Design of multistage evaporators for integrating with Scheffler Solar concentrators for food processing applications.

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1. Abstract

Authors designed and experimented with multistage evaporation system for production of distilled water. Two Scheffler concentrators of 16 sqm each were used for generating steam in the first stage at 8 bar pressure and the pressure is gradually brought down to 1 bar, in four stage distillation unit. Total yield obtained in the project was 2.4 times that of single stage distillation. Temperature drop in every subsequent stage was designed to 25 degree centigrade. Heat of condensation in the last stage was dissipated in a solar dryer to enhance its performance. In further testing this heat of condensation in the last stage and also sensible heat of the condensate in all the stages was used for preheating of water in the next batch. The system has great potential in food processing industry for applications of juice thickening, sauces, jams, salt concentrating systems and distilled water applications. Results of the project are very encouraging.

2. Introduction

2.1 Climate change due to use of conventional fuels

Increasing access to energy is not a Goal, but it is one of the five priority areas identified by the World Summit on Sustainable Development. Energy is an important input into the development process. Considerable technological innovations are taking place in energy generation and use, which will continue to be of strategic policy interest for all countries. Over the long term, the use of fossil fuels is unsustainable. Burning fossil fuel results in the emission of carbon dioxide and exacerbates the **Greenhouse Effect and Global Warming**. Although global temperatures and sea level have been fairly stable in recent centuries, the future may be very different. Increasing concentrations of carbon dioxide, methane, chlorofluorocarbons, and other gases released by human activities could heat the earth to temperatures warmer than at any time in the last two million years and thereby accelerate the rate of **sea-level rise**. About 80 percent of all climate warming is caused by emissions of carbon dioxide. One promising solution for reducing these emissions is the development of small, environment friendly power plants, units, and systems. The medium-term prospects for doing so are promising.

2.2 Use of Solar energy

One of the promising options is to make more extensive use of the renewable sources of energy derived from the Sun. Solar energy can be used both directly & indirectly. It can be used directly in a variety of thermal applications like heating water or air, drying, distillation and cooking. The heated fluids can in turn be used for applications like power generation or refrigeration. A second way in which solar energy can be used directly is through the photovoltaic effect in which it is converted to electrical energy. Indirectly, the sun causes winds to blow, plants to grow, rain to fall and temperature differences to occur from the surface to the bottom of the oceans.

The proposed project **"Design, Development and performance Evaluation of Solar Multistage Distillation system"** is primarily concerned with use of direct solar thermal energy for industrial applications.

3. Background

Solar water distillation is a technology with a very long history and installations were built over 2000 years ago, although to produce salt rather than drinking water. Documented use of solar stills began in the sixteenth century. An early large-scale solar still was built in 1872 to supply a mining community in Chile with drinking water. Mass production occurred for the first time during the Second World War when 200,000 inflatable plastic stills were made to be kept in life-crafts for the US Navy.

3.1. Scheffler Concentrators:

Fixed focus concentrators developed by Mr. Wolfgang Scheffler have proved to be a mile stone in solar thermal energy utilisation. Over last few years the size of the concentrator is increasing and now 16 sqm concentrators are commercially available. These concentrators provide approx. 5 kW thermal heat at focus on normal sunny day, totalling around 40-50 kWh per day, which evaporates around 50 liters of water in a day.

3.2. Solar stills:

Solar stills are very commonly used for low requirements of distilled water. Solar stills are low temperature devices and require large areas. As the evaporation and condensation is done in one single unit, yield is low. Normal output of the still is around 2-3 liters per sqm of area per day, on good sunny day. For increasing yield per sqm of area, multistaging of condenser-evaporator units is recommended.

3.3. Multistage solar evaporator:

Wolfgang Scheffler has experimented with multistage evaporators, especially for desalination applications. This was non pressurised system where solar steam in introduced in first condensing stage at atmospheric or slightly above atmospheric pressure. Vapour pressure in further evaporating stages was lowered by providing wetting surface and introducing sea water manually. This is a low cost option which is very successful and can yield up to 3 times more yield than single staging. As the temperature of the steam generated in subsequent stages drops, vaporising water becomes more and more difficult and that is the limitation on how many stages one can try in such system. Sterlisation may be criteria for few applications where distilled water is used and this low temperature evaporation in later stages may not assure sterlisation. With new 16 sqm Scheffler concentrators, it is possible to conveniently get pressurised steam up to 10 bar, hence authors decided to design pressurised multistage evaporators. It is possible to accommodate more number of stages of evaporation-condensation when supply pressure of steam is higher.

