Operate A Vapour Absorption Refrigeration System By Using Solar Energy

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Abstract- *The Current Study air-conditioning and refrigeration systems in the Kingdom of Saudi Arabia consume more than 60% of the electrical energy of the building sector. Most of the used systems are of the vapor-compression type. Using solar energy to power such systems will save a large amount of energy (primary or electrical) that can be utilized by the production sectors such as industries. Therefore in the present study, alternate designs for a 24-h operating solar-powered absorption refrigeration technology have been developed in detail. The development includes an in-depth review of the design and operation of the conventional and solar-assisted absorption refrigeration systems coming-up with new alternative designs, detailed thermodynamic analysis of some of the new alternative designs and selection of the most suitable alternative design. The analysis indicates that continuously operating solar-powered aqua-ammonia absorption system with refrigerant storage is the most suitable alternative design for an uninterrupted supply of cooling effect.*

Keywords- operation, solar-powered, absorption, refrigeration,operate,solar energy,refrigeration system.

I. INTRODUCTION

The excessive demand for air-conditioning in the Kingdom of Saudi Arabia is a direct result of the extreme temperatures during summer, when the ambient temperature frequently reaches 46 C Thus it is imperative to use refrigeration and air-conditioning in all fields of life. The application of refrigeration and air-conditioning is mostly in the building sector i.e. commercial, industrial and residential buildings. Presently almost all the cooling produced in the Kingdom is by means of vapor-compression systems. The compressor of these vapor-compression systems are directly run by the electrical energy that is generated by burning fossil fuel. This electrical energy is high-grade energy and it can be effectively utilized in high value applications such as industrial purposes. Therefore, it creates the need for the development of a refrigeration system that may run on an alternative source of energy so that electrical energy from the fossil fuels may be employed in the production sector rather than being utilized in the consumption sector such as comfort conditioning. Such systems will significantly share the load of electrical energy generated by burning fossil fuel, thus helping in the reduction of carbon emission , hence reducing environmental pollution and global warming effects. Out of the various renewable sources of energy, solar energy proves to be the best candidate for Refrigeration and air-conditioning because of the coincidence of the maximum cooling load with the period of greatest solar radiation input. Solar energy can be used to power a refrigeration system in two ways. First, solar energy can be converted into electricity using photovoltaic cells and used to operate a conventional vapor-compression refrigeration system. Second, solar energy can be used to heat the working fluid in the generator of a vapor sorption (absorption or adsorption) refrigeration system. Kim and Infante Ferreira (2008) made a comparison between solar electric and solar thermal refrigeration systems both from the point of view of energy efficiency and economic feasibility. The comparison showed that solar electric refrigeration systems using photovoltaic appear to be more expensive than solar thermal systems. Several researches in this field have been done and a lot more is still undergoing. For instance, Jakob et al. (2008) performed the experimental investigation and simulation of aqua-ammonia absorption chiller. The experimental results showed that evaporator temperatures of 15 C to 5 C can be achieved at the generator temperatures varying from 65 C to 115 C. Bouaziz et al. (2011) proposed a hybrid cooling system using compression-absorption processes operating at three pressure levels. The simulation analysis showed that their proposed design has better performance compared to conventional systems. Wang et al. (2009) discussed the typical small-scale systems for potential residential applications.

Vapour Absorption Refrigeration Systems

When a solute such as lithium bromide salt is dissolved in a solvent such as water, the boiling point of the solvent (water) is elevated. On the other hand, if the temperature of the solution (solvent + solute) is held constant, then the effect of dissolving the solute is to reduce the vapour pressure of the solvent below that of the saturation pressure of pure solvent at that temperature. If the solute itself has some vapour pressure (i.e., volatile solute) then the total pressure exerted over the solution is the sum total of the partial pressures of solute and solvent

