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Design and fabrication of an absorber for a solar-powered desalination system

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Abstract: Solar energy is used in solar desalination systems to heat saltwater, which is accomplished through the use of a parabolic solar concentrator. The steam that has been created is subsequently condensed to provide clean drinking water. An absorber is positioned within the focus region of the concentrator to keep the water from evaporating. The construction of an absorber with the appropriate size allows for the most efficient usage of solar energy. The parabolic dish type concentrator is typically used for cooking; however, this article will cover its application in steam generation. The paper describes the design and manufacture of an absorber before comparing the results with those obtained using a regular cooking pot. The material for the absorber is chosen with consideration for the impacts of saltwater, the capacity to withstand high temperatures, and the ease of manufacture. A heat-resistant coating is applied to ensure that the maximum amount of radiation is absorbed. Rolling, pressing, and welding techniques are used to construct an absorber that is intended as a thin-walled pressurised pressure vessel. The rate of evaporation of water in the proposed absorber is compared to the rate of evaporation of water in the traditional vessel under various sunlight circumstances. It has been observed that the absorber that has been designed is more efficient.

Keywords: Concentrator, Absorber, Focal Area, Solar Radiations, Evaporation.

I. INTRODUCTION

Water and energy are two interconnected elements that regulate our lives and contribute to the advancement of human civilization. The desalination of seawater or brackish water is now the most widely used process [1]. Today, the distillation process is the most established and commonly utilised technology for saltwater desalination. Thermal energy may be used to distil seawater or brackish water, which allows for the distillation of these waters [2]. The absorption heat transformer is one of several alternatives available for improving the energy efficiency of desalination plants, and it stands out among them. It is possible to distribute heat at temperatures greater than the temperature of the fluid through which it is passed by using a heat transformer. Absorption heat transformer systems are desirable because they may be used to recycle waste heat from industrial operations as well as renewable energy sources such as solar and geothermal power [6].

We must do everything we can to lessen our reliance on conventional energy. Parabolic concentrators are widely used across the world for converting solar energy into thermal energy, and they have high efficiency. According to the property of a parabola, all incident rays that are parallel to its axis are reflected at a location known as the focal point. The cooking pot is placed in the focus region in order to capture the maximum amount of solar energy for cooking or heating purposes. The need for pure drinking water is rapidly increasing as the world's population continues to grow at an alarming rate. The desalination of saltwater using a solar concentrator may be able to resolve the water scarcity issue [4][7]. In this technique, water is maintained in a vessel known as an absorber at the focal point, where it is turned into steam by the solar energy that is received. The steam is subsequently condensed by the condenser, which results in pure water production. The amount of steam that can be converted depends heavily on the amount of solar energy that is available during the day. According to the manufacturer, the effectiveness of parabolic concentrators is between 30 and 35 percent [8]. Instead of utilising a traditional cooking pot, the efficiency can be enhanced by employing the appropriate-sized absorber [9]. The absorber is constructed in such a way that it can endure scale development caused by saltwater, absorb the greatest amount of solar radiation, and withstand high temperatures.

II. MATERIAL SELECTION

As a part of a seawater desalination system, the absorber was to be developed [5]. Sodium chloride, calcium sulphate, magnesium sulphate, and potassium salts are found in seawater. Salinity is reduced in the vessel through evaporation. The absorber's scale and corrosion can be caused by calcium sulphate and sodium chloride. Corrosion tests have indicated that carbon steel has the highest rate of deterioration among the major structural metals and alloys.

In order to maintain the system's efficiency, the absorber's substance must be resistant to scaling.

It's also vital to consider the system's maximum temperature. Temperatures of 2500C to 2600C were discovered to be obtained at the focus region in experiments conducted under a variety of settings, whereas maximum temperatures of 1200C to 1400C were measured for water. Temperature fluctuation is caused by shifts in the sun's rays. For the sake of safety, some settings were set to their maximum value. When developing the absorber, water temperature of 1500C, corresponding to 4.7 bar pressure and 2600C focal temperature, were considered. Consideration was given to the use of three popular materials for cooking and boiling vessels. Table 1 lists their characteristics.

Material	Name	Tensile Strength (MPa)	Yield Strength (MPa)	Maximum temperature range (^{0}C)	Corrosion allowance (mm)
SA 106 Gr B	Carbon steel	415	240	Above 800	3
SB-241 Gr T6 Alloy 6061	Aluminum	225	195	204	0.5
SA-312 Gr 304 18 Cr 8 Ni	Stainless Steel	515	205	816	1.5

Table 1: Comparison of Properties of Materials for the Absorber

A kind of carbon steel commonly used for pressure vessels, SA 106 Gr B, is prone to corrosion, yet it can tolerate high temperatures. ASME SA 106 Gr B is the preferred carbon steel for higher temperatures service by most designers.

