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Improving Solar Hot Water Tank Performance with a Copper Hallow Shaft

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Abstract:

A solar water heater can be used for a variety of purposes to provide hot water for both residential and commercial use. Renewable energy Policy Network data shows that more over 90 million people view daily access to hot water as necessary. When compared to other solar-powered devices, a solar water heater is not only less expensive to use and maintain, but it is also more environmentally friendly. The widespread usage of solar water heating in India is a result of numerous variables, particularly in low-temperature commercial applications. For Indian hotels, restaurants, and other food processing enterprises to be operational, hot water is a critical necessity. Active and passive solar water heaters are the two main categories of solar water heaters. By adding hollow copper tube to the solar water galss tubes and enlarging the pipe's surface area, the project's primary goal is to maintain the outlet temperature and raise the temperature of the outlet water. The temperature increase that is anticipated is between 8and 12oC. There is undoubtedly a slow temperature rise issue when the hollow copper line is inserted into the solar glass tube. As the copper tube is placed inside the solar glass tube, I definitely come across the problem of slow temperature rise.

Keywords — **Solar Collector, Storage Tank, Wooden Powder, Copper Pipe etc.**

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1. INTRODUCTION

Harnessing the sun's power for hot water needs, solar water heating systems offer an eco-friendly and cost-effective solution for homes, businesses, and even industries. These clever systems work by capturing sunlight in solar collectors. Imagine these collectors as solar sponges, soaking up the sun's rays. The captured heat is then transferred to a fluid, usually water mixed with antifreeze for colder climates, that acts like a heat-carrying messenger. This fluid circulates throughout the system, absorbing the collected heat from the solar collectors and carrying it to a well-insulated storage tank. The stored hot water is then readily available for whenever you need it, like showering, washing dishes, or even running radiant floor heating.

Flat plate collectors are the most popular choice for domestic hot water due to their simple design and effectiveness at moderate temperatures. Think of them as broad, flat panels facing the sun, efficiently capturing its warmth. In areas with extreme temperatures, an antifreeze solution is added to the water to protect the system from freezing, overheating, or corrosion. Propylene glycol, a type of alcohol, is often used for its eco-friendly properties, but it's important to note that it can break down at very high temperatures and become corrosive.

The process of solar water heating is quite straightforward. Sunlight streams through a transparent cover on the collector, reaching a dark absorber plate within. This absorber plate, much like a car dashboard on a hot day, traps the sun's heat. The heat is then transferred to the circulating fluid flowing through tubes attached directly to the absorber plate. As the cooler water travels through these tubes, it absorbs the heat, becoming hot water itself. This hot water, lighter than the cooler water entering the system, naturally rises and flows into the storage tank for later use. Clever design ensures the water flows through the bottom of the collector tubes first, maximizing heat absorption from the hot absorber plate. Insulation surrounding the collector further enhances efficiency by minimizing heat loss to the environment.

Researchers are constantly innovating to improve solar water heating systems. One method involves using turbulators within the collector tubes. These turbulators are like tiny bumps or ridges that help the fluid flow more vigorously, improving heat transfer and potentially raising the final hot water temperature. However, their effectiveness is limited, especially at higher temperatures. Evacuated tube collectors (ETCs) are another promising technology. These collectors use a double-walled glass tube with a vacuum in between, significantly reducing heat loss. This allows them to operate efficiently at a wider range of temperatures and achieve higher overall efficiency. However, even ETCs have their challenges. Dust buildup on the collector tubes can reduce performance, and some evacuated tube designs may take longer to heat water initially. To address this, some systems incorporate copper tubes within the evacuated tubes themselves. Copper is a great conductor of heat, so this additional element helps transfer heat to the fluid more quickly, reducing heating time.