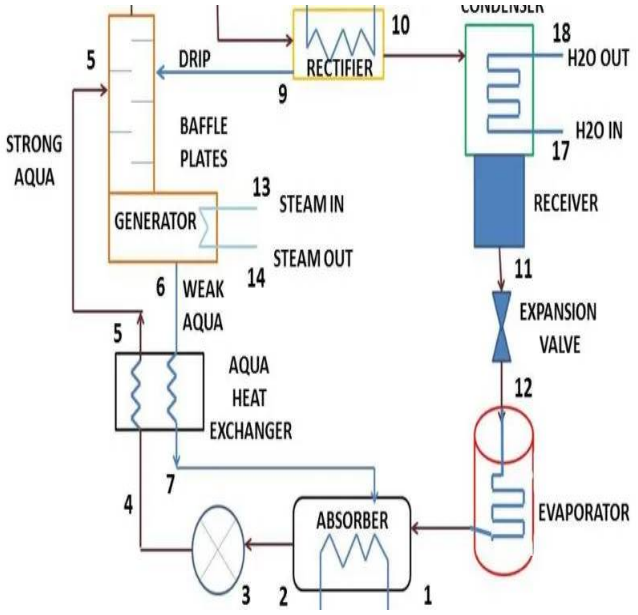


Fig 1.Vapour Absorption Refrigeration Systems

If the solute is nonvolatile (e.g. lithium bromide salt) or if the boiling point difference between the solution and solvent is large (≥ 300o C), then the total pressure exerted over the solution will be almost equal to the vapour pressure of the solvent only. In the simplest absorption refrigeration system, refrigeration is obtained by connecting two vessels, with one vessel containing pure solvent and the other containing a solution. Since the pressure is almost equal in both the vessels at equilibrium, the temperature of the solution will be higher than that of the pure solvent. This means that if the solution is at ambient temperature, then the pure solvent will be at a temperature lower than the ambient. Hence refrigeration effect is produced at the vessel containing pure solvent due to this temperature difference. The solvent evaporates due to heat transfer from the surroundings, flows to the vessel containing solution and is absorbed by the solution. This process is continued as long as the composition and temperature of the solution are maintained and liquid solvent is available in the container. For example, Fig.1 shows an arrangement, which consists of two vessels A and B connected to each other through a connecting pipe and a valve. Vessel A is filled with pure water, while vessel B is filled with a solution containing on mass basis 50 percent of water and 50 percent lithium bromide (LiBr salt). Initially the valve connecting these two vessels is closed, and both vessels are at thermal equilibrium with the surroundings, which is at 30o C. At 30o C, the saturation pressure of water is 4.24 kPa, and the equilibrium vapour pressure of water-lithium bromide solution (50 : 50 by mass) at 30o C is 1.22 kPa.

Components in Vapour Absorption Refrigeration System:

1. Evaporator

The main function of the evaporator is to provide cooling to the area with which it is in contact. The chilled liquid will enter inside this evaporator and will receive heat from the evaporator and will convert into vapour. This vapour will be at low pressure. From this evaporator, the ammonia vapour comes out at low pressure and will go towards absorber.

2. Absorber

The absorber is used to absorb the refrigerant. At the absorber, there will be a weak solution of water and ammonia. When the ammonia vapour from evaporator will reach the absorber, water present in the absorber will absorb it. As water will absorb ammonia, strong solution of ammonia and water will start getting created.

When the water will absorb ammonia water will liberate heat and the absorbing capacity of water reduces. So, cool water is supplied in the absorber so that the absorbing capacity stay high so that it continuously absobs the ammonia vapour.

3. Pump

The pump will pump the strong solution of ammonia and water from the absorber to the generator

4. Generator

Ammonia and water solution is used inside this system. Ammonia is used as a refrigerant and water is used as an absorbent. A solution of these two is made because water has a strong affinity towards ammonia. Water plus ammonia solution is present inside the absorber. The generator is provided with auxiliary heat from outside. For providing this auxiliary heat steam or hot water or any type of heater can be used. The heat is provided so that the ammonia and water solution converts to vapour.

5. Analyzer

Analyzer is placed at the top of the generator. Ammonia will convert into vapour before the water but some water particles convert into vapour with ammonia. This analyzer is used to separate the water particles from ammonia vapour. If the water particles move forward from the generator, it will decrease the efficiency of the whole system.

If the water particle passes forward in large quantity, it can damage the system also.

