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Thermodynamics Characterization of Density models for an Effective Solar Water Heater Sizing

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Abstract

The problem faced in Sizing of an effective Solar Water Heater (SWH) by engineers to meet certain design requirement is highly enormous. Using the thermodynamic characterization relation and the knowledge of Solar Water Heater (SWH) density's model; various design were evaluated. The result shows that density model actually predicts adequately and providing alternative means of estimating these design parameters. Also, the properties of the system, such as entropy and enthalpy (specific heat capacities), which cannot be determined directly from experimental axiom, were evaluated. These evaluations therefore, give room to express the thermodynamics properties of the system and consequently improve the design performance. Further comparisons with experimental results reveal a better outfit. Therefore through the knowledge of thermodynamic relation an efficient Solar Water Heater is operated and empirical data is expanded.

***Key words**: Thermodynamic Relation, Density Model, SWH parameters, thermodynamic and dimensionless properties.*

1. Introductions

Thermosyphon solar water heater is a naturally operated system that performs using the force of gravity. It is the oldest form of the system but less utilized due to its system efficiency. Though it could be highly effective if proper optimized and operated in most temperate developing countries where less power are supplied, low income purchasing for active equipments and less ability to procure require measuring equipment for system optimization; Agbo, (2012). As a result of this; evaluation models are developed to obtain various data whose equipment is not readily available. Density model is one of those models in solar water heater to ease the evaluation of system parameters which are difficult to obtain during experimentations. But despite the use of these models by various researchers, (Aasa and Ajayi 2012, Agbo and Unachukwu 2007), some thermodynamics properties are yet to be evaluated. These parameters, (specific capacity, entropy and enthalpy etc) are of immense important during system optimizations which give us rooms for maneuvering the energy available during the proper system sizing. Further to this, thermodynamics characterizations give room for analysis and calculation of various system parameters which are difficult to obtain during experimentations. Many researchers have used the ability of this skill to obtain parameters that cannot be estimated during the course of experiment. Reiner and Harns, (1994) used the standard formulation of thermodynamic properties to present the fundