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DESIGN AND PERFORMANCE ANALYSIS ON PORTABLE SOLAR WATER HEATERS AND COOLERS

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Abstract

Solar energy is an inexhaustible source of energy. It is one of the most promising non-conventional energy resources. Unlike fossil fuels and nuclear power, it is also an environmentally clean source of energy. The ultimate source of much of the world's energy is the sun, which provides the earth with light, heat and radiation. While many technologies derive fuel from one form of solar energy or another, there are also technologies that directly transform the sun's energy into electricity. Since generating electricity directly from sunlight does not deplete any of the earth's natural resources and supplies the earth with energy continuously, solar energy is a renewable source for electricity generation. Solar energy is our earth's primary source of renewable energy. In the present study the pollution and its effect to environment should be minimised from simple equipments such as heaters and coolers. By using non biodegradable materials (plastics, waste cotton cloths, compact disks) equipment has to be fabricated with low cost and better efficiency. With the help of solar and wind, the objective is to fabricate an equipment which will results in heating and cooling simultaneously. The equipment/prototype will be easily available and portable at low cost.

Keywords: Solar Energy, Heater, Cooler, Design, Uses, Copper Tubes, Bottles, and pipes.

1. Introduction

Solar radiation is electromagnetic radiation in the 0.28 to.3.0 µm wavelength range. The solar spectrum includes a small share of ultraviolet radiation (0.28...0.38 µm) which is invisible to our eyes and comprises about 2% of the solar spectrum, the visible light which range from 0.38 to 0.78 µm and accounts for around 49% of the spectrum and finally of infrared radiation with long wavelength (0.78...3.0 μm), which makes up most of the remaining 49% of the solar spectrum. The sun generates an enormous amount of energy - approximately 1.1 x 10 E20 kilowatt-hours every second. (A kilowatt-hour is the amount of energy needed to power a 100 watt light bulb for ten hours.) The earth's outer atmosphere intercepts about one two-billionth of the energy generated by the sun, or about 1500 quadrillion (1.5 x 10 E18) kilowatt-hours per year. Because of reflection, scattering, and absorption by gases and aerosols in the atmosphere, however, only 47% of this, or approximately 700 quadrillion (7 x 10 E17) kilowatt-hours, reaches the surface of the earth.

Chandrasekar and Kandpal[1] have presented a methodology to estimate the potential number of households that can use solar water heater systems. The methodology establishes a relationship between the seasonal and diurnal variations in ambient temperature at a place and the need of hot water for bathing. This has been used to estimate the expected capacity utilization of solar water heater for different locations in the country. The income levels of the households directly affect their capacity to purchase solar water heater. Using the income distribution of households in the country, the capital cost of typical solar water heater, and the rate of interest on the loans provided to the users to purchase solar water heater, the potential number of households who can use solar water heater have been estimated. In one of the examples presented in the paper, it is estimated that 45 million households in India can use solar water heater. This translates into a potential of 90 million m2 of solar water heater in the residential sector.

Pillai and Banerjee[2] have presented a methodology for potential estimation of solar water heater in an area taking into consideration the factors affecting adoption at the end use level (micro-level factors) and factors that affect the aggregate market (macro-level factors). The methodology can be used to estimate the potential for the individual Sectors and also for the target area as a whole. In the paper, the methodology is illustrated for a synthetic area at Pune with an area of 2 sq. km and population of 10,000. The end use sectors considered are residential, hospitals, nursing homes and hotels. The estimated technical potential and market potential are 1700 m2 and 350 m2 of collector area, respectively.

Schlaich [3] insisted on urgent action regarding global problems such as energy demand, rapid population growth and pollution by the utilization of large scale solar energy generation. He endorsed the use of solar power plant for future electricity generation. Schlaich also gave details of construction, construction materials, operation, tests and experimental data of the pilot solar plant in Manzanares. Based on the experience gained from the experimental plant, rough investment and energy generation cost calculations are presented for developing large scale solar power plants. In a supplement to the book, water-filled black tubes are identified as a possible means to enhance the plant's natural energy storage capability.