6. Pressure Reducing Valve

After the ammonia vapour passes through the analyzer, the weak solution present in the generator will pass through the pressure reducing valve and will reach the absorber again.

7. Condenser

Condenser is used to convert the ammonia vapour into liquid phase. This condenser can be either water-cooled or air-cooled.

8. Expansion Valve

Its main function is to convert the liquid into chilled liquid and give it to the evaporator.

At the expansion valve, the ammonia liquid will come from the condenser and the temperature and pressure of this liquid ammonia will reduce and this ammonia liquid will become chilled liquid ammonia temperature of which will be very low.

II. LITERATURE REVIEW

Several research related to this project have been studied. Here two paper review are as following

Hitesh Panchal,(2018)

This review paper is to study various researchers' work on solar milk pasteurisation system. Hence, it also covers important aspects required for solar pasteurisation like flat plate collector, heat exchanger and solar water heating system. Solar energy is available freely. Hence, nowadays people are working on solar energy when compared with conventional sources of energy. Dairy industries require heat, which can be generated by the use of boiler with the aid of wood. Hence, due to increment in global warming, it is necessary to use renewable energy.

Mohamad Aramesh, (2019)

In this article, the performance of a double-effect LiBr-H2O absorption refrigeration cycle is studied and is improved by applying solar energy and utilizing nanofluids. A trough collector is used to preheat the working fluid before entering the generator of the cycle. In addition, four different nanofluids are considered as the heat transfer fluid of the collector: Al2O3, Ag, Cu, and CuO. The effects of using nanofluids on the outlet temperature of the heat transfer fluid, the temperature of the working fluid entering the generator, the heat produced by the generator, and COP of the cycle are studied. Different concentrations of the nanoparticles from 0 to 2.5% are considered for the nanofluids. The results indicate that in all the concentrations, Ag nanoparticles will have a better performance comparing to the other types. Furthermore, it was concluded that the higher concentrations of the nanoparticles and along with it the higher inlet temperature of the generator will decrease the generator heat production rate up to 4%. Moreover, considering the constant cooling capacity of the cycle, usage of the Ag nanoparticles in the concentration of 2.5% increases the value of COP up to 3.9%, with respect to the pure water.

Reza Shirmohammadi,(2018)

In This results point out that the exergy destruction of the CO2 in striper and absorber columns are the highest, and according to the cost-based information, potential location for the process improvement are proposed. A comprehensive method based on thermodynamic and mathematical methods has been proposed to acquire efficient design parameters and consumed power in compressors. It is based on a combination of Aspen HYSYSVR and MATLABVR to do calculations and then an optimization procedure based on genetic algorithms. Results show that the production cost of each ton CO2 is equal to 6.05 (USD/ton) and return on investment can also be obtained by 2.5 years Exergy and exergoeconomic analyses have been used to set out weaknesses of the postcombustion CO2 capture unit of Besat power plant that uses an ammonia absorption refrigeration system for CO2 liquefaction. The energy required for the absorption system is provided by the flue gas. The liquefied CO2 is used for beverage and food industries. The exergoeconomic costs of all utility streams and processes are calculated through 6a systematic method of assigning exergetic cost relations to the streams.

Tahir A.H. Ratlamwala, (2017)

In the present study The absorption cooling cycles are operated on the solar heat in order to improve the utilization of high temperature heat sources for absorption systems. The absorption refrigeration cycles of multi□effect are modeled and designed for the identical refrigeration capacity along with the similar operating conditions. The engineering equation solver tool is deployed to analyze the coefficient of performance (COP) and exergetic efficiency of the absorption cooling cycles. Performance simulations were carried out over a range of operating conditions, including the effect of heat transfer fluids (nanofluids) used in solar parabolic trough collectors. The COP of the triple effect absorption refrigeration cycle (TEARC) is observed to be 1.752. The COP of the double effect absorption refrigeration cycle (DEARC) is perceived to be 51.9% higher as compared with single effect absorption refrigeration cycle (SEARC) which has a COP of 0.852. The exergetic efficiency of the TEARC is witnessed to be 16% higher than DEARC, and it is 31% higher than SEARC at an evaporator temperature of 7℃. The effect of nanoparticle's (Al2O3) concentration and percentage of weak and strong solutions of LiBr□H2O is also evaluated at design conditions. A high temperature heat reservoir is required to operate the TEARC, whereas, the SEARC and DEARC operate on lower temperatures than triple effect cycle. The performance comparison of multi□effect absorption refrigeration systems has been conducted.

