Solar Absorption Aqua-Ammonia Absorption system simulation base on Climate of Malaysia

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Abstract:- Solar energy is one of the most well known green sources of energy. This research presents a feasibility study of evacuated solar thermal collector by aqua-ammonia ejector absorption systems as a small scale air conditioning unit. The modeling has been performed using TRNSYS software. The solar fraction is 10% to 36% for collector area of $10m^2$ to $50m^2$. The economic analysis has also been conducted. Electrical cost less than 0.25 USD/kW in not economical and leads to negative saving.

Keywords: - Evacuated tubes, solar assisted absorption system, Ejector

1 Introduction

Energy supply to refrigeration and air-conditioning systems constitutes a significant role in the world. The cooling load is generally high when solar radiation is high. Together with existing technologies, solar energy can be converted to both electricity and heat; either of which can be used to power refrigeration systems.

The idea is not new; a solar-driven refrigerator was first recorded in Paris in 1872 by Albel Pifre [3]. A solar boiler was used to supply heat to a crude absorption machine, producing a small amount of ice. Later, solar powered refrigeration systems have been installed worldwide in many countries e.g. Australia, Spain, and the USA. Most are thermally driven absorption systems, designed for air-conditioning purposes.

Local factors are so important. So, it is undeniably difficult to design a 'one-size-fits-all' refrigeration or air-conditioning system, which can be applicable world-wide. The effects of the widely varying local conditions must also be taken into consideration.

The ejector, which is the heart of the jet refrigeration system, was invented by Sir Charles Parsons around 1901 for removing air from a steam engine's condenser. In 1910, an ejector was used by Maurice Leblanc in the first steam jet refrigeration system. This system experienced a wave of popularity during the early 1930s for air conditioning large buildings. Ejector absorption system is an absorption system developed by an Ejector. The ejector was invented by Sir Charles Parsons around 1901 for removing air from a steam engine's condenser [3].

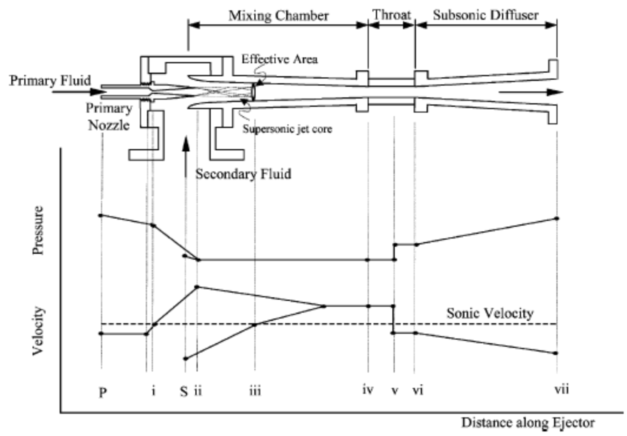

Fig. 1: Schematic view and the variation in stream pressure and velocity as a function of location along a steam ejector [4]

Kanjanapon Chunnanond et al [4] provided a literature review on ejectors and their applications in refrigeration. They described basic background and development of an ejector and its application in refrigeration purposes. They evaluated the possibility of utilizing low grade energy, as like solar energy for driving ejector systems. Even though, the jet refrigerator has suffered from its very low COP, the improved COP from combining ejector to other types of refrigeration system (vapour compression and absorption system) was remarkable.

Humberto Vidal [1] hourly simulated an ejector cooling cycle assisted by solar energy. The system is simulated using the TRNSYS program and the typical meteorological year (TMY) file that contains the weather data from Floriano´ polis, Brazil. A cooling capacity of 10.5 kW is considered. The model was used to investigate the effect of the area, slope and collector type, storage tank size and hot water flow rate on solar fraction, useful heat gain and auxiliary heat. Simulation results show the auxiliary energy usage and the useful heat gain for different types and areas of solar collector. The optimized system consists of 80 m^2 of flat plate collector tilted 22^o from the horizontal, a 4 m^3 hot water storage tank and a mass ratio equal to 8.

2 Mathematical Model

Since we are dealing with solar assisted ejector absorption system, we can divide the system to 3 sub system: Solar thermal collector, absorption chiller and cooling load.

