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Thermodynamic analysis and improvement of a novel solar driven atmospheric water generator

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ABSTRACT

In this study, an improved novel solar driven atmospheric water generator device has been proposed to generate more water with less power usage. The system consisting of three parts: solar driven ammonia absorption refrigeration cycle, saline water desalination cycle and air dehumidification cycle. The system generates water from two great water sources simultaneously with equal power input to common AWG (Atmospheric Water Generator). Thermodynamic analysis of system has been done by parametric analysis of sub series cycles. The device performance curves have been introduced according to results. These curves can be used to determine the water generation of the improved novel AWG device in every place (or City) with having air relative humidity, and temperature of desired location. The performance of improved novel AWG device was analyzed in four cities of Iran. AWG water generation rate in case cities improved averagely about 165% by improvement process.

1. Introduction

Air humidity and saline water are the main storages of water. Saline water contains a high concentration of salt then cannot be used directly as drinkable or distilled water. Almost all water purification processes are costly [1]. The amount of water vapor in air depends on air relative humidity and temperature. Refrigeration cooling cycles have been used to separate water vapor from dry air [2–5]. Humid air passes through evaporator and the water vapor condenses on evaporator pipes.

Different types of cooling cycles have been used on atmospheric water generator to produce water from humid air [2,4]. Compression refrigeration cycles and absorption refrigeration cycles are two well-known cooling cycles which used in AWG. The main difference between absorption cycles and compression refrigeration cycles are input energy type. The input energy of compression refrigeration cycle is electrical power which runs the compressor. Thermal power is the input energy of absorption refrigeration cycles which apply to generator and runs the cycle. Thermal power can be absorbed from sun by high efficiency parabolic collectors. In addition, vapor compression cycles generate a very loud sound.

Mohammad alobaid et al. [4] collected experimental and computational works on solar driven absorption cycle in their research. They provided different types of collectors efficiency and specification in different types of absorption cycles. Based on their research, the average area to produce cooling power for single effect absorption refrigeration cycles is about 4.95 m^2/kW.

Jean phillipe praene et al. [5] worked on single effect solar absorption refrigeration cycle. They tested different types of solar collectors to run absorption refrigeration cycle. Based on their research, evacuated tube and parabolic tube collectors have highest efficiency to run a single effect absorption refrigeration cycles.

Anbarasu et al. [6] performed a research on dehumidifying unit using vapor compression refrigeration system. Mentioned system has higher efficiency than other water production units, but it lacks in the sense that it is not portable and it generates a lot of sound and also this system is more costly than other water production systems.

From the paper [7], we observed that even though dehumidification by liquid desiccant method is new and possess a lot of potential theoretically but when the researchers tested it experimentally, the results were not satisfying because the device could produce only 72.1 mL of water per kW-hr.

Kabeel et al. [8] proposed and simulated numerically a simple design method to make a portable water recovery system from the atmosphere. Their studied method was designed for Persian Gulf countries using solar-based thermoelectric generator utilization. According to their research, mentioned device is very portable and environment friendly but its efficiency in water production is lower than vapor refrigeration compression system.

Sri Suryaningsih and Otong Nurhilal [9] presented a method to develop a prototype of an AWG based on thermo-electric cooler. The

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Nomenclature

AWG	atmospheric Water Generator
$\dot{m}$	mass flow rate [kg/s]
$\dot{W}$	mechanical power [kW]
$\dot{Q}$.	heat power [kW]
X	concentration
h	enthalpy [kJ/kg]
COP	coefficient of performance
RH	relative humidity [%]
ω	specific humidity [kg/kg]
P	pressure [bar]
T	temperature [K] & [°C]
s	entropy [kJ/kg°C]
η	efficiency

Subscripts

i	inlet
DA	dry air
GW	total water generation
e	outlet
T	air dehumidification cycle streamlines
TW	water at saturation temperature
A	ammonia absorption cycle streamlines
W	water desalination cycle streamlines

result of their research was presented as an experimental prototype of an AWG based on Thermo-electric cooler and compared with other conventional products in Indonesia. Pontious et al. [10] designed an AWG device which converts water vapor into liquid water in regions where water scarcity exists.

Many Researches have been conducted to investigate the reduction possibility of AWG power requirement, [11–16]. For example Choi [11] suggested the improvement method of freshwater productivity by re-utilizing the brines of a few top evaporators. He claimed that brine re-utilization increases energy efficiency. The development of a simulation model for standalone AWG driven by photovoltaic modules had been presented by Aye et al.[13]. Based on their analysis it was deduced that the monthly average daily efficiency is strongly related to the monthly average relative humidity of the ambient air

Joshi et al. [17] presented an experimental investigation of a portable thermoelectric fresh water generator. They concluded the quantity of water generated is directly proportional to electric current, air mass flow rate and humidity of moist air in the domain of experimentation. Tan, and Fok [18] presented the experimental evaluation of parameters that influence the amount of water, collected from condensation of water vapor on a cooled surface.

