Three dimensional numerical analysis of unglazed solar water heater for enhancement in thermal performance

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Abstract- Most of the modern day energy needs is being supplied by fossil fuels and these are being consumed at such a rate that the reserves of oil and gas would last for not more than 250years. If we try to see the implications of these limited reserves we will be faced with a situation in which the unit cost of energy will be high. In addition to this is also the concern about the environmental pollution caused by the burning of the fossil fuels. One of the important renewable energy sources is the solar energy. An important application of solar energy is in the water heating applications for domestic and industrial purposes. However, the solar thermal systems such as flat plate solar collectors suffer from lower efficiency level and energy losses by re-radiation and convection. This project uses the concept of enhancing the heat transfer to water from the absorber plate of the forced circulation flat plate solar collector by using finned circular tube and rectangular tubes with and without fins. We carried out CFD analysis using FLUENT software. The CFD results are validated against experimental results for the base model.

Keywords: Solar energy, CFD simulation, Unglazed collector, Thermal performance.

I.INTRODUCTION

1.1 Solar Heaters

Solar heaters, or solar thermal systems, provide environmentally friendly heat for household water, space heating, and swimming pools. The systems collect the sun’s energy to heat air or a fluid. The air or fluid then transfers solar heat directly or indirectly to home, water, or pool. Solar water heaters, sometimes called solar domestic hot-water systems, may be a good investment. Solar water heaters are cost effective for many applications over the life of the system. Although solar water heaters cost more initially than conventional water heaters, the fuel they use sunshine is free. Solar heating technologies can be used in any climate. To take advantage of solar energy, we usually need to have an unshaded area that faces south, southeast, or southwest, such as a roof. In some cases, a solar professional may recommend west facing roofs for solar collectors. The type of system you choose, including the type of collector and whether it is active or passive, depends on several factors. These include the site, the climate, installation considerations, and cost.

Unglazed collectors have long been used in solar pool heating systems, with low cost and good performance, such favorable economics are likely needed to create significant markets for SDWH, since unglazed collectors can be significantly lower in cost than glazed collectors, there is some cost reduction potential for unglazed SDWH, and assessment of that potential motivated this work

1.2 Solar Collectors

Solar collectors are the key component of active solar-heating systems. They gather the sun's energy, transform its radiation into heat then transfer that heat to a fluid. The solar thermal energy can be used in solar water-heating systems, solar pool heaters, and solar space-heating systems.

There are a large number of solar collector designs that have shown to be functional. These designs are classified in two general types of solar collectors:

- Flat-plate collectors.
- Concentrating collectors.

1.3 Unglazed Solar Collectors

A solar collector that consists of an absorber without the glass covering of a glazed flat-plate collector. In North America, unglazed flat-plate collectors currently account for the most area installed per year of any solar collector. Because they are not insulated, these collectors are best suited for low temperature applications. By far, the primary market is for heating outdoor swimming pools, but other markets exist including heating seasonal indoor swimming pools, pre-heating water for car washes, and heating water used in fish farming operation.

The unglazed collector has a number of compelling advantages. It is the lowest cost type of solar collector and it is rugged, durable, and lightweight. These advantages have made it the most widely installed type of solar collector in North America. Being a plastic collector, the unglazed collector may be unable to withstand high water pressures, such as those that would occur if the collector were connected to the residential water supply. Before using the collector at high water pressures, consult the manufacturer's specifications. For swimming pools, a filtration pump normally circulates water through the unglazed collectors, resulting in much lower pressures.

II. EXPERIMENTAL SET UP

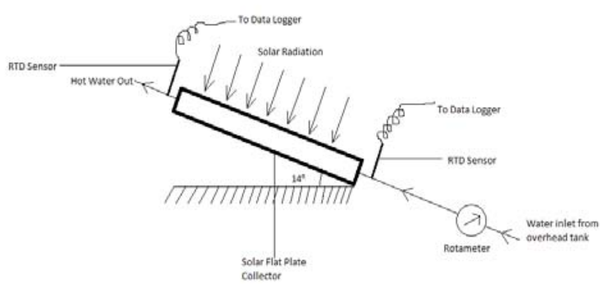


Figure 2.1 Block diagram for an experimental setup of circular model.