After the construction of the aforementioned experimental solar power plant in **Manzanares, Haaf et al. [4]** discussed the basic principles behind the operation, construction, power generation, energy balance and cost analysis of a solar power plant. Haaf also makes mention of a similar notion used centuries before by Leonardo da Vinci, (according to his sketches of a barbecue- spit driven by an up draught through a chimney).

Following his publication in 1983, **Haaf [5]** documented preliminary test results from the Manzanares prototype plant, with experimental findings which correspond well with model calculations.

Padki and Sherif [6] researched the chimney in particular, investigating the influence of various geometrical configurations on the performance and efficiency of the power plant.

Von Backstrom and Gannon [7, 8] developed an alternate approach by regarding the solar power plant as an air standard thermodynamic cycle. Certain parameter relationships are also developed within this study. A further publication by Von Backstrom and Gannon investigates the compressible air-flow through the plant of a large-scale solar power plant. The study evaluates all losses associated with the plant, specifying relevant pressure drop contributions to the total pressure drop across the plant. Gannon and Von Backstrom also presented an analysis of the solar chimney that includes chimney friction, turbine and exit kinetic energy losses and a simple solar collector model.

2. Experimental setup

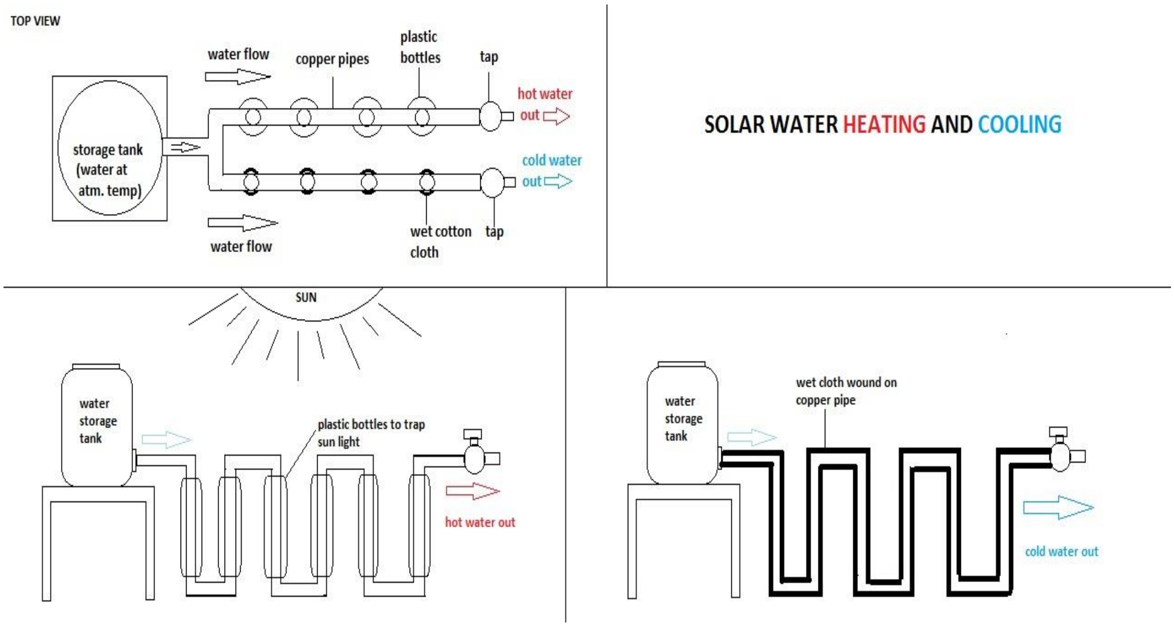

Fig 2.1 Schematic diagram of experimental setup

Components used

The experimental setup consists of:

- Copper tubes
- Plastic bottles
- Waste cloths
- Compact disk
- Storage tank
- Connecting pipes
- Valves
- Miscellaneous

3. Problem statement and Methodology

3.1 Renewable resources:

One disadvantage with renewable energy is that it is difficult to generate the quantities of electricity that are as large as those produced by traditional fossil fuel generators. This may mean that we need to reduce the amount of energy we use or simply build more energy facilities. It also indicates that the best solution to our energy problems may be to have a balance of many different power sources. Another disadvantage of renewable energy sources is the reliability of supply. Renewable energy often relies on the weather for its source of power. Hydro generators need rain to fill dams to supply flowing water. Wind turbines need wind to turn the blades, and solar collectors need clear skies and sunshine to collect heat and make electricity. When these resources are unavailable so is the capacity to make energy from them. This can be unpredictable and inconsistent. The current cost of renewable energy technology is also far in excess of traditional fossil fuel generation. This is because it is a new technology and as such has extremely large capital cost.

