Design of solar water sterilizer assisted with aqua ammonia solar vapour absorption system

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ABSTRACT— Safe drinking water is the basic need of human being. There is a necessity of water sterilizing devices which are cheap and reliable. .Along with this, another major area of concern is the depletion of conventional energy sources. The most abundant form of non-conventional energy is solar energy. This project deals with fulfilling both above needs with solar energy. It consists of a combined system having water sterilizer that uses evacuated tubes and aqua-ammonia vapour absorption system.The condenser pressure is 10 bar while evaporator pressure is 4 bar. The paper includes the design calculations for evaporator, condenser, heat exchanger and generator.

Keywords:pasteurization, sterilizer, shell-tube heat exchanger, vapourasorption refrigeration, aqua ammonia.

I. INTRODUCTION

Solar energy is a very large source of energy available. Approximately 1.8×10^{11} MW energy is received on the earth from the Sun. That is why solar energy can be used effectively to fulfill the present and future energy needs of the world. Solar energy is a clean source of energy as well as it is free and widely available everywhere. But along with this, there are certain problems related with solar energy such as it a dilute source of energy because about 6kWh/m^2 of solar radiation is available throughout the day. Second problem is that its availability varies with time.

Water is a very essential source for human life for its sustainability as well for the development. Therefore, pure and potable water is the basic need of every human being. According to WHO, more than 3.4 million people die because of water related diseases per year. Boiling is the most widely used method for water purification. But it is unnecessary to boil water to remove its pathogens; hence it goes as wastage of energy.[1][2]

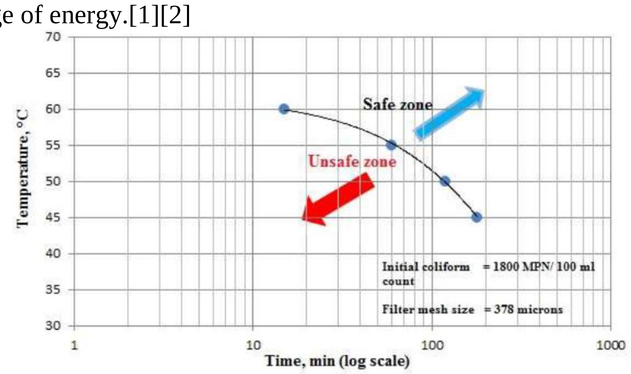

Fig.1: Temperature Time regime for treatment of filtered water

As per the research conducted by Nimbkar Agricultural Research Institute, water can be made potable by filtering water through four layered cotton saree cloth (mesh size less than 378 microns) and then heating it to 60^0Cfor 15 minutes so that all coliforms are removed out of it. Tests done by NARI in its labs showed that such filtered water heated either to 60^0C for 15 minutes or 45^0C for 3 hours,inactivated all the coliforms.This project is going to make use of this concept for sterilization of water. [2]

Peter Kalt et al [1] has discussed different water treatment mechanisms that use solar energy. Solar pasteurization involves heating water to a sufficient temperature for a time in order to destroy pathogenic microbes.He has mentioned that a system that maintains water temperatures above 60^0C may be suitable to address the pathogens that are of primary concern.

NandiniNimbkar et al[2] has focused her attention primarily on solar water sterilization during clear and cloudy days.

Experimental data showed that filtration of raw water through layered cotton sari cloth (250μm) reduced the coliform count and further heating to sub-boiling temperatures (55-60) ^{0}C for less than hour resulted in complete inactivation of coliforms.

Anil Rajvanshiet al[3] has developed unique and low cost solar water cleaner for rural households and has also developed a protocol to make water potable by using this.

A.Jacobet al[4] has analyzed the meteorological data collected by NARI at Phaltan since 1983. The average data shows that that mean daily solar radiation in Phaltan is 4.77 kWh/m^2.

J.K.Tangka [6] has designed, fabricated and tested a simple solar powered intermittent absorption refrigeration system with ammonia and water as working fluids. The heat source used here was a solar radiation collector that collects and radiates solar thermal energy onto a black body generator. The collector was a simple black box. He has found that the average highest and lowest temperatures inside the solar collector were 100^0C and 40^0C respectively. The average lowest refrigeration temperature was 4^0C. The COP of the system was estimated at 0.487.

This project aims at using three concepts, namely solar energy utilization, solar water pasteurization and vapour absorption refrigeration, together to create a unit that will provide sterilized water for drinking along with refrigeration effect.