Selection of base diameter:

The size and base of the absorber were initially determined during the design process. A piece of plywood was used for this purpose, and it was placed in the specified focal point. A direct hit from the sun's rays caused the board to immediately catch fire. The plyboard was removed after only five minutes of working time. The exact diameter of absorbers was indicated by a black burnt circular section on the ply. The plyboard's burn marks were then tallied up. At the focus point, the plyboard was placed parallel to the absorber stand's base while remaining vertical. There were 18 cm of burnt plyboard and a height of 25-30 cm of the absorber on which radiation fell for the absorber. The absorber's horizontal and vertical dimensions were determined through a series of experiments.

Focus area travelled in a different experiment. The parabolic concentrator was aligned with the sun's beams to direct all incident energy to a single spot, the parabola's focal point. A steel plate was placed at the absorber's focal point to trace the path of the sun's rays on the absorber's surface. Afterwards, the size was measured and discovered to be 0.3 metres long. To measure the time it takes for the sunrays to pass through the 0.3-inch-by-0.3-inch box, it was built. The box loses focus after 18 to 20 minutes of testing, which was done several times at various times. The experiment was replicated on separate days, and a bright spot on the plate was designated to serve as a reference. The brightness area for the same tracking location was found to fluctuate with time for the same tracking position. Every five minutes, a plate was used to measure the distance travelled by the focus region, and the results showed a travel distance of 5-6 cm. At least a portion of the absorber will be heated in one tracking mode if the 0.3 m diameter absorber is utilised for 20 minutes [3].

Tests demonstrate that after 20 minutes, heating is no longer beneficial. For validation, ray-tracing software was used to study the influence of focus area shifts on absorber temperatures, and FE analysis was used to investigate this effect.

Height Selection|:

According to experiments, the absorber's height was found to be between 25 and 30 centimetres. To determine the minimum absorber height, we used equation 3.25 and an absorber diameter of 0.3 m. This yielded the following results:

$$8 \times 10^{-3} = \frac{\pi}{4}(0.3)^2 H$$

$$H_{min} = 0.11m$$

The steam outlet must be separated from the water surface by a distance large enough to keep the steam leaving the absorber dry and free of water droplets, even at high evaporation rates. The absorber's diameter was set at 0.3 m to ensure that it remained in the experiment's focus zone at all times.

Absorber Thickness

The thickness of the absorber's material was determined by considering the absorber's operating temperature and pressure after the diameter and elevation were decided. Considering that the absorber's diameter to layer thickness is more than 15, it can be considered a thin-walled pressure vessel.

Thickness of the shell

For reasons of safety, the vessel is constructed in accordance with the ASME boiler pressure vessel code. After forming and independent of product shape or material, the minimum thickness allowable for shells and heads is 1.5 mm, excluding any corrosion tolerance. Under internal pressure, the minimum thickness of shells must not be less than that calculated by the following formulae, which is also required by UG-27 (a).

Steel must have a corrosion allowance of 1.5 mm. The ASME 2010 Boiler and Pressure Vessel code calculates the pressure generated using the cylindrical shell idea with a thickness of 1.5 mm. The lesser of the pressure values given by the longitudinal stress and circular stress equations using section UG – 27 (c) (1) and (2) with Ro the outer radius of 150 mm, S the maximum stress of 138 MPa, t the thickness of 1.5 mm and the pressure P can be estimated as follows is the maximum allowable working pressure for cylindrical shells.

First longitudinal stress, t is determined

For longitudinal stress, $1.5 = \frac{p(150)}{2(138)+1.4p}$

$\therefore$ p = 3.57 bar

Circumferential stress is then determined

$1.5 = \frac{p(150)}{138+0.4p}$

$\therefore$ p = 7.2 bar

Minimum pressure computed is 3.57 bar and the steam temperature is 1390 C. The absorber produces 1000C steam at atmospheric pressure, and the steam flows continuously out of it. No added pressure will build up in the vessel since there is no barrier to the passage of steam. During experiments, highest surface temperature achieved by the surface was 1100C, and maximum pressure equivalent to this temperature would be 1.5 bar. Because this number is significantly lower than the preceding range, the design is deemed to be secure. The ellipsoidal head is supplied at the top to aid passage of steam. The shallow disc shape of the head also reduces the cost of forming, making this design more cost-effective.

Geometric Modeling:

ANSYS workbench's Design Modeller module was used to generate a basic geometric model of the absorber. The cylindrical shell and elliptical head are seen in Figure 1. The container also contains 8 kg of water.