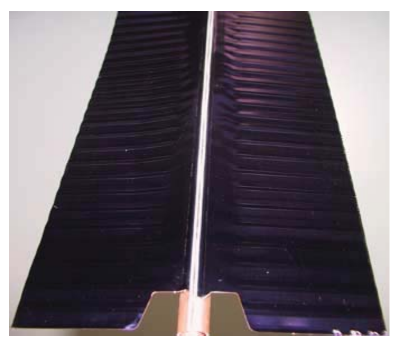


Figure2.2 Absorber Plate.

The Components of the Experimental Setup Are

*Absorber Plate:*For efficiently transmitting heat from the absorbing surface to the fluid, materials with high thermal conductivity are required. Copper offers a thermal conductivity of 386 W/MK and aluminium offers a thermal conductivity of 204.2 W/mk. In this project, it is made of copper with black paint coating. Its thickness is 0.0001 m. The black paint improves the heat absorption capabilities. The dimensions are 1m x0.115 m. This is soldered to the absorber tube. The matt of black surface is an excellent absorber as it converts about 95% of the incident radiation into heat. It is also an excellent radiator of heat, as the temperature increases, so does the rate of emission of heat.

Absorber Tube : Copper tubes of outer diameter 12.5 mm are used. The working fluid flows through the tube and gets heated. Thermocouples are attached at the inlet and outlet sides of the tube. The tubes outside the casings are covered with insulation (wool) to reduce conduction or convection losses. These copper tubes are then connected to Plastic tubes as plastic is a bad conductor of heat.
Insulated casing: It is an aluminium casing in which the tubes, insulation and absorber plates are placed. The casing contains the Rock Wool. The thermal insulation reduces the heat losses from the sides and back of the panel. The aluminium casing also ensures the lightness of the heater.
Rota meter: The flow is controlled by a rotameter, which not only helps us set the exact flow rate we need to conduct the experiment but also provides a constant flow thus ensuring uniform heating
Resistance Temperature Detectors (RTDs): Resistance temperature Detectors is temperature sensors that exploit the predictable change in electrical resistance of some materials with change in temperature.

To measure the temperature of the water flowing through the model, we use thermocouples or RTDs (resistance temperature detector). These are inserted at the inlet and outlet of the absorber tube to measure the inlet and outlet temperature of the water.
Data Logger: The previously mentioned RTDs (Resistance Temperature Detectors) measure the temperature by measuring change in resistance, but this has to be displayed as temperature readings, and to do this we use a data logger.
Experimentation of circular model: The experiment is conducted on a sunny day so as to obtain maximum results. The model having outer diameter of 12.5, inner diameter 11.5 mm and length 1000 mm. absorber plate having width 115 mm thickness 0.1 mm and 1000 mm length and model is kept at 14^o inclination [1] which is the latitude of the location to absorb maximum solar radiation .

The solar radiation flux at location is calculated using empirical equations [1] from 9 am to 4 pm for every 1 hour time duration, analytical calculation and CFD simulation are carried out on calculated heat fluxes and validated against analytical CFD and experimental results.

III. MODELLING AND MESHING.

The modelling and the meshing were done with the help of the software GAMBIT 2.4.6 on a 64 bit system. The iteration and the post processing were done on ANSYS FLUENT 6.3.26.

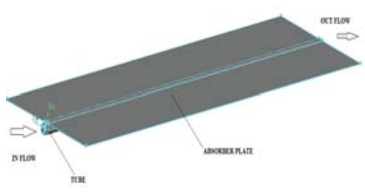


Figure 3.1 Circular model in gambit software

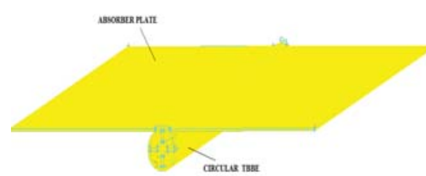


Figure 3.2 Meshed circular model geometry

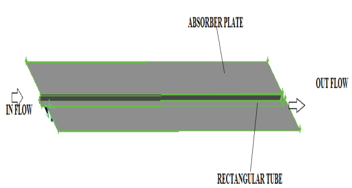


Figure 3.3 Rectangular model in gambit software

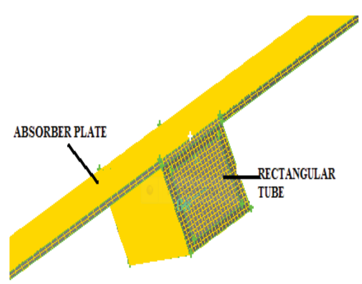


Figure 3.4 Meshed rectangular model geometry.