4. Project

To evaporate one kg of water at 1 bar atm. Pressure, 2260 kJ is the net energy requirement. In simple evaporators all this 2260 kJ of heat is wasted to atmosphere by way of cooling to get distilled water. Multistage evaporators, also called as multieffect evaporators, use this heat rejected in condenser to evaporate water in the next stage and such battery of condensers-evaporators can be constructed to recycle heat of condensation and increase net yield of distillate. Generating basic information on yield ratio and yield of distillate per sqm of concentrator area, was one of the aim of the study. Such information will help in sizing of the system in case of design of system for different capacities.

Authors used first stage boiling with a pair of Scheffler concentrators of 16 sqm followed by three condensation and evaporation stages, making it a system with effectively four stages of evaporators and condensers. Authors decided to design a system with no external power requirement and hence all system components are designed accordingly. Conventional multistage evaporators require external power source for pumping feed water continuously and mechanism to drain condensate. In current project hand pumping of feed water and intermittent drainage of condensate by manually operation of valves was designed.

4.1. System Components:

System primarily included two major components, Scheffler Steam system and multistage evaporators. A heat exchanger was added later on to the system to heat feed water from last stage of steam condensation and from the sensible heat loss of the condensate.

4.1.1 Scheffler Steam System:

Scheffler Steam system consisted of two Scheffler concentrators of 16 sqm each, facing south, also referred as standing dishes. Solar radiation is concentrated within 400 mm diameter of receivers delivering concentration ratio in the range of 100. Both the receivers are connected to a water-steam storage tank with inlet and outlet connections. All piping and storage systems are insulated with rockwool insulation of 70 mm thick. System is provided with safety features like pressure relief valve, fusible plug etc. System can be seen in photograph 4.1

4.1.2 Multistage evaporator:

Three stages of evaporator were designed and constructed. First two stages were designed with temperature drop of 25 degree centigrade and last stage with 15 degree centigrade. As the system used all manual operation, continuous drainage of condensate was not possible. Hence the system is designed with storage for condensate which can be drained every two hours. Similarly evaporator sections were designed large enough to accommodate water for at least 3 hours. Feed water is also introduced in all stages with hand operated piston pump.

4.1.3 Heat Recovery Unit:

First few trials were taken without a heat recovery unit, and feed water was introduced at room temperature. Authors realised that heat of condensation of steam in the last stage of evaporation and sensible heat of condensed water in early stages can be used for preheating feed water. Hence a heat recovery unit was added later on to the system.

A schematic layout of the system with all three main components as above and is shown in Fig. 4.1 showing all system components as well as instrumentation. Water and steam flows are marked with arrows.

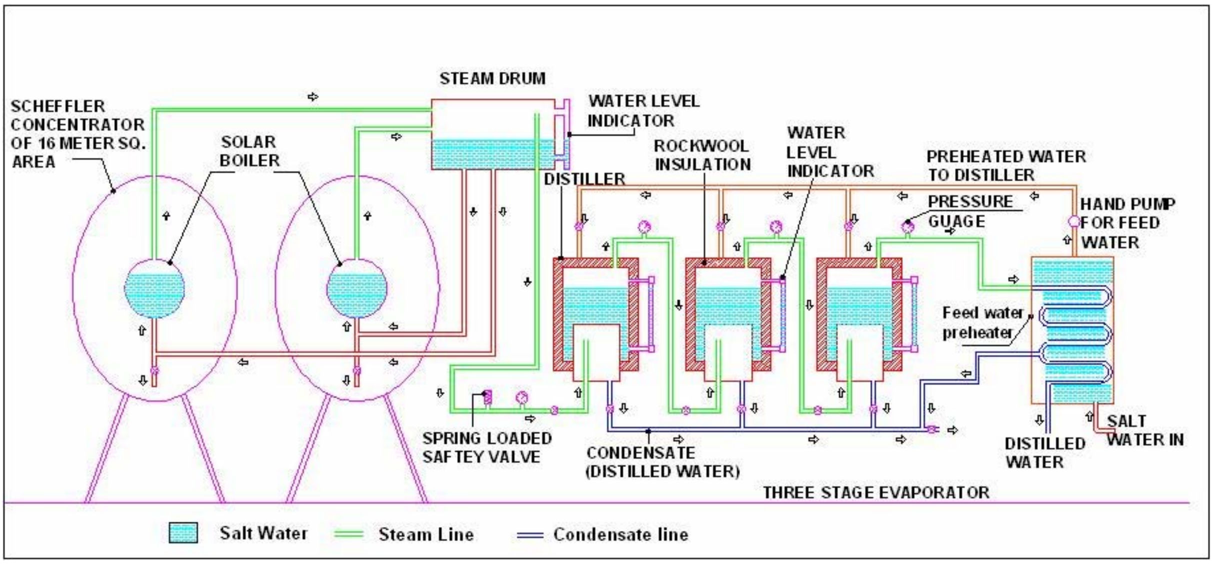

Fig. 4.1 Schematic layout of Multistage evaporators with Scheffler concentrators & H.R. unit.