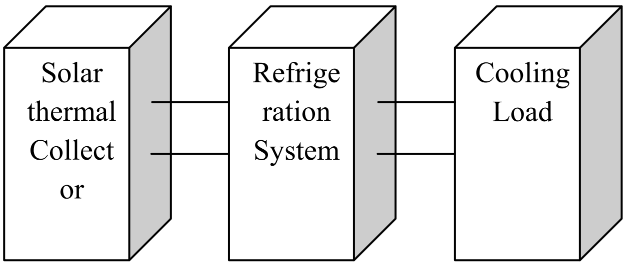

Fig. 2: schematic of solar assisted air conditioning system

There is large number refrigeration system that could be run by solar thermal energy. In this research we concentrated on Aqua-Ammonia Ejector Absorption system that is appleciable for refrigeration and Air-conditioning
Aqua ammonia is a binary liquid mixture. The properties of this mixture could be extracted from diagrams. Here we present the derivative equations for this mixture that has been used in simulation [6]:

The resulting functions are:

$$T(p,x) = T_o \sum_i a_i (1-x)^{m_i} \left[ln\left(\frac{p_o}{p}\right)\right]^{n_i}$$

Table 1: Exponents and coefficients

i	m_i	n_i	a_i	i	m_i	n_i	a_i
1	0	0	$+0.322302\times10^{1}$	8	1	2	$+0.106154\times10^{-1}$
2	0	1	-0.384206×10^{0}	9	2	3	-0.533589×10^{-3}
3	0	2	$+0.460965\times10^{-1}$	10	4	0	$+0.785041\times10^{1}$
4	0	3	-0.378945×10^{-2}	11	5	0	-0.115941×10^{2}
5	0	4	$+0.135610\times10^{-3}$	12	5	1	-0.523150×10^{-1}
6	1	0	$+0.487755\times10^{0}$	13	6	0	$+0.489596\times10^{1}$
7	1	1	-0.120108×10^{0}	14	13	1	$+0.421059\times10^{-1}$

T_o=100 K p_o=2 Mpa

$$h_l(T,x) = h_o \sum_i a_i \left(\frac{T}{T_o} - 1\right)^{m_i} x^{n_i}$$

Table 2: Exponents and coefficients

i	m_i	n_i	a_i	i	m_i	n_i	a_i
1	0	1	-0.761080×10^{1}	9	2	1	$+0.284179\times10^{1}$
2	0	4	$+0.256905\times10^{2}$	10	3	3	$+0.741609\times10^{1}$
3	0	8	-0.247092×10^{3}	11	5	3	$+0.891844\times10^{3}$
4	0	9	$+0.325952\times10^{3}$	12	5	4	-0.161309×10^{4}
5	0	12	-0.158854×10^{3}	13	5	5	$+0.622106\times10^{3}$
6	0	14	$+0.619084\times10^{2}$	14	6	2	-0.207588×10^{3}
7	1	0	$+0.114314\times10^{2}$	15	6	4	-0.687393×10^{1}
8	1	1	$+0.118157\times10^{1}$	16	8	0	$+0.350716\times10^{1}$

h_o=100 kj kg^{-1}
T_o=273.16 K

$$h_g(T,y) = h_o \sum_i a_i \left(1 - \frac{T}{T_o}\right)^{m_i} (1-y)^{n_i/4}$$

Table 3: Exponents and coefficients

i	m_i	n_i	a_i	i	m_i	n_i	a_i
1	0	0	$+0.128827\times10^{1}$	10	1	3	$+0.164508\times10^{2}$
2	1	0	$+0.125247\times10^{0}$	11	2	3	-0.936849×10^{1}
3	2	0	-0.208748×10^{1}	12	0	4	$+0.842254\times10^{1}$
4	3	0	$+0.217696\times10^{1}$	13	1	4	-0.858807×10^{1}
5	0	2	$+0.235687\times10^{1}$	14	0	5	-0.277049×10^{1}
6	1	2	-0.886987×10^{1}	15	4	6	-0.961248×10^{0}
7	2	2	$+0.102635\times10^{2}$	16	2	7	$+0.988009\times10^{0}$
8	3	2	-0.237440×10^{1}	17	1	10	$+0.308482\times10^{0}$
9	0	3	-0.670515×10^{1}				

h_o=1000 kj kg^{-1}
T_o=324K

An aqua ammonia ejector absorption system could be modeled by equations below [5,7]:

Absorber:

$$\dot{m}_6 + \dot{m}_{12} = \dot{m}_7$$
$$\dot{m}_6 x_6 + \dot{m}_{12} x_{12} = \dot{m}_7 x_7$$
$$\dot{m}_6 h_6 + \dot{m}_{12} h_{12} = \dot{m}_7 h_7 + Q_{absorber}$$

Pump:

$$\dot{W}_p = \frac{\dot{m}_7 v_7 (P_8 - P_7)}{\eta_p}$$
$$\dot{m}_7 h_7 + \dot{W}_p = \dot{m}_8 h_8$$

Heat Exchanger:

$$\varepsilon = \frac{T_{10} - T_{11}}{T_{10} - T_8}$$
$$\dot{m}_8 h_8 + \dot{m}_{10} h_{10} = \dot{m}_{11} h_{11} + \dot{m}_9 h_9$$