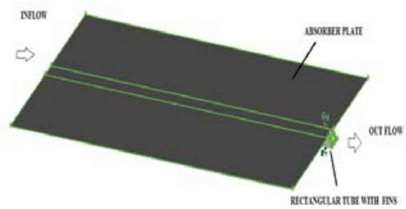


Figure 3.5 Rectangular with fins model geometry as in gambit software

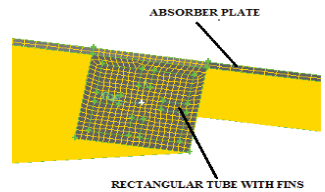


Figure 3.6 Meshed rectangular with fins model geometry

Figure 3.1 to 3.6 shows the construction of circular with fins model, square model and square with fins model models are constructed by creating coordinates in gambit software and joining the coordinates by line and creating the wire frame then make the face mesh in the gambit and extrude or sweep the model with the mesh Meshing is carried out by Quadra map method, after completion of the model give the boundary conditions like in flow, out flow, heat in, material, liquid and other properties then export to FLUENT software, in FLUENT for give heat flux and mass flow rates and other properties and give the convergence criteria number of iterations and iterate up to converging of results and note down the results, same procedure is followed for all the models

IV. RESULTS AND DISCUSSIONS

4.1 Comparison of CFD results with experimental results of circular model.

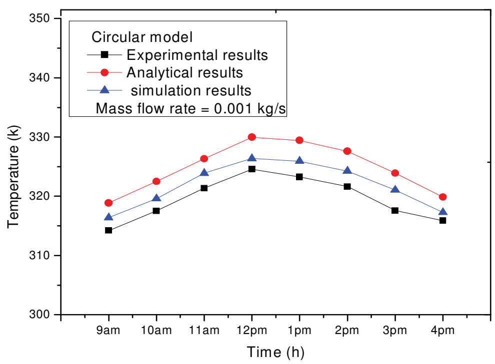
Three dimensional CFD simulation using commercial software FLUENT is carried out on unglazed solar collector for the calculated solar heat flux from 9 am to 4 pm for a mass flow rate of 0.001 kg/s for a circular tube model.

The exit temperature of water from CFD simulation is compared with that of experimental results as shown in graph 4.1 it can be observed that the CFD results match closely with the experimental results thus giving the confidence of using CFD for further analysis.

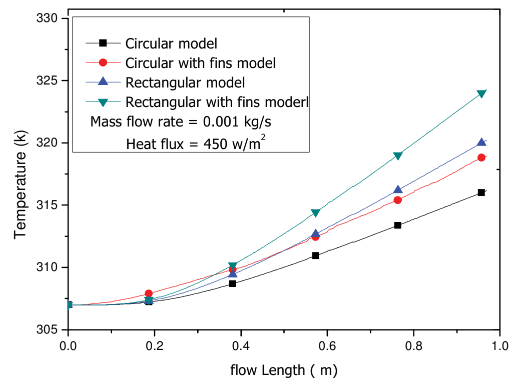
Table 4.1 Validation results table for circular model.

Time in hours.	Heat flux in W/m^2	Experimental temperature (K)	CFD analysis temperature (K)
09:00am	455.48	314.21	316.401
10:00am	611	317.53	319.609
11:00am	819.73	322.36	323.916
12:00pm	939.81	324.57	326.394
01:00pm	917	323.25	325.923
02:00pm	836.19	321.62	324.256
03:00pm	682.035	317.58	321.075
04:00pm	499.008	315.89	317.297

The exit temperature of water obtained by CFD analysis has been noted for each one hour duration from 9am to 4pm and these results along with the results obtained by experimental results have been tabulated [Table 4.1] and comparison can be made from table 4.1 it can be observed that the CFD results are in good agreement with the results obtained by the experimental setup.



Graph 4.1Validation graph for circular model.



Graph 4.2 Temperature raise of water in different models forHeat flux of 450 W/m2.