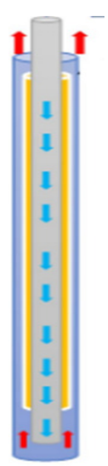

Fig. 1 Evacuated Glass Tube

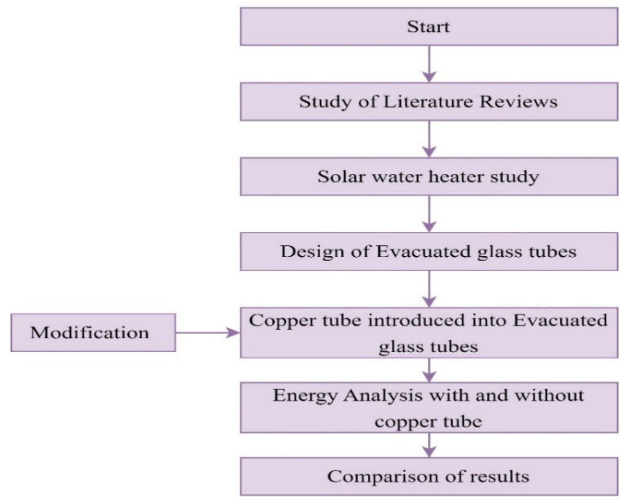

Fig. 2 Process Steps to Analysis

2. DESIGN OF SOLAR EVACUATED TUBES

Solar energy collectors are the workhorses of solar thermal systems, acting like heat exchangers that trap the sun's energy and convert it into usable warmth. These collectors come in two main flavors: non-concentrating and concentrating. Non-concentrating collectors, often stationary and simpler in design, rely on their surface area to absorb as much sunlight as possible. Concentrating collectors, on the other hand, employ mirrors or lenses to focus the sun's rays onto a smaller area, achieving higher temperatures but requiring tracking mechanisms to follow the sun's path across the sky.

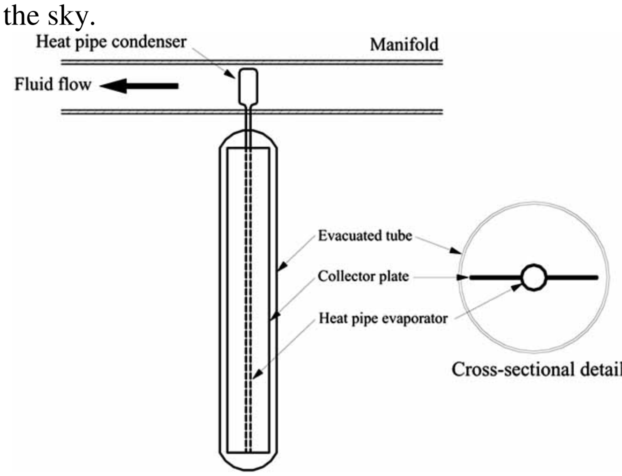

Fig.3 Schematic representation of an evacuated tube collector

3. ANALYSIS OF SOLAR EVACUATED TUBES

Evacuated tube solar collectors (ETCs) are high-performance alternatives to flat plate collectors, particularly for applications requiring hotter water (above 80°C). Their secret lies in a two-pronged approach: a special surface coating and superior insulation. The coating selectively absorbs sunlight while minimizing heat radiation, and the evacuated space between the glass tubes significantly reduces heat loss. This combination allows ETCs to achieve remarkable efficiency, making them ideal for supplying hot water or heating systems in homes.

One common type of ETC uses heat pipes for efficient heat transfer. Imagine a sealed glass tube containing a copper pipe and a small amount of liquid. Sunlight heats the absorber plate (a black copper fin) inside the tube, causing the liquid to evaporate. This vapor rises to the condenser end of the heat pipe, where it releases its heat and condenses back into a liquid. This liquid then flows back down the pipe, completing the cycle and continuously transferring heat to the connected system. The evacuated space around the heat pipe minimizes heat loss during this process. Finally, multiple evacuated tubes are arranged in rows and connected by a header pipe for efficient collection and distribution of heat.