3.2.2 Non renewable resources:

Fossil fuels are non-renewable and will eventually run out because we are using hem much faster than they can be restored within the earth. Burning fossil fuels produces photochemical pollution from nitrous oxides, and acid rain from sulphur dioxide. Burning fuels also produce greenhouse gases including vast amounts of carbon dioxide that may be causing the phenomenon of global warming that the planet is currently experiencing.

Henceforth a setup should be developed which overcomes the above problems. The pollution and its effect to environment should be minimized from simple equipments such as heaters and coolers. By using non biodegradable materials (plastics, waste cotton cloths, compact disks) equipment has to be fabricated with low cost and better efficiency. With the help of solar and wind, the objective is to fabricate an equipment which will results in heating and cooling simultaneously. The equipment/prototype will be easily available and portable at low cost.

4. Methodology:

4.1 Hot water section:

In the Hot water section, the copper pipes are being enveloped by plastic bottles. As the solar radiation is incident on the apparatus, the heat is absorbed and transferred to the water inside the pipes. The main purpose of using plastic bottles is to direct the solar rays as well as to entrap the solar energy within the air molecules present in the bottle. This entrapped energy is then transferred to the water present inside the pipes through free convection process. The bottle also serves as an insulation to reduce the convection from the pipes to the atmosphere as it doesn't allow the atmospheric air to carry away the heat freely.

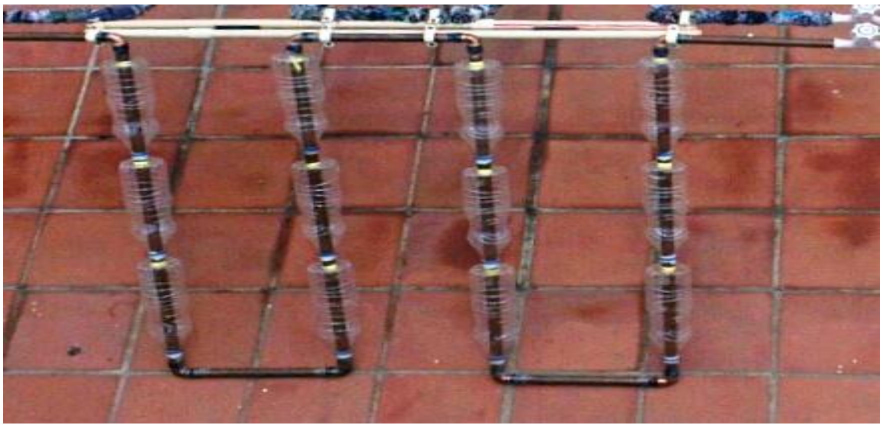

Fig 4.1 Hot water section

4.2 Cold water section:

In the cold water section initially water inside the copper tubes will be at atmospheric temperature. The copper tubes are completely wound by waste cotton cloth. Due to which the sun rays are not incident on the surface of the copper tubes. These cotton cloths are kept wet throughout the process. Since the copper tubes are not exposed to the solar radiation from sun they absorb the heat from the water present inside them and this heat will be transferred to the wet cloth. The wind energy carries away the heat from the wet cloth. This process repeats and thus reducing the temperature of water.

Fig 4.2 Cold water section

4.3 parabolic reflectors:

A parabolic (or paraboloid or paraboloidal) reflector (or dish or mirror) is a reflective surface used to collect or project energy such as light, sound, or radio waves. Its shape is part of a circular paraboloid, that is, the surface generated by a parabola revolving around its axis. The parabolic reflector transforms an incoming plane wave traveling along the axis into a spherical wave converging toward the focus. Conversely, a spherical wave generated by a point source placed in the focus is reflected into a plane wave propagating as a collimated beam along the axis.