Rasoul Nikbakht, (2020)

In this paper, it is intended to conduct a literature review on various technologies implemented to improve the COP of absorption refrigeration systems. Among effective and promising workarounds for increasing the COP of absorption refrigeration systems, this work refers to cycle design improvement, heat recovery method, development of new working pairs, adding sub-components, and improvement of operating conditions.Absorption refrigeration technology was introduced to address some serious issues such as the energy crisis, increased fuel prices, and environmental problems associated with the conventional compression refrigeration systems. It has attracted an increasing deal of interest thanks to such advantages as utilization of low-grade heat sources and environment-friendly working fluid pairs. Nevertheless, this technology suffers from two major obstacles including the usually too large size of the cooling unit and the low coefficient of performance (COP), preventing the absorption systems from being commercially successful. Numerous research works have been done to develop strategies in order to improve the COP of the absorption systems, so as to make the absorption refrigeration technology more competitive with the conventional compression refrigeration systems.

III. METHODOLOGY

The methodology adopted to solve the mathematical models of the integrated system is presented in this section. The integrated system comprises the PTSC using nanofluids as heat transfer fluids and the absorption refrigeration systems of single, double, and triple effect absorption refrigeration cycles working on lithium bromide□ water (LiBr□H2O) solution. The engineering equation solver (EES) tool is used to solve the mathematical models of the integrated systems. The EES tool has a built□in library routine for the selected working solution (LiBr□ H2O). The properties of the working fluid such as vapor pressure, enthalpy, and entropy are used to model the systems at higher temperatures of the working fluid. These properties are within the range as proposed by Patek and Klomfar,32 Feurecker,33 and Kaita.34 In order to solve the mathematical models of the integrated system, the following mentioned assumptions have been made:

- The system is working under steady□state conditions.
- The dead state conditions such as atmospheric pressure and ambient temperature are taken as 100 kPa and 27℃
- The pipe loses are considered as negligible.
- The condenser and absorber lose heat to the environment
- The solution is considered as a weak solution (52.25% LiBr) at the absorber exit and strong solution at the generator exit (56.94% LiBr) as proposed by Gebreslassie et al.7
- The refrigerant is saturated liquid at the exit of the condenser.
- The refrigerant is saturated vapor at the exit of the evaporator
- The enthalpy is supposed to be same at both ends of the valves.
- The temperature of the vapor at the exit of the generators is at the mean temperature of the solution (T19 = (T9 + T10)/2, in case of TEARC) for all 3 absorption cycles as proposed by Gebreslassie et al.

IV. DESIGN OF VARIOUS COMPONENT

Calculation for mass flow rate:

At outlet of condenser it is saturated liquid,
We have assume, pressure at that point, P2 = 10.7 bar And Concentration of NH3 in refrigerant Xr = 0.98
Using the enthalpy concentration diagram for Ammonia / Water We get: Condenser temp T2 = 54□
h2 = 200 KJ/Kg

Expansion

At expansion valve,
Expansion of refrigerant through expansion valve from high pressure to low pressure at constant enthalpy
h2 = h3 = 200 KJ/Kg T3 = 2□
P3 = 4.7 bar

Evaporator

At evaporator,
Extraction of heat by low pressure ammonia vapour in the evaporator Saturation Pressure in evaporator; P4 = 4.7 bar
Evaporator temp; T4 = 2□
Using Enthalpy concentration diagram;
Considering the ammonia vapour as saturated. h4 = 1220 KJ/Kg Heat Extracted by evaporator;
QE = mr * (h4 - h3)
mr = Mass flow rate of refrigerant QE = 0.875 KW
0.875 = mr * (1220-200)
mr = 0.8578 gm/sec Here,
Mass Of solution (Ms) = Mass of refrigerant (Mr) + Mass of absorbent (Mw) But here,
ms Xs = mr Xr + mw Xw
(mw + mr) Xs = mr Xr + mw XW
(mw +0.8578) * 0.42 = 0.8578 * 0.98 + mw (0.38)
mw = 12 gm/s
so, ms = mr + mw ms = 0.8578+12
ms = 12.857 gm/s