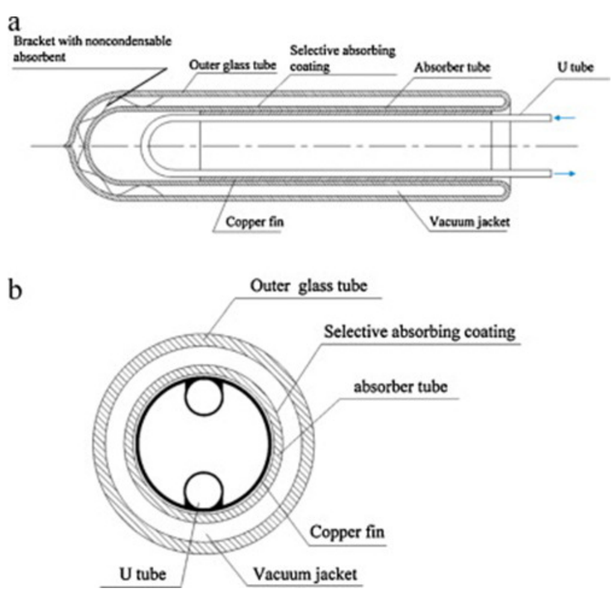

Fig.4 Glass evacuated tube solar collector with U-tube

Researchers explored a novel design for a solar collector that integrates a phase change material (PCM) for thermal storage. This design places the PCM within the collector's header, allowing it to directly absorb heat from a heat pipe. This configuration is particularly suited for evacuated tube collectors that utilize heat pipes. The study investigated using water as the collector fluid for both charging and discharging the PCM in a theoretical setting. During the charging cycle, heat from the condenser section of the heat pipe transfers to both the PCM and the water-based working fluid, which flows perpendicular to the heat pipe (as shown in Figure 6.2). Interestingly, this design utilizes water during the charging phase but switches to air for heating during discharge. The researchers also developed a thermal model to analyze the collector's ability to store and release heat, specifically for space heating applications in climates like North India. Their findings suggest that this system could be particularly beneficial in regions with abundant sunshine.

3.1 Analysis of Solar-Evacuated tubes

Analysis1

MESH:

Entity	Size
Nodes	381
Elements	981

ELEMENT TYPE:

Connectivity	Statistics
TE4	981 (100.00%)

ELEMENT QUALITY:

Criterion	Good	Poor	Bad	Worst	Average
Stretch	333 (33.94 %)	648 (66.06 %)	0 (0.00 %)	0.165	0.310
Aspect Ratio	48 (4.89 %)	279 (28.44 %)	654 (66.67 %)	8.059	5.564

Materials.1

Material	Copper
Young's modulus	1.1e+011N_m2
Poisson's ratio	0.33
Density	8900kg_m3
Coefficient of thermal expansion	1.65e-005_Kdeg
Yield strength	2.9e+008N_m2

Static Case

Boundary Conditions

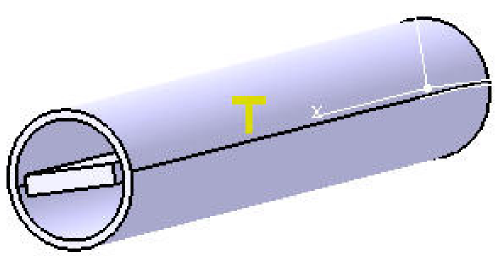

Fig.5Evacuated tube

STRUCTURE Computation

Number of nodes : 381
Number of elements : 981
Number of D.O.F. : 1143
Number of Contact relations : 0
Number of Kinematic relations : 0
Linear tetrahedron : 981

RESTRAINT Computation

Name: Restraints.1

Number of S.P.C : 162

LOAD Computation

Name: Loads.1

Applied load resultant :

Fx = -2 . 488e-011 N
Fy = -6 . 886e-010 N
Fz = 1 . 062e-009 N
Mx = 2 . 384e-012 Nxm
My = -1 . 455e-011 Nxm
Mz = -1 . 630e-010 Nxm

STIFFNESS Computation

Number of lines : 1143
Number of coefficients : 17937
Number of blocks : 1
Maximum number of coefficients per bloc : 17937
Total matrix size : 0 . 21 Mb

SINGULARITY Computation

Restraint: Restraints.1

Number of local singularities : 0
Number of singularities in translation : 0
Number of singularities in rotation : 0
Generated constraint type : MPC

CONSTRAINT Computation

Restraint: Restraints.1

Number of constraints : 162
Number of coefficients : 0
Number of factorized constraints : 66
Number of coefficients : 0
Number of deferred constraints : 0

FACTORIZED Computation

Method	:	SPARSE
Number of factorized degrees	:	1077
Number of supernodes	:	203
Number of overhead indices	:	5844
Number of coefficients	:	41640
Maximum front width	:	90
Maximum front size	:	4095
Size of the factorized matrix (Mb)	:	0 . 317688
Number of blocks	:	1
Number of Mflops for factorization	:	2 . 344e+000
Number of Mflops for solve	:	1 . 719e-001
Minimum relative pivot	:	1 . 761e-004