Graph 4.1 shows the exit temperature of water at different time intervals and the temperature of water obtained from CFD simulation, experimental results for a flow rate of water at 0.001 kg/s it can be observed that the temperature of water obtained from simulation closely matches the experimental values. The temperature obtained by simulation is found to be higher than experimental results since the losses from the collector plate are neglected in CFD simulation for ease of analysis. From graph we can conclude that the temperature difference is uniform in all the methods.

4.2 Comparison of water temperature rise in different models for heat flux of 450W/m^2

Table-4.2Temperature of water in the different models for heat fluxes of 450W/m2

Model	Flow Length(m)				
	0.2	**0.4**	**0.6**	**0.8**	**1**
circular	307.283 K	308.891 K	311.303 K	313.866 K	316.286 K
circular with fins	307.21 K	309.054 K	312.378 K	316.11 K	319.609 K
Rectangular	307.408 K	309.732 K	313.216 K	316.918 K	320.413 K
Rectangular with fins	307.534 K	310.573 K	315.128 K	319.97 K	324.541 K

Table 4.2 shows the temperature of water in different models for heat flux of 450 W/m^2 at various lengths from the tube inlet. It shows that at a distance of 0.2 m temperature of water is 307.283 K, distance of 0.4 m temperature is 308.891 K at distance of 0.6 m temperature is 311.303 K at distance of 0.8 m temperature is 313.866 K, at distance of 1 m out flow temperature is 316.286 K. It can be observed that rectangular with fins model achieve higher temperature than all the models, rectangular model and circular with fins model are having nearly same out flow temperature as tabulated in table 4.2.

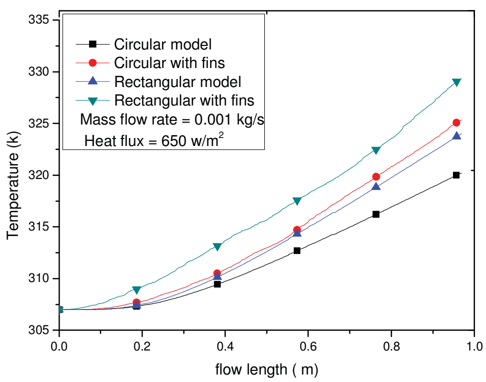
Graph 4.2 shows the temperature distribution of water for all the models for a flow rate of 0.001 kg/s under constant heat flux of 450 W/m^2 it shows that all the improved models performs better than the base model as all the improved models have higher surface area for convective heat transfer to water than the base model it also shows that the models with rectangular tubes without fins and circular tube with fins are have almost same performance level the temperature rise in circular tube with fin model is about 12.75 k while it is 13.41 k in rectangular model hence use of rectangular tube model is better than the circular with fins model. It interesting to see that rectangular tube with fins performs the best as compare to all the models with a temperature raise of about 17.54 k because this model as higher surface area for convective heat transfer to water as compare to all other models. Table 4.2 shows the increase of outlet temperature of different models in the table there is an increase of temperature in rectangular with fins model is very high.

4.3 Comparison of water temperature rise in different models for heat flux of 650W/m²

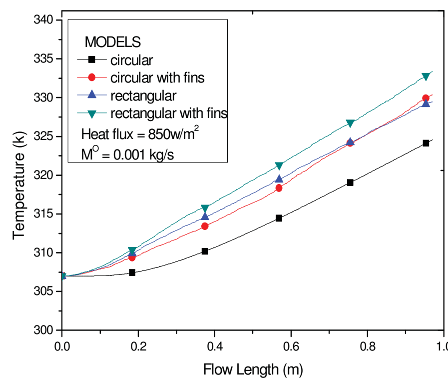
Table 4.3 Temperature raise of water in the different models for heat fluxes of 650W/m2

Model	Flow Length(m)				
	0.2	**0.4**	**0.6**	**0.8**	**1**
circular	307.422K	309.762k	313.251K	316.956K	320.413K
circular with fins	307.563K	310.094k	314.69K	320.451K	325.515K
rectangular	307.525K	310.515k	314.996K	319.759K	324.086K
rectangular with fins	307.18K	311.443k	318.153K	323.43K	329.5K

Table 4.3 shows the water temperature at various tube lengths from inlet for different models at heat flux of 650w/m². At a distance of 0.2 m temperature of water is 307.422 K, at distance of 0.4 m temperature rise is 308.891 K at a distance of 0.6 m temperature is 311.303 K at distance of 0.8 m temperature is 313.866 K, at distance of 1 m out flow temperature is 316.286 K. It can be observed that rectangular with fins model achieve higher temperature than all the models, rectangular model and circular with fins model are having nearly same out flow temperature as tabulated in table 4.3.