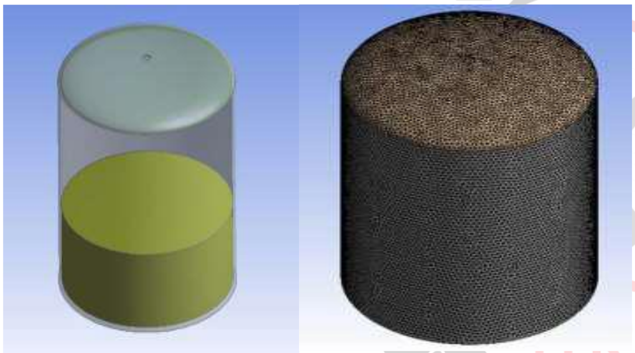

Figure 1: Accumulator containing 8 kg of water as well as mesh

A mesh file (.msh) was saved in the working directory after the geometry was imported into the meshing module of ANSYS Mechanical, and meshing was performed in the model module. The mesh was designed to represent the boundary layer effect as well as the discretized areas as accurately as possible. The precision and stability of numerical computations are highly dependent on the mesh quality. The quality of the mesh, irrespective of the nature of mesh employed in the domain, is critical. Skewness and facet ratio are critical metrics to look for when evaluating mesh quality. The maximum skewness and aspect ratio must be smaller than 0.98 and 35, respectively. Since curved geometry calls for an unstructured mesh with tetrahedral pieces, that's what we went with. Table 2 shows the mesh statistics for the specified model.

Domain	Nodes	Elements	Max. Skewness	Aspect Ratio
8 kg	241457	109564	0.963725	28.163

Table 2: Mesh Statistics

They were discovered to be within the performance limit, so they could be analysed.

Boundary Conditions:

The circumstances in which the analysis is carried out are referred to as the "boundary conditions." In the analysis module's setup stage, boundary conditions are modelled. The literature has established that convection and radiation are the primary modes of heat transmission from the cooking pot. As a result, the heat input for transient thermal analysis must account for these losses.

The amount and location of heat input must be specified for this study. There is a correlation between the amount and location of solar radiation. As a result, we went with a transitory analysis. The software took into account the coefficients of heat flow from the top, bottom, and sides. A black-coloured absorber also had to be included in the calculations. The system's radiation and convection losses were modelled using these parameters.

III. FABRICATION OF THE ABSORBER

Experiments, ray tracing, and finite element analysis were used to determine the absorber's diameter and height. The following actions and safeguards were performed during the production of the absorber. Attachments for a temperature gauge and a pressure gauge were made available for use in measuring temperature and pressure. Water and steam can flow in and out of these openings. A flanged connector was created at the top since gaskets cannot resist high temperatures and do not effectively prevent steam leaking. Figure 2 depicts a handle for gripping the absorber and a drain system for emptying off any remaining water.

The plate was cut to the exact dimensions needed for the elliptical and cylindrical shells. There were 30 degree V grooves on each side of the plate. Rolling was used to creating the cylindrical shell, and pressing was used to create the elliptical head. Tungsten inert gas welding was used to complete the whole shell (TIG). Elliptical head, then cylindrical shell, were joined together. Blasting was used once hydro testing was completed.

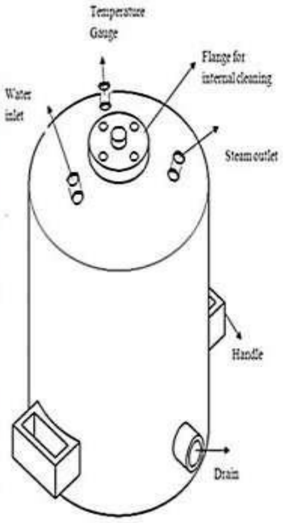

Figure 2: Design and Production of Absorber for Use in Experiment

Emissions were reduced to a minimum by painting the absorber in Catalac black with an emissivity of of 0.88. The black heat-resistant coating was completed. Adding a black coating to a surface creates a robust, heat-resistant finish. Because it is made with unique chemicals that prevent contamination from metals, it protects metal surfaces from corrosion and can tolerate temperatures of up to 5500C.

IV. CONCLUSION

The absorber's material was chosen based on the type of fluid it would be holding. Experimentation and modelling were used to refine the measurements of diameter and height. Pressure vessel codes were used to determine the absorber's thickness. When everything was said and done, the 0.33-meter-tall (0.3-meter-diameter-thick) absorber was created for steam generation. According to our findings, steam generation begins after 40 minutes of system operation in favourable solar circumstances. In order to achieve an equilibrium between the amount of heat received and the frequency with which monitoring is performed, tracking must be performed every 20 minutes. More water can be evaporated by lowering monitoring time, although this requires much physical labour. Using regular tracking, 8 kg of water may be evaporated even in low-sunshine settings. Even if the weather is cloudy, this amount can be raised to 11 kg.

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