Design of Condenser

Ammonia Vapour Entering the condenser shell as a Saturated Vapour P1 = 10.7 bar
Xr = 0.98
Using h-x Diagram for Ammonia/Water,
T1 = 54□
h1 = 1135 KJ/Kg
Heat rejected by condenser Qc = mr * (h1- h2)
Qc = 0.8578* (1135 – 200)
Qc = 0.802 KW
Here we use air cooled condenser So we assume,
Inlet temperature of air = 25 0C Outlet temperature of air = 45 0C For LMTD
Condenser temperature = 54 0C θ1 = 54- 25 = 29 0C
θ2 = 54 – 45 = 9 0C
LMTD = θ1 - θ2 / ln (θ1 / θ2) LMTD = 29 – 9 / ln (29/9)
= 17.09 0C QC = UA *LMTD
0.802 * 1000 = 1000 × A * 17.09 A = 0.046 m2
Considering the number of Condenser tubes (n) = 12 The effective area of Condenser (A) = n * 3.14 * D* L 0.046 = 12 * 3.14 *0.008 * L
So length of each tube, L = 15 cm

Design of Evaporator

Let air inlet temperature to evaporator th1 = 30□ Air outlet temp, th2 = 5□.
And evaporator temperature = 2 0C θ1= 30- 2 = 28□
θ2 =5-2 = 3□
LMTD = θ1 - θ2/ ln (θ1 / θ2) LMTD = (28-3) / ln(28/3)
LMTD = 11.193□
Assuming, Overall heat transfer coefficient (U) =1000 W/m2
QE = UA*LMTD
0.875 * 1000 = 1000 * A *11.193 A = 0.078 m2
Considering the number of evaporator tubes (n) = 12 Here from market we get diameter of pipe = 8 mm
The effective area of evaporator, (A) = n * 3.14 * D * L So, 0.078 = 12*3.14*0.008*L
So, length of each tube L = 25 cm

Design of Generator

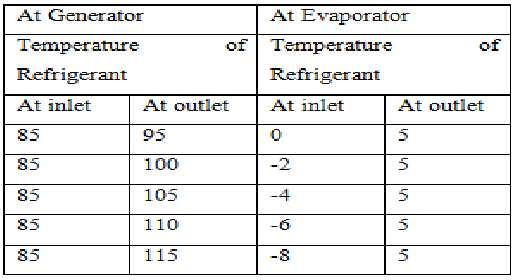
Strong solution entering the pump as saturated liquid, P5 = 4.7 bar
Xs = 0.42
Using enthalpy-concentration diagram,
T5 = 52□
h5 = 0 KJ/Kg
High pressure saturated strong solution entering the generator, P6 = 10.7 bar
Xs = 0.42
h5 = h6 = 0 KJ/Kg
Weak solution leaves the generator at saturation temperature of generator, P7 = 10.7 bar
Xw = 0.38
Using h-x diagram h7 = 255 KJ/Kg
T7 = 120□
Using energy balance for generator QG = Heat added to generator
QG = mrh1 + mwh7 - msh6
= (0.8578 * 1135) + (12 * 255) – (12.85 * 0)
= 4033 W
= 4.033 KW

Design of Absorber Heat rejected in the absorber, QA = mwh8 + mrh4 - msh5

QA = (12 * 255) + (0.8578 * 1220) – (12.85 * 0) QA = 4.11 KW

Considering the absorber to be direct contact heat exchanger in which the weak solution from the generator mixes with the ammonia gas from the evaporator and due to the direct mixing the heat is rejected. Air is used as cooling medium.