Parabolic reflectors are used to collect energy from a distant source (for example sound waves or incoming star light) and bring it to a common focal point, thus correcting spherical aberration found in simpler spherical reflectors. Since the principles of reflection are reversible, parabolic reflectors can also be used to project energy of a source at its focus outward in a parallel beam, used in devices such as spotlights and car headlights. The CD's used in this setup helps to reflect the sunlight towards the copper pipes to get better efficiency. The CD's are arranged in such a way as to act as parabolic reflectors.

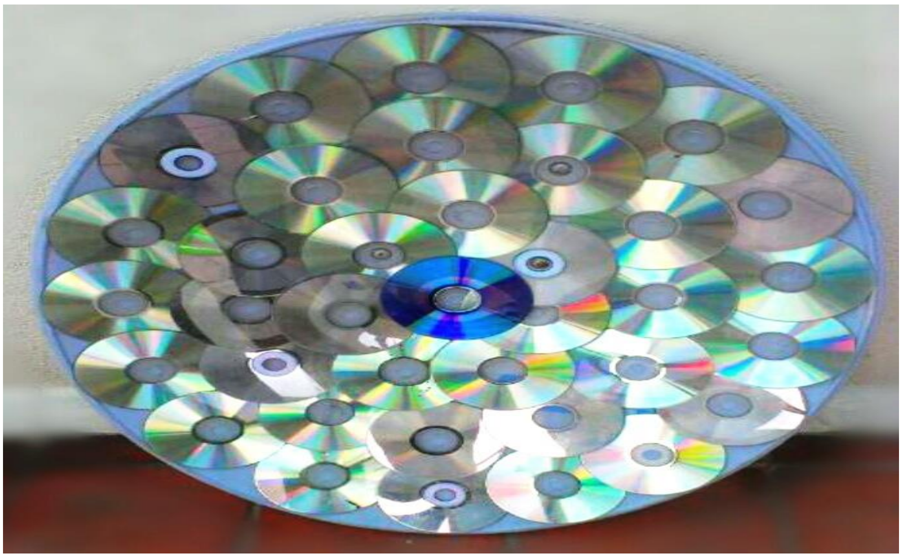

Fig 4.3 Parabolic reflectors

Fig 4.4 Final setup of solar water heater and cooler

5. Calculations

5.1 Total heat transfer

From eqn's (1),(2),(3)

- $Q = Q_1+Q_2+Q_3+Q_4$

$Q = mC_P dT/dt$

$Q = 1.2\times4187\times (24/15\times60)$

$= 133 W/mK$

- Area of plastic bottle:

  $A_1 = 2\pi rH+2\pi r^2$

  $= 2\times\pi\times0.038\times026+2\times\pi\times (0.038)^2$

  $=0.0704 m^2$

- Area of copper tube:

  From eqn (5)

  $A_2 = 2\pi rH+2\pi r^2$

  $= 2\times\pi\times9.5\times10^{-3}\times0.91+2\times\pi\times (9.5\times10^{-3})^2$

  $= 0.0551\ m^2$

- Temperature difference:

  From eqn (6)

  $T_w = (T_i + T_o)/2$

  $= (58+34)/2$

  $= 46^oC$

  $\Delta T_4 = T_c - T_W$

  $= 70 – 46$

  $= 24\ ^oC$

- Therefore heat transfer is

  $Q = hA_1\Delta T_1 + hA_2\Delta T_2 + \sigma A_2\varepsilon(\Delta T_3)^4 + hA_2\Delta T_4$

  $133=h\times.0704\times12+h\times0.0551\times12\times4 + 5.67\times10^{-8}\times0.0551\times0.9\times36^4\times4 + h\times0.0551\times24\times4$

  $133 = 10.128h + 2.6448h + 4.67123\times10^{-3} + 5.288h$

  $133 = 18.075h + 4.67\times10^{-3}$

  $132.9953 = 18.075h$

  $h = 7.3592 KJ/Kg$

5.2 Cold water section

- Vapor pressure of water, P_{sat} (atm)[a]