In this paper, solar driven ammonia absorption refrigeration cycle is proposed and simulated to produce fresh and distilled water from humid air and saline water simultaneously. Dehumidification of air done by running it through the ABS (Advanced Brine Solutions) evaporator. Simultaneously, heated ammonia vapor, at generator outlet, has been used to vaporize salty water and separate salt from saline water. In addition, in current study the required specific area of collectors provided to make an optimal solar driven system.

2. System description

Cooling power needed to generate water from humid air. Single effect ammonia absorption refrigeration cycle chosen to generate cooling power. Generated cooling power transfers to the humid air by finned tube cross flow heat exchanger. The finned tube heat exchanger decreases humid air temperature to lower than its dew point. Then, the water vapor condenses and converts to liquid and remains on heat exchanger fins and pipes.

Traditional AWG contains solar driven absorption cycle (with index A in Fig. 1), and Air dehumidification cycle (with index T in Fig. 1). Absorption cycle output cooling power used to condense water vapor of

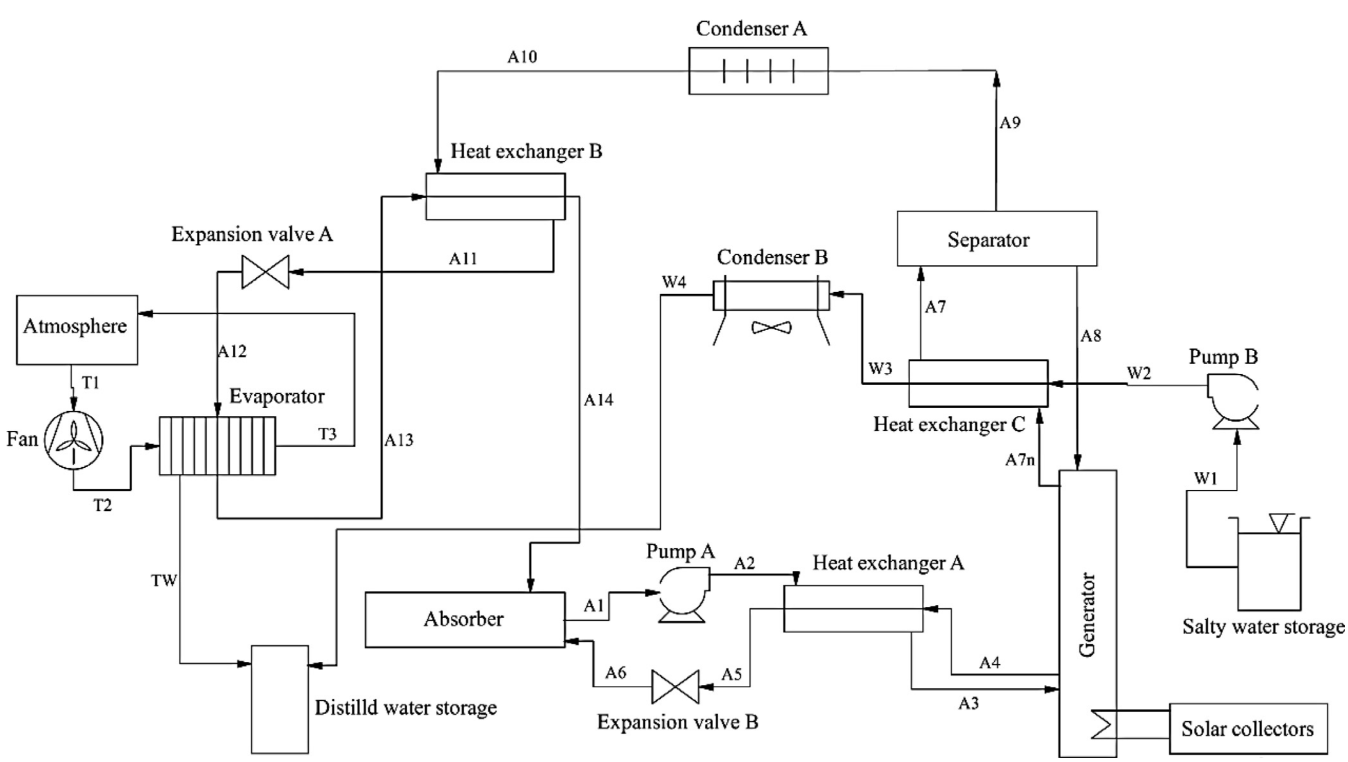

Fig. 1. Block diagram of improved AWG system.