Minimum and maximum pivot

Value	Dof	Node	x (mm)	y (mm)	z (mm)
1.0758 e+006	Tz	118	4.9487 e+001	1.7962 e+001	-3.7318 e+000
1.7865 e+010	Tz	200	1.8182 e+002	-3.8195	-2.1739

				e-001	e+001

Minimum pivot

Value	Dof	Node	x (mm)	y (mm)	z (mm)
4.6938 e+006	Ty	118	4.9487 e+001	1.7962 e+001	-3.7318 e+000
7.1904 e+007	Tz	381	2.4780 e+002	0.0000 e+000	3.7318 e+000
7.9247 e+007	Ty	381	2.4780 e+002	0.0000 e+000	3.7318 e+000
1.4882 e+008	Tz	80	1.9825 e+002	-2.5000 e+001	0.0000 e+000
1.4901 e+008	Tx	101	1.9837 e+002	2.5000 e+001	0.0000 e+000
1.7517 e+008	Tx	118	4.9487 e+001	1.7962 e+001	-3.7318 e+000
1.9579 e+008	Tz	87	6.6017 e+001	-2.5000 e+001	0.0000 e+000
2.0433 e+008	Tz	92	3.2958 e+001	2.5000 e+001	0.0000 e+000
2.0736 e+008	Tz	72	1.8059 e+002	2.1743 e+001	0.0000 e+000

Translational pivot distribution

Value	Percentage
10.E6 -->10.E7	1.8570e-001
10.E7 -->10.E8	1.8570e-001

10.E8 -->10.E9	3.3890e+001
10.E9 -->10.E10	5.8774e+001
10.E10 -->10.E11	6.9638e+000

DIRECT METHOD Computation

Name: Static Case Solution.1

Restraint: Restraints.1

Load: Loads.1

Strain Energy : 1.036e+000 J

Equilibrium

Components	Applied Forces	Reactions	Residual	Relative Magnitude Error
Fx (N)	-2.4881e-011	3.8654e-010	3.6165e-010	2.8295e-015
Fy (N)	-6.8862e-010	1.0741e-010	-5.8121e-010	4.5472e-015
Fz (N)	1.0623e-009	1.2005e-009	2.2628e-009	1.7704e-014
Mx (Nxm)	2.3839e-012	1.2842e-011	1.5226e-011	4.5078e-016
My (Nxm)	-1.4552e-011	-2.1919e-010	-2.3374e-010	6.9200e-015
Mz (Nxm)	-1.6295e-010	-5.1017e-012	-1.6805e-010	4.9753e-015

Static Case Solution.1 - Deformed mesh.2

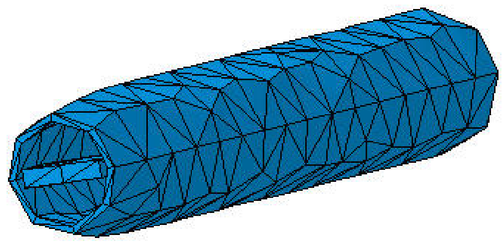

Fig.6 Evacuated tube deformation

On deformed mesh ---- On boundary ---- Over all the model

Static Case Solution.1 - Von Mises stress (nodal values).2

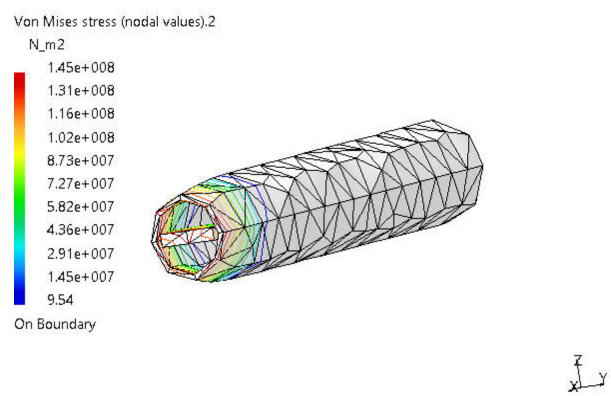

Fig.7Evacuated tube Von Mises stress

3D elements: : Components: : All

On deformed mesh ---- On boundary ---- Over all the model

Global Sensors

Sensor Name	Sensor Value
Energy	1.036J
Global Error Rate (%)	47.806835175

CONCLUSION

The analytical findings indicate that the incorporation of the hollow copper tube into the solar-evacuated tube leads to enhanced efficiency and heat gain, surpassing the performance of the current system in its absence. The study revealed a significant increase in heat energy, rising from 1.036 to 5.048 J. The efficiency of heat transfer increases significantly when the amount of sunlight radiation is reduced, and the absorption of heat is enhanced by using a hollow copper tube. It is evident that the solar water heater equipped with a hollow copper tube has superior efficiency compared to the one lacking this feature.

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