Generator and rectifier:

$$\dot{m}_9 h_9 + Q_{net} = \dot{m}_{10} h_{10} + \dot{m}_{13} h_{13}$$
$$\dot{m}_9 x_9 = \dot{m}_{10} x_{10} + \dot{m}_{13} x_{13}$$
$$Q_{net} = Q_{generator} - Q_{rectifier}$$

Absorber throttle valve:

$$\dot{m}_{11} = \dot{m}_{12}$$
$$h_{11} = h_{12}$$
$$x_{11} = x_{12}$$

Evaporator throttle valve:

$$\dot{m}_2 = \dot{m}_3$$
$$h_2 = h_3$$
$$x_2 = x_3$$

Condenser:

$$\dot{m}_1 = \dot{m}_2$$
$$x_1 = x_2$$
$$\dot{m}_1 h_1 = \dot{m}_2 h_2 + Q_{condenser}$$

Evaporator:

$$\dot{m}_3 = \dot{m}_4$$
$$x_3 = x_4$$
$$\dot{m}_3 h_3 = \dot{m}_4 h_4 + Q_{evaporator}$$

Ejector:

$$i_5 \dot{m}_5 + i_{13} \dot{m}_{13} = i_1 \dot{m}_1$$
$$\dot{m}_5 + \dot{m}_{13} = \dot{m}_1$$
$$\dot{m}_5 x_5 + \dot{m}_{13} x_{13} = \dot{m}_1 x_1$$

COP:

$$COP = \frac{\dot{Q}_e}{\dot{Q}_e + \dot{W}_p}$$

3 TRNSYS Environment

Dynamic simulation is a key method for evaluating the system performance and optimum sizing of the system components. In this study we developed he simulations in TRNSYS 16 environment.

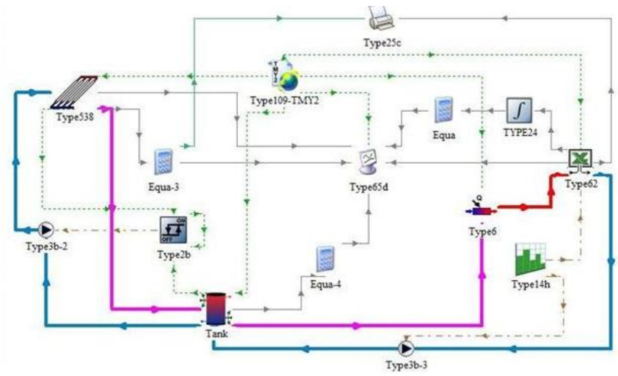

Fig. 3: Simulation studio window of TRANSYS 16

4 Results of Simulation

We used weather data for Kuala Lampur Airport (KLIA) in all runs. Results of dynamic simulation of the system by using the TRNSYS 16 software are as below:

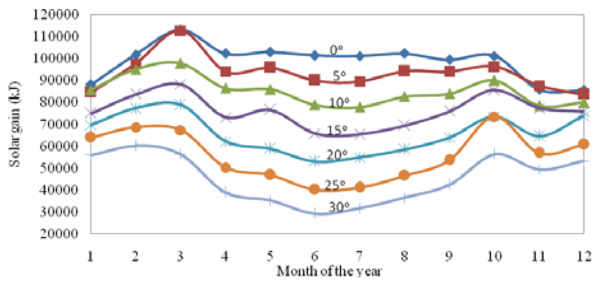

Fig. 4: Monthly Solar gain by different slope of collector

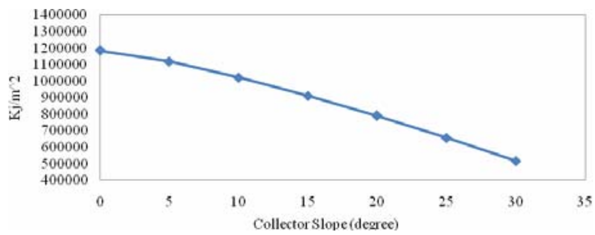

Fig. 5: Annual Solar gain as a function of collector slope

According to the result of simulations, the optimum collector slope is around 0. In theory, the optimum collector slope is equal to the latitude of the place of installation, so for KualaLampur it would be around 3°. Dusting effect imposes the 15° collector slope as technical Issue.

Aqua-ammonia ejector absorption system is a normal aqua-ammonia absorption equipped by an ejector component. In this study we assumed an ejector placed after rectifier (before condenser). In this case, primary flow is the flow leaving the rectifier and the secondary one is the flow leaving the evaporator. High pressure (high temperature) flow from rectifier sucks the low pressure (low temperature) secondary flow from evaporator.

Storage tank functions as energy storage device for damping the solar gain fluctuation, hour by hour, day by day and season by season, base on its storage capacity.

