerant vapor is compressed to higher pressure and temperature (state 2). The high pressure superheated vapor is cooled in the condenser by flowing air stream and exits as a liquid (state 3). The high pressure liquid refrigerant is expanded through a capillary tube where its pressure is dropped (state 4). The specifications of the base air conditioning system used for the study are listed in Table 1.

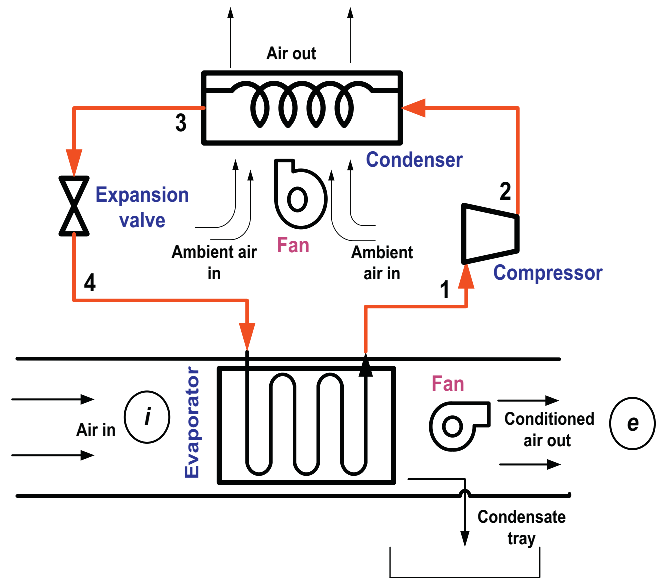

Fig. 1. Basic components of a conventional vapor compression system.

2.1. Analytical prediction of condensate extraction

The rate of condensate extraction from the air conditioning system is evaluated by applying conservation of mass and energy across the components of the system for the available climate data. An analytical model is formulated and the Engineering Equation Solver (EES) [13] software is implemented for predicting the rate with the following assumptions:

a. Steady state condition prevails in the system.
b. Pressure losses in the refrigerant pipes are neglected.
c. Pipe heat losses in the system are neglected.
d. The refrigerant at the outlets of the evaporator and condenser is saturated.

The psychrometric representation of the cooling/dehumidifying process is shown in Fig. 2. As the air enters the coil at state (i), a portion of the air stream comes into direct contact with the surface of the coil and is cooled almost to the coil surface temperature, T_s. State (s) is also called the apparatus dew point (ADP) where T_s is equal to the refrigerant temperature. The percentage of air that is in contact with the cooling coil is referred to as *contact factor*. The rest of the air passes between the tubes and fins without making physical contact and therefore is unaffected by its passage through the coil. This portion of the air is referred as the bypass air and its percentage is called the bypass factor.

Table 1
Specifications of the base air conditioning system.

Parameter	Value
Cooling capacity at 27 °C DB/19 °C WB and 35 °C DB outdoor	4.747 kW
Power input	2.075 kW
Current input	9.7 A
Energy efficiency rating (EER)	7.81
Refrigerant 22 charge	1.3 kg
Rotary compressor	–