4.3 System operation:

A schematic layout of the system is shown in Fig. 4.1 and actual photograph is shown in photograph 4.2. Steam is generated by solar boiler comprising of Scheffler solar concentrators, receivers and steam tank. Steam tank is half filled with water. Water circulation to the receivers is by gravity and steam comes back in the top of the tank and is stored there. This pressurised steam is fed to the condensing tank of first evaporator. Condensing tanks are designed in place of coils to accommodate two hours of condensate so that the tanks can be manually drained. Heat of condensation in the earlier stage is used for evaporating water which is further condensed in following stage. Heat transfer areas are calculated taking 25 degree C temperature drop, which gives optimal overall heat transfer coefficient. In current project steam generated in water-steam drum is the first stage of evaporation and there are further three stages added, making it a four stage evaporation-condensation system.

Fig. 4.2 : Photograph of Solar steam generator with multistage evaporators.

4.2. Results:

Trials were taken on the test unit for a month. Typical data sheet for a day is shown in the table 4.1

Time	T1	Pressure P1	Yield	T2	Pressure P2	Yield	T3	Pressure P3	Yield	T4	Press. P4	Yield
(Hour)	(° C)	Bar	gms	(° C)	Bar	gms	(° C)	Bar	gms	(° C)	Bar	gms
7:00 AM	28	-	-	28	-	-	28	-	-	28	-	-
8:00 AM	69	-	-	29	-	-	29	-	-	29	-	-
9:00 AM	101	1	-	29	-	-	29	-	-	30	-	-
10:00 AM	146	4	-	29	-	-	29	-	-	29	-	-
11:00 AM	172	7.8	-	30	-	-	29	-	-	29	-	-
12:00 PM	169	7.6	12600	129	2.7	2800	66	-	-	30	-	-
1:00 PM	171	7.6	14300	146	4.1	10700	128	2.5	5800	46	-	-
2:00 PM	167	7.2	16300	147	4.1	12100	127	2.4	8600	89	-	350
3:00 PM	171	7.8	14800	149	4.5	11000	123	2.2	7800	94	-	4900
4:00 PM	164	7	14600	144	4	10400	123	2.1	7600	95	-	4300
5:00 PM	148	4.6	9800	131	2.7	7500	116	1.7	4600	94	-	3800
6:00 PM	121	2.2	5600	108	1.1	4400	100	1	3200	93	-	2300
7:00 PM	94	1	2300	97	1	2200	91	1	1500	67	-	200
8:00 PM	66	-	900	64	-	100	58	1	100	55	-	-

Table 4.1: Typical data sheet

Net Yield per square meter per day and improvement in yield because of multistaging were important parameters. Average figures for these parameters are mentioned below.

a. Net yield per sqm of concentrator: 6.5 liters/sqm
b. Yield ratio because of multistaging: 2.3

Using these parameters it is possible to design and scale up the system for customer's requirements of higher magnitudes.

5. Conclusion:

Multistage evaporators coupled with Scheffler solar concentrators can be a very effective gadget for generation of distilled water. During the course of experimentation and study, there were few commercial inquiries for other applications like salt concentration systems, juice thickening, making jams and sauces etc. Industrial applications for thickening effluents is also one of the possibility using this gadget.

Experimental set up used only two 16 sqm Scheffler concentrators and ended up with larger fixed losses as can be seen from the observation table. This has been the experience with all steam generation systems using solar concentrators. Bigger systems with large number of Scheffler concentrators are likely to improve yield ratio to around three and net yield per sqm of concentrator to around eight liters per sqm of area in similar operating conditions.

Last stage of evaporator in current system generates steam at atmospheric pressure. Design used by Wolfgang Scheffler uses steam at atmospheric pressure and delivers yield of 2.5 to 3 times. If this steam generated in last stage of pressurised multistage evaporator is used as primary source in design developed by Wolfgang Scheffler, then it is possible to increase the overall yield ratio above five.

Results of the project demonstrated that there exists huge potential of projects of nature for applications like generating distilled water for food processing, pharmaceutical and other industries on moderate scale. The project also has high potential in areas of salt concentration systems, thickening of salt fruit juices, jams, pulps, sauces and similar applications where water is evaporated on large scale. Evaporating water for thickening of effluent of industries is other promising area.

It is observed that the system takes time to heat up itself and practical steam generation starts only after 11.00 a.m. Also all stored heat in the system is wasted overnight and one has to have a fresh start next morning. Authors recommend having some other renewable energy back up system like biogas or biomass for overnight operation. This will not only increase yield because of added operating hours, but also will reduce overnight system losses to a large extent, increasing overall project efficiency. Solar steam generation can start early and will continue for more operating hours.