1. Nomenclature

L:Length of evacuated tube
D_o: Outer diameter of tube
m_w:Mass flow rate of water
m_r:Mass flow rate of refrigerant
C_{pw}: Calorific value of water
ΔT_{lm}: Log-mean temperature
U:Overall heat transfer coefficient

2. Proposed experimental setup

The proposed setup is as shown below:

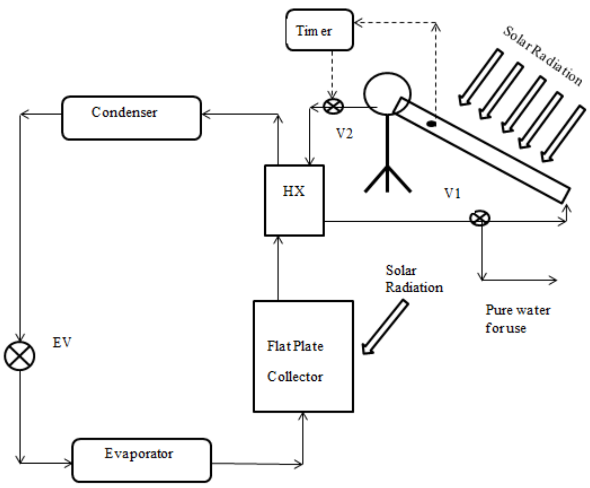

Fig.2: Proposed experimental setup

It consists of following components:

- Solar water cleaner with evacuated tubes
- Electronic processing unit with temperature sensor(T), counter and a servo motor
- Heat exchanger (here, HX)
- Flat plate collector (Generator for VAR system)
- Evaporator
- Expansion valve (EV)
- Condenser (water cooled)
- Valves V1 and V2

Raw water is poured in the solar water sterilizer through a cotton cloth of specified mesh size. That water is heated up to the stagnation zone inside the evacuated tubes. A temperature sensor is fitted inside the tube to measure the temperature of water. An electronic unit is fixed in the system which consists of a counter, timer and a servo motor. The required condition for water sterilization is entered inside the processor which is in terms of the protocol developed as discussed earlier. When the sterilization condition gets satisfied, the unit turns on an alarm and the servo motor opens the valve V2. By this, pure water passes through the heat exchanger and then can be taken for use. Hence, water is sterilized as well as it is drinkable.

Once the water is removed for use, valve V1 is closed. Again, fresh water is filled into the tubes. Now henceforth, water heater acts as an additional heat source to the generator and hence contributes towards the functioning of VAR system.

The main source of input to the VAR is the flat plate collector which gives heat input to the generator. The VAR system is designed in such a way that, the flat plate collector should fulfill the input requirement in the absence of water heater’s input

In this way, this system serves number of function simultaneously as:

- Provides pure water
- Provides refrigeration effect
- Saves electricity

The details of the components are discussed below:

a) Solar water heater

Solar collector tubes are normally sold as an integrated part of a water treatment system. It implies accessory parts such as inner tank, inlet and outlet pipes to remove the treated water and a structure that gives support to the tubes and the manifold. An inclination, normally 30^0, is generally provided allowing increase in area of solar radiation.[3]

Fig. 3: Solar water heater

In this project, as it is designed for a family (generally of 4 people), system capacity is taken as around 15 liters/day.
The specifications of evacuated tubes available are as follows:

Material : Borosilicate glass
Inner diameter: 47mm
Outer diameter : 58mm
Length : 1.8m
Volume per tube : 2.7 L
Total collection area = No. of tubes × D_o× Length

$$= 4 \times 0.058 \times 1.8$$
$$= 0.4176 \text{ m}^2$$

b) Electronic unit

It consists of a temperature sensor, counter, timer and a servo mover. It is mainly used in this system so as to check whether the water sterilization condition is satisfied or not. Accordingly, it opens the valve with the help of servo mover and the potable water is taken out, after which, the solar water heater serves as a source of heat to the generator in the VAR system.

c) Heat Exchanger

It is required to transfer the heat from hot water from the solar heater to the refrigerant (ammonia).
Shell-tube heat exchanger is designed by the following procedure:[7]
Shell side fluid: Water
Tube side fluid: Refrigerant (ammonia R-717)
Inlet water temperature T1= 60^0C
Water exit temperature T2= 20^0C
Inlet temperature of ammonia t1= 5^0C
Exit temperature of ammonia t2= 40^0C
Assuming, the mass flow rate of water as 100kg/hr.