CFD Analysis



At Generator		At Evaporator	
Temperature of Refrigerant		Temperature of Refrigerant	
At inlet	At outlet	At inlet	At outlet
85	95	0	5
85	100	-2	5
85	105	-4	5
85	110	-6	5
85	115	-8	5

Taking Values of enthalpy (kj/kg)

$$\text{COP} = \frac{\text{Refrigerating Effect}}{\text{Generator Heat}}$$

1st Reading:

COP= 5 – 0 / 85 – 95

= (223.21 – 200) / (1467.53 +356) – 1449.01 = 0.061

2nd Reading:

COP= 5 – (-2) / 85 – 100

= (223.21 –190.76) / (1467.53 +356) – 1436.6 = 0.083

3rd Reading:

COP= 5 – (-4) / 85 – 105

= (223.21 –181.54) / (1467.53 +356) – 1421.57 = 0.103

4th Reading:

COP= 5 – (-6) / 85 – 110

= (223.21 –172.34) / (1467.53 +356) – 1403.08 = 0.120

5th Reading:

COP= 5 – (-8) / 85 – 115

= (223.21 –163.16) / (1467.53 +356) – 1379.99 = 0.135

6th Reading:

COP= 5 – (-10) / 85 – 110

= (223.21 –154.01) / (1467.53 +356) – 1350.23 = 0.120s

SOLAR PANEL OUTPUT

A good place to start is by understanding the parameters that earn a solar panel its wattage rating. How many watts your solar panel is able to produce might be anywhere between 250 watts and 370 watts. Does this mean that your system will generate that exact amount all of the time? Not really. That's where those variables come in. But a solar panel efficiency number is a gauge of how many watts your solar panel is capable of producing in ideal conditions.

Here's a simple formula for calculating your solar panel's power output.

Solar panel watts x average hours of sunlight x 75% = daily watt-hours

250-watt solar panels and live in a place where you get 5 hours of sunlight per day. What's that 75 percent for? That's to account for all those variables we've been going over.

250 watts x 5 hours x .75 = 937.5 daily watt hours

To translate this into the more familiar kilowatt hours you're used to seeing on your electricity bill, simply divide by 1000.

937.5 / 1000 = 0.937

To round up and make it pretty, that's 0.94 kilowatt-hours per solar panel.

We required 4.11 KW/hr

4.11/0.94 = 4.37 No

Require 5 No of Solar Panels

Problem statement of the study:

"Operate A Vapour Absorption Refrigeration System By Using Solar Energy

Objectives of the study:

1. Introduce vapour absorption refrigeration systems
2. Explain the basic principle of a vapour absorption refrigeration system
3. Obtain expression for maximum COP of ideal absorption refrigeration system
4. Discuss properties of ideal and real refrigerant-absorbent mixtures

Limitations of the study:

1. High initial cost
2. costly refrigerant
3. Environmental hazardous refrigerant involved
4. Must ensure the prevention of leakage of refrigerant.

Analysis and Results

The methodology mentioned above was used to evaluate the utilization potential of R1233zd(E) and R1336mzz(Z). In all calculations, the heat load of the evaporator in the bottom stage was kept the same (1 kW). The entrainment ratio of the ejector, pump work, and heat loads of heat exchangers in the cycle were obtained and the results were presented in this section.

Entrainment ratio and pump work with different refrigerants In the hybrid refrigeration cycle, the entrainment ratio of the ejector has a great influence on the overall COP of the cycle, and it is also the most important indicator to evaluate the refrigerant used in the ejector refrigeration cycle. The pump work and entrainment ratio with different generator temperatures are presented in the Fig. 1. It can be found that the pump works of all the three refrigerants increased with the generator temperature.

Meanwhile, the pump works of R1233zd(E) and R1336mzz(Z) were 14.59% and 38.05% lower than those of R245fa maximum, respectively. It was primarily caused by the higher pressure of the R245fa as indicated in Fig. 1. The systems with R1233zd(E) and R1336mzz(Z) also presented higher entrainment ratios as could be seen from Fig.1(b). Nevertheless, the entrainment ratio difference between working fluids was not very significant. The entrainment ratios of R1233zd(E) and R1336mzz(Z) were just slightly higher than those of R245fa by 0.5% and 2.17% when Te,g=95°C, respectively.