Graph 4.3 Temperature rise of water in different models for Heat flux of 650W/m2



Graph 4.4 Temperature rise of water in different models forHeat flux of 850W /m2.

Graph 4.3 shows the temperature distribution of water for all the models for a flow rate of 0.001 kg/s under constant heat flux of 650 W/m² it can be observed that all the improved models performs better than the base model as all the improved models have higher surface area for convective heat transfer to water than the base model it also shows that the models with rectangular tubes without fins and model circular tube with fins model have almost same performance level the temperature raise in circular tube with fin model is about 18.51 K while it is 17.08 K in rectangular model hence use of rectangular tube model is better than the circular with fins model. It interesting to see that rectangular tube with fins performs the best as compare to all the models with a temperature raise of about 22.5 K because this model as higher surface area for convective heat transfer to water as compare to all other models. Table 4.3 shows the increase of outlet temperature of different models in the table there is an increase of temperature in rectangular with fins model is very high.

4.4 Comparison of water temperature rise in different models for heat flux of 850W/m²

Table 4.4 Temperature rise of water in the different models for heat fluxes of 850W/m2

Model	Flow Length(m)				
	0.2	**0.4**	**0.6**	**0.8**	**1**
circular	308.985 K	312.278 K	316.307 K	320.519 K	324.149 K
circular with fins	309.092 K	312.876 K	318.179 K	324.228 K	329.425 K
Rectangular	309.13 K	313.532 K	318.297 K	325.194 K	330.354 K
Rectangular with fins	309.591 K	313.876 K	319.321K	326.499 K	333.976 K

Table 4.4 shows the exit water temperature in different models for heat flux of 850 W/m^2 and a water tube length of 1 m. From the above table it can be observed that circular with fins model and rectangular model having same performance level and rectangular with fins model having higher performance level compare to all the models. There is an increase of temperature of 9.8 K compare to circular model and 4.5 K compare to circular with fins model and 3.6 K compare to rectangular model.

Graph 4.4 shows the temperature profiles of water for all the models for a flow rate of 0.001 kg/s under constant heat flux of 850 W/m^2 it is seen that all the improved models performs better than the base model as all the improved models have higher surface area for convective heat transfer to water than the base model it is also seen that the models with rectangular tubes without fins and model circular tube with fins model have almost same performance level the temperature raise in circular tube with fin model is about 23.5 K while it is 22.5 K in rectangular model hence use of rectangular tube model is better than the circular with fins model. It interesting to see that rectangular tube with fins performs the best as compare to all the models with a temperature raise of about 26.3 K because this model as higher surface area for convective heat transfer to water as compare to all other models. Table 4.4 shows the increase of outlet temperature of different models in the table there is an increase of temperature in rectangular with fins model is very high.

4.5 Temperature contour plots.

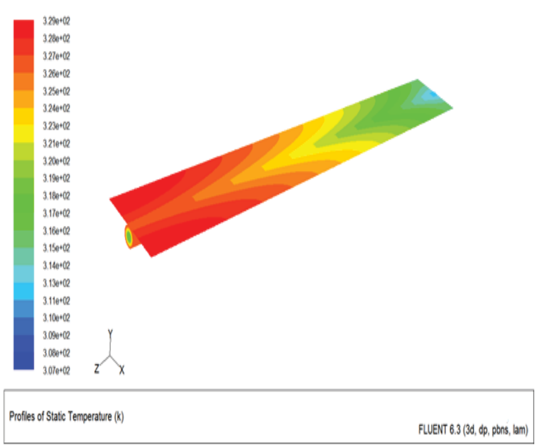


Figure 4.1 Temperature contour plots of circular model for heat flux of 455.48 W/m^2