Here we present the effect of size of storage tank on solar gain:

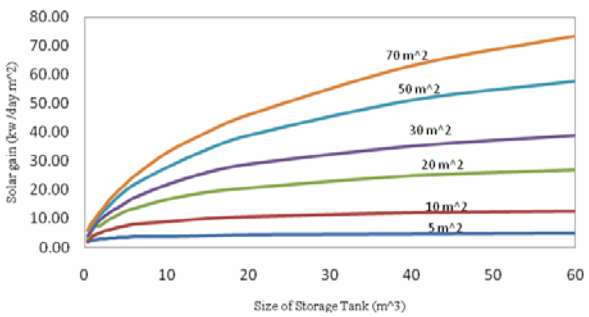

Fig. 6: Effect of size of storage tank on solar gain (Scale I)

4.1 Economic Analysis

We develop the economic analysis to find the most economic system design too meet the demand.

Installed cost of solar equipment can be shown as below [2]:

Total cost of installed solar energy equipment = Total Area dependent Cost x Collector Area + Total Area independent Cost

Area-dependent cost: all cost that varies by collector area such as Solar collector cost, piping cost, installation cost, a portion of cost of storage tank.

Area-independent cost: are the costs of equipment that does not varies significantly by the size of collector area such as controlling system, fans, blowers and etc.

Solar saving is the difference between the cost of a conventional system and a solar system.

$$\text{Solar Saving} = \begin{pmatrix} \text{Cost of} \\ \text{Conventional} \\ \text{Energy} \end{pmatrix} - \begin{pmatrix} \text{Cost of} \\ \text{Solar} \\ \text{Energy} \end{pmatrix}$$

In this equation it is not necessary to evaluate the costs that are common to both the solar and the nonsolar system [2].

John A. Duffie, William A.Beckman describe the economic analysis as below:

The economic problem in solar process design is to find the lowest cost system. In principle, the problem is a multivariable one; with all of the components in the system and the system configuration have some effect on the thermal performance and thus on cost. The design of the load system must also be considered in the search for optimum design. System performance is much more sensitive to collector area than to any other variable.

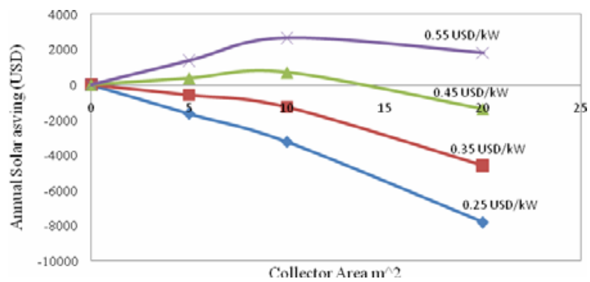

Fig. 7: Annual solar saving as a function of solar collector area

Figure above illustrates the solar saving of an aqua-ammonia solar absorption system with average cooling capacity of 3.5Kw. It's clears that for the current cost of electricity (0.25 USD/kW) the solar saving is negative for all collector areas. We would be able to forecast the benefit of investigating the solar collector in future, if we consider the cost of energy in future.

5 Conclusion

In air conditioning and refrigeration applications we need relatively low temperature energy source ($85\sim95^{oC}$) that could be provided by evacuated tube solar collectors (heat pipe). This source can run the system but not continuously. That why we need auxiliary source to assure the system will functions properly. Auxiliary source could be an electric heater, gas burner, fuel cell, geothermal, wind energy, biomass, and etc; the most important thing is that, whatever it is, it's essential. This study presents the solar fraction for different collector area for a small scale aqua-ammonia ejector Air conditioner.

Economic analysis illustrates negative solar saving for the current cost of electricity (0.25 USD/kW). In first glance we may find this system as a non economic and useless technology; but the fact is at the moment the fuel cost is affordable, because of almost low cost non-renewable but invaluable Oil sources. We have to replace the conventional energy resources by renewable ones, for the time that there will be no oil any more. By economic analysis we would be able to find the most economic system design and sizes.

In this study, we evaluated effect of 5~50m^2 evacuated collector areas. In simulations we set all tubes in series, but there is no fact that this is the optimum arrangement of collectors. A combination of series and parallel collector may be more effective.

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COP Coefficient of performance
T Temperature (K)
P Pressure (Mpa)
x Ammonia mole fraction in liquid phase
y Ammonia mole fraction in gas phase
h specific enthalpy (kJ/kg)
i specific enthalpy (kJ/kg)
$\dot{m}$ Mass flow rate (kg/hr)
Q Thermal energy (kW)
$\dot{W}$ Work input to pump (kW)
f Solar fraction
C_p specific heat (kJ/kg.K)

Greeks

ω The entrainment ratio (Ejector Capacity)
v_7 Specific volume (m^3/kg)
η_p Efficiency of pump

Subscripts

g Gas phase
l liquid phase
o reference data