  $P^{sat}(T) = c_1e^{c2T}$

  $= 2.607\times10^{-10}\times e^{(.0624\times23)}$

  $P^{sat}(T) = 8.682\times10^{-10} atm$

- Latent heat of vaporization of water, λ (J/g)[a] :

  $\lambda(T) = C_3+C_4T$

  $= 3151.5+(-2.38\times23)$

  $\lambda(T) = 3096.7$ J/g

- Heat capacity of water, *cp,water* [J/(g K)]

  Cp= 4.187 J/g-k

- Thermal conductivity of water, *kwater* [W/(cm K)]

  Kwater= 6.15×10^{-3}W/cm-k

- External mass transfer coefficient, $k_{f,ext}$ (cm/s) :

  $k_{f,ext} = c_5RH_{amb} + c_6$

  $=.014\times.46+.203$

  $k_{f,ext} = .20944$ cm/sec

- Ratio of external mass and heat transfer coefficients, $k_{f,ext}/h_{ext}$ (cm^3 K/J)

  $k_{f,ext}/h_{ext} = c_7RH_{amb} + c_8$

  $= 4.941\times.46+264.517$

  $k_{f,ext}/h_{ext} = 266.78$ cm^3K/J

- Wet-bulb or equilibrium temperature, T_{eq} (°C),

  $T_{eq} = c_9RH_{amb} + c_{10}$

  $= 0.085\times0.46+13.369$

  $T_{eq} = 13.4081$°C

6. Results and Discussions

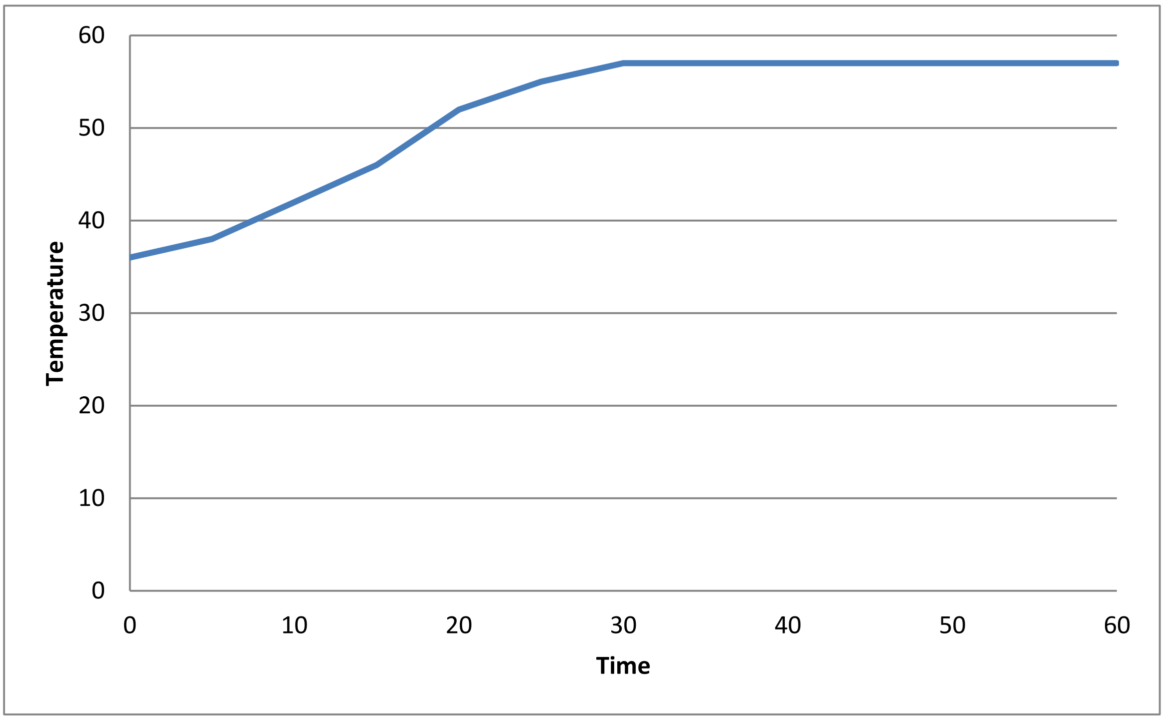

Fig 6.1. Hot water graphical representation of change in temperature v/s time

From the figure its very clear that as the temperature increases in the hotter section with respect to time.