The influence of the evaporator temperature on the pump work and the entrainment ratio is shown in Fig.1. It could be found that with the increase of evaporator temperature, the pump work decreased and the entrainment ratio increased for all the refrigerants. It is because the pressure difference between the inlet and outlet of the pump decreases as the evaporator temperature increases. At the same time, the irreversible losses of the mixed process in the ejector also decreased. Furthermore, the R1233zd(E) and R1336mzz(Z) systems both had a low maximum pump work compared against R245fa, by 14.52% and 38.24% at Te,ev=20°C, respectively. The entrainment ratio difference of the working fluids seemed not sensitive to the evaporator temperature as shown in Fig. 1(b).

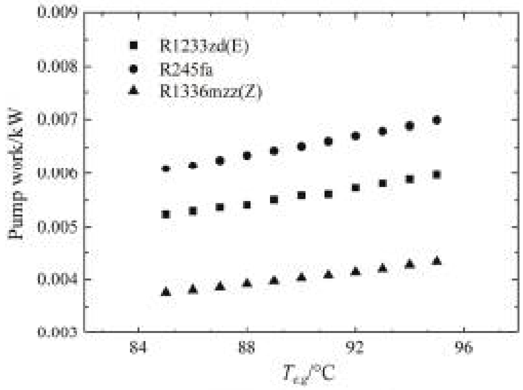


Fig 1. (a)Influence of generator temperature

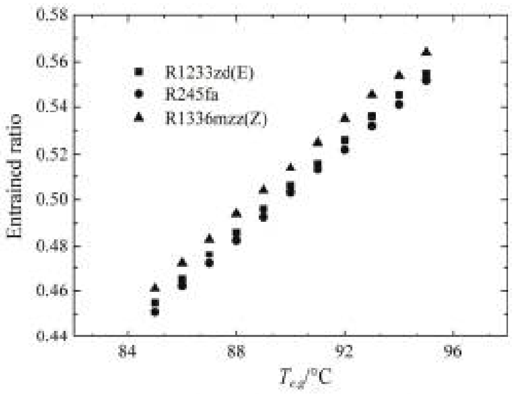


Fig 1. (b)Influence of generator temperature

V. CONCLUSION

Solar energy is readily available, and it is free. Hence, due to the increment in pollution in the environment, the researchers from all around the word are attracted towards the use of solar energy in place of conventional sources.

- Solar energy can be best used for the dairy industries.
- The temperature required for milk pasteurisation system is around 63–72°C, and it is easily obtained by a solar water heater.
- Quality of milk is a prime concern for milk pasteurisation systems, and it should be investigated.
- A HE is very important for milk pasteurisation systems.

REFERENCES

[1] Nikbakhti, R., Wang, X., Hussein, A. K., & Iranmanesh, A. (2020). Absorption cooling systems – Review of various techniques for energy performance enhancement. *Alexandria Engineering Journal*, *59*(2), 707–738. https://doi.org/10.1016/j.aej.2020.01.036

[2] Panchal, H., Patel, R., & Parmar, K. D. (2020). Application of solar energy for milk pasteurisation: a comprehensive review for sustainable development. *International Journal of Ambient Energy*, *41*(1), 117–120. https://doi.org/10.1080/01430750.2018.1432503

[3] Aramesh, M., Pourfayaz, F., Haghir, M., Kasaeian, A., & Ahmadi, M. H. (2020). Investigating the effect of using nanofluids on the performance of a double-effect absorption refrigeration cycle combined with a solar collector. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, *234*(7), 981–993. https://doi.org/10.1177/0957650919889811

[4] Shirmohammadi, R., Soltanieh, M., & Romeo, L. M. (2018). Thermoeconomic analysis and optimization of post-combustion CO2 recovery unit utilizing absorption

refrigeration system for a natural-gas-fired power plant. *Environmental Progress and Sustainable Energy*, *37*(3), 1075–1084. https://doi.org/10.1002/ep.12866

[5] Ratlamwala, T. A. H., & Abid, M. (2018). Performance analysis of solar assisted multi-effect absorption cooling systems using nanofluids: A comparative analysis. *International Journal of Energy Research*, *42*(9), 2901–2915. https://doi.org/10.1002/er.3980