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Design of a renewable energy based air-conditioning system

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ABSTRACT

This paper presents the design of a solar-biomass hybrid system for air-conditioning. Three possible overall system configurations were first considered, based on which the most suitable configuration considered for the design. The principles of component selection of a flat plate solar collector with storage, biomass gasifier with boiler, and a LiBr–H_2O absorption system has been described, and the design criteria for the proposed system elaborated. The design was to satisfy a cooling load of 4.5 kW, and solar to auxiliary heat ratio of at least 0.7. Simulation at various solar collector size and storage tank volume for the weather conditions at Bangkok indicate the most suitable design and specifications for the size/capacity of the solar collector, storage tank, set point temperature of the absorption generator and biomass-gasifier boiler.

1. Introduction

To address the global warming and energy crisis issues, using renewable energies appear as an interesting alternative. As the ambient temperature increases, the need for air conditioning will dramatically increase. To reduce the electricity consumption and CO_2 emissions, solar air conditioning systems seems appropriate and vital [1].

The two main solar air conditioning options are electrical and thermal driven systems. The electrical systems require the use of photovoltaic panels; these are still expensive and have low efficiencies. The thermal driven systems are divided into heat transformation systems and thermo-mechanical processes. Most thermo-mechanical processes are in laboratory scale and they use engines to drive a compressor instead of an electrical motor. The heat transformation processes are divided into close and open cycles, and they may use liquid or solid sorbents. Almost all solar cooling systems are closed cycle liquid sorbent systems.

Solar driven system offers a good model of a clean process for sustainable technology [2]. The two driving energy sources for the conventional solar cooling systems are without auxiliary heat source and with fossil fuel auxiliary heater. As solar energy is intermittent, the solar cooling system without auxiliary heat source cannot be continuously used, especially at night, and so its reliability is low. Almost all solar cooling systems use gas (LPG/CNG) as an auxiliary heater [3]. Thus, a conventional solar cooling system has three major sub-systems – absorption chiller, solar water heating system and backup/auxiliary heating sub-systems (renewable or fossil fuel based).

A solar-biomass hybrid cooling system has been proposed, which is a completely renewable energy based system [3,4]. This paper first identifies the optimal system configuration (among three options), and then presents the design procedure of a solar-biomass hybrid cooling system for the chosen option. Section 2 describes the possible system configurations of solar-biomass hybrid absorption cooling system (SBAC). Section 3 presents the mathematical model and simulation inputs used for the design of the SBAC system. Section 4 presents the selection of the best system configuration. Section 5 presents the design of a solar-biomass hybrid air-conditioning system. Finally, the conclusions are given in Section 6.

2. Possible system configurations

As demonstrated in Fig. 1, most conventional solar cooling systems use fossil fuel as an auxiliary heat source, and so their operating cost and emissions are high. This research proposes biomass energy as a cheaper (or free if it is the waste material) auxiliary heat source to address the above issue. Thus, the main difference of the proposed system as compared to the conventional system is

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Nomenclature

A	area (m^2)
C	specific heat capacity, (kJ/kg K)
F_R	heat removal factor
G_T	solar insolation on tilted surface (kW/m^2)
h	specific enthalpy (kJ/kg)
LHV	low heating value (kJ/kg)
M	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
$\dot{Q}$	energy rate (kW)
t	time (s)
T	temperature (K)
U	heat transfer coefficient (W/m^2 K)
U_L	overall heat transfer coefficient (W/m^2 K)
$\dot{V}$	volumetric flow rate (m^3/s)
v	specific volume (m^3/kg)
x	solution mass concentration (%)
Greek symbols	
η	efficiency
τ	transmittance
α	absorptance
β	tank load control function
γ	temperature differential control function
φ	boiler load control function
ε	heat exchanger effectiveness
ρ	density (kg/m^3)
Subscripts	
0	initial condition
a	ambient
ab	absorber
aux	auxiliary
b	boiler
BM	biomass
bl	boiler to load
c	collector
co	condenser
ev	evaporator
f	liquid state
fg	liquid-vapor mixture
flu	flue gas
g	vapor state
ge	generator
gw	gas to water
hi	high
i	inlet
lo	low
o	outlet
PG	producer gas
ref	refrigerant
set	set point value
sol	solution of refrigerant and absorbent
st	storage tank
tl	tank to load
u	solar useful energy
w	water
we	water to environment

that the fossil auxiliary heat source is replaced by biomass based gasifier boiler.

Fig. 2 shows three possible system configurations for solar-biomass hybrid cooling system: (Case 1) an auxiliary heater is connected in series with the solar water heating system, (Case 2) an auxiliary heater is connected in parallel with solar collector, and (Case 3) an auxiliary heater is connected in parallel with the solar water heating system.

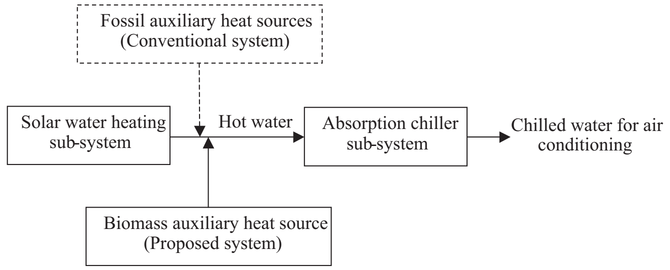

Fig. 1. Conventional and proposed solar cooling system.

The common feature in all the three cases is that the insulated biomass gasifier boiler has two functions: it works as an auxiliary energy source when solar energy is not enough and works as the main heat source when the solar radiation is not available. In Case 1 and 3, the gasifier boiler is controlled by a controller and supplies hot water to the generator of the absorption chiller. The solar energy heats the water at the collector field which is then pumped to the hot water storage tank. This pump will be activated by controller. Usually, it remains off until the difference between collector outlet and inlet water temperature is above the upper dead band value. The controller will switch the pump off when this difference reaches the lower dead band.

The cooling is provided by a single-effect LiBr–H_2O absorption chiller. Heat from solar collector or from biomass-boiler evaporates the water (strong solution of water and LiBr) in the generator of the absorption chiller. This is led to the condenser, where it rejects heat to the ambient and condenses. This is taken to the evaporator through the expansion valve, where it receives heat from the space to be cooled and evaporates. The evaporated refrigerant (water) is absorbed by the weak solution in the absorber (from the generator). The absorption process also releases heat to the ambient, and the solution, now rich in water (strong solution) is taken to the generator (by a pump) to complete the cycle. The heat required for its generator is drawn from hot water pumped from a hot water storage tank fed by the solar collectors and/or sometimes boosted/fed by biomass boiler. The condenser and absorber of absorption chiller are cooled by water pumped through a cooling tower. The chilled water produced from evaporator is pumped for cooling proposes.

3. Mathematical model and input parameters used for the design

The mathematical model of the SBAC system and its validation presented in [3] was used in the system configuration selection and system design. The procedure used the governing equations for each sub system, and that the inputs and outputs between each sub-system were according to the configuration in Fig. 2. The model equations were constructed using the following assumptions:

(1) The model considered the energy and mass balances at each component, and of the overall system.
(2) The system is considered to be at steady state.
(3) The specific heat and density of the working fluids are constant.
(4) The loss of the water vapor and moisture (at the hot water storage tank and solar collector vents) is not taken into account.
(5) There is no pressure loss and no heat loss/gain in the lines (pipes) connecting the system components.
(6) The fluid temperatures increasing due to the friction in plumbing and valves, blowers and pumps are negligible.