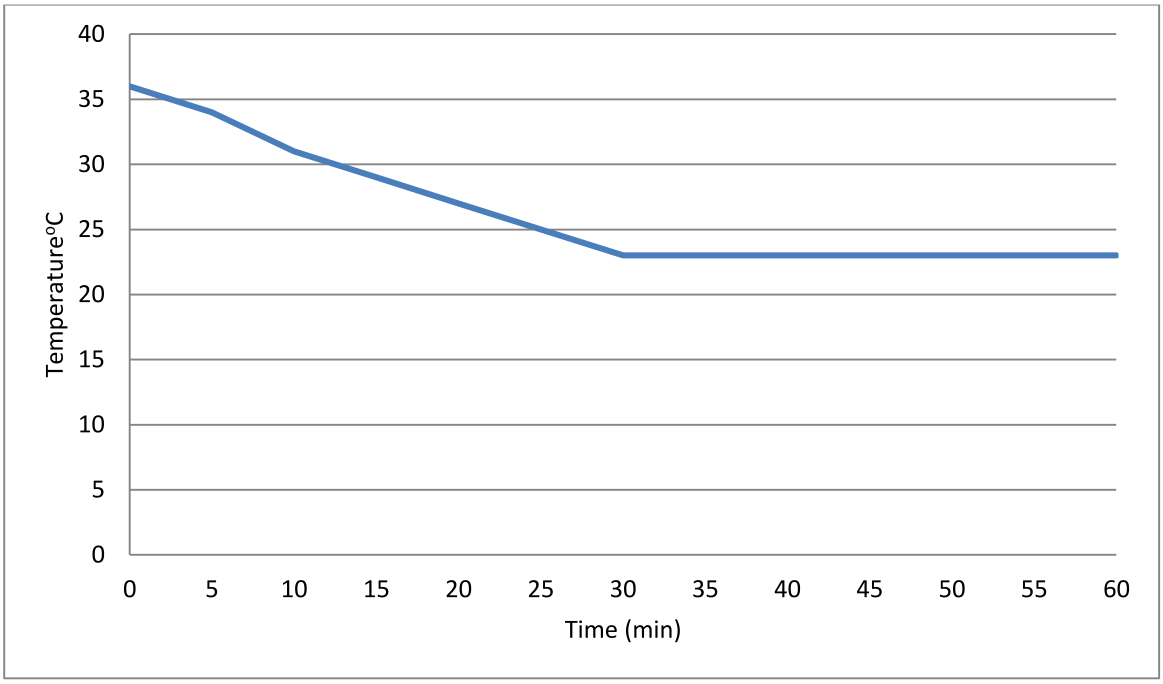

Fig.6.2 cold water graphical representation of change in temperature v/s time

From the figure it's very clear that as the temperature decreases in the colder section with respect to time.

7. Conclusion

A system has been fabricated to heat and cool water efficiently at a low cost. The system uses non-conventional energy sources and also meets the objectives stated. The system is portable and also can be commercialized. It is necessary to build flexible programs that can adapt to changing markets and accommodate changing perceptions of the users and improve the legal and regulatory environment for encouraging the installation of solar water heater and cooling systems. In doing all this, it is very important to create awareness about the solar water heater and cooling systems. The idea of solar water heater and cooler is not very complex, it is certainly one of the better sources of both hot and cold water. Technical advancements can be made by incorporation of fins in the cold water section for maximum efficiency. Methane gas which is having good wavelength can be introduced inside the bottles for maximising the temperature. Special coatings can be provided for the drawbacks of fouling factor. It is necessary to build flexible programs that can adapt to changing markets and accommodate changing perceptions of the users and improve the legal and regulatory environment for encouraging the installation of solar water heater and cooling systems. In doing all this, it is very important to create awareness about the solar water heater and cooling systems.

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