Heat load on exchanger:

$$HL= m_w \times Cp \times (\Delta T)_w = 4.67 \text{ kW}$$

Calculating the mass flow rate of refrigerant,

$$m_r = 0.10 \text{ kg/sec}$$

From the graph,
R-factor = 1.14 and S-factor= 0.64

Mean temperature difference:

$$\Delta T_{lm} = \frac{(T1-t2)-(T2-t1)}{(\ln (T1-t2) \div (T2-t1))} = 20.48\ ^0C \text{ [6]}$$

Estimated overall coefficient

$U= 600W/m^{2}\,{}^{0}C$

Provisional area of heat exchanger= 0.47 m^2
Length of tube = 0.5m
Shell diameter = 210mm
Shell length = 530mm
Shell thickness= 1.0927mm
Number of tubes = 16

The detailed layout of heat exchanger is as shown below:

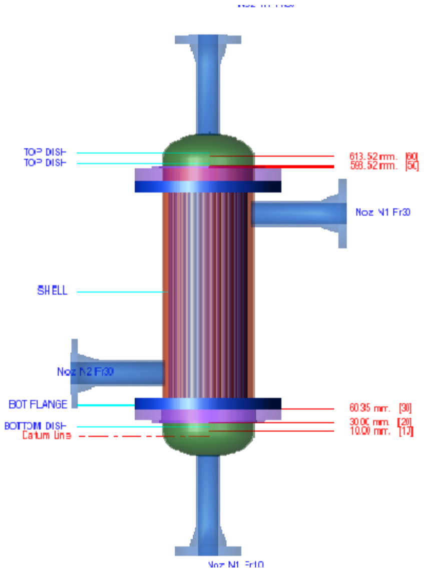

Fig.4: Layout of heat exchanger

d) Condenser
Shell side fluid: Water
Tube side fluid: Refrigerant (ammonia R-717)
Inlet water temperature= 25^0C
Water exit temperature= 50^0C
Inlet temperature of ammonia= 70^0C
Exit temperature of ammonia= 25^0C
Heat load on exchanger=5.98kW
Mean temperature= 81.93^0C
Area of exchanger= 0.14 m^2
Shell diameter= 150mm
Shell length= 320mm
Length of tube coil= 2400mm
The detailed layout of evaporator is as shown below:

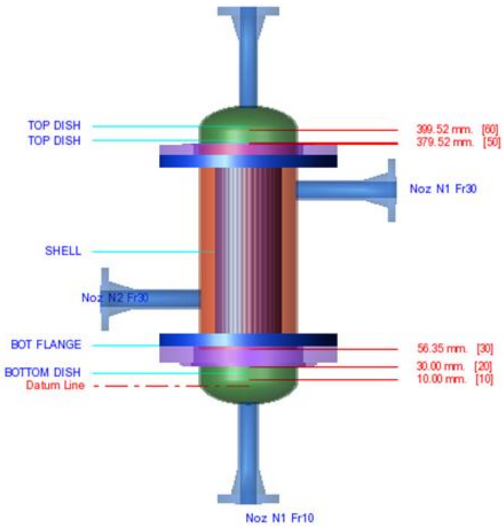

Fig.5: Layout of condenser

e) Evaporator

Shell side fluid: Air
Tube side fluid: Refrigerant (ammonia R-717)
Inlet air temperature= 25^0C
Air exit temperature= 8^0C
Inlet temperature of ammonia= -1^0C
Exit temperature of ammonia= 5^0C
Heat load on exchanger= 0.80kW
Mean temperature= 45.06^0C
Area of exchanger= 0.03 m^2
Shell diameter= 100.36mm
Shell length= 320mm
Length of tube coil= 2400mm

f) Generator

Shell side fluid: Air
Tube side fluid: Refrigerant (ammonia R-717)
Inlet air temperature= 85^0C
Air exit temperature= 50^0C
Inlet temperature of ammonia= 40^0C
Exit temperature of ammonia= 70^0C
Heat load on exchanger= 3.99kW
Mean temperature= 20.48^0C
Area of exchanger= 0.36 m^2
Shell diameter= 200mm

II. CONCLUSION

The project satisfies needs of the society of clean drinking water along with refrigeration. The solar water sterilizer uses evacuated tubes. While designing the system, inlet and outlet temperatures of working fluids were pre-assumed and then different components were designed by using heat exchanger design procedures. As per the calculations, the heat load on the evaporator is 0.8kW while the heat transfer surface area is $0.36m^2$.

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