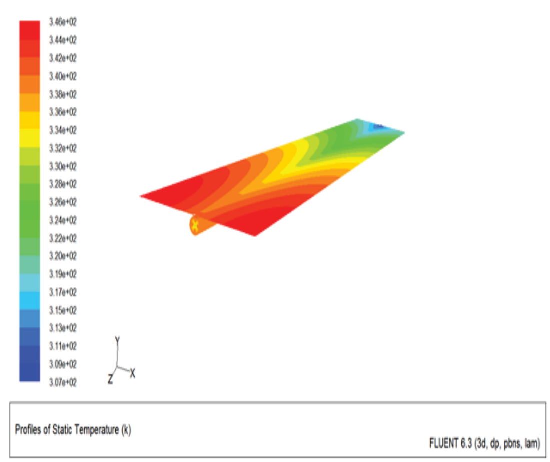


Figure 4.2 Temperature contour plots of circular with fins model for heat flux of 650W/m^2

Figure 4.1 shows the temperature contour plot of circular model at heat flux of 455.48 W/m^2 and water temperature rises to 316.401 K and maximum temperature of absorber plate is 329 K as shown in figure.

Figure 4.2 shows the temperature contour plot of circular with fins model at heat flux of 650 W/m^2 and water temperature rises to 325.515 K and maximum temperature of absorber plate is 346 K as shown in figure.

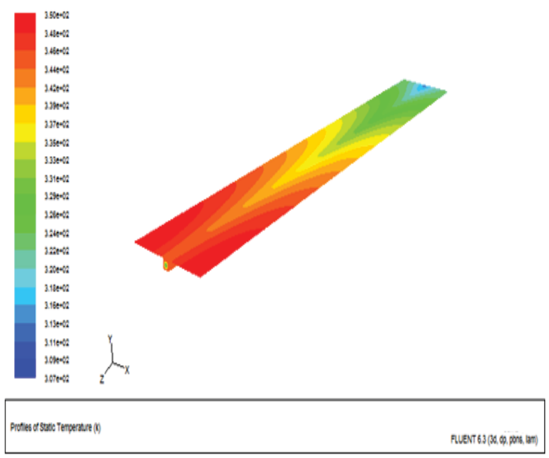


Figure 4.3 Temperature contour plots of rectangular model for heat flux of $650W/m^2$

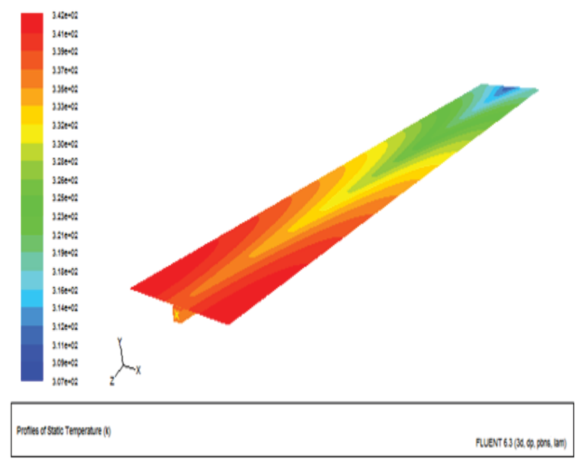


Figure 4.4 Temperature contour plots of rectangular with fins model for heat flux of $650W/m^2$

Figure 4.3 shows the temperature contour plot of circular with fins model at heat flux of 650 W/m^2 and water temperature rises to 324.086 K and maximum temperature of absorber plate is 350 K as shown in figure.

Figure 4.4 shows the temperature contour plot of circular with fins model at heat flux of 650 W/m^2 and water temperature rises to 329.5 K and maximum temperature of absorber plate is 342 K as shown in figure.

V. CONCLUSIONS

- It is found that, the temperature rise of exit water for finned circular tube model is 5.27 K, for unfinned rectangular tube model is 6.26 K and for finned rectangular tube model is 9.8 K higher than the conventional unfinned circular tube model.
- The solar collector with finned circular tube model finned rectangular tube model and rectangular tube without fins model performs better than the circular model.
- The model with finned circular tube and the model with rectangular tube have the same performance level and hence use of rectangular tube is better option if fins have to be provided in the circular tube.
- The solar collector with finned rectangular tube as the highest performance level then other models there is an increase of outlet temperature of water in circular model is 324 K, circular with fins model is 330.542 K, rectangular model is 329.45 K and rectangular with fins model is 333.384 K.
- The most common application of unglazed solar collector is for building ventilation air heating, crop drying, and swimming pools water heating and industrial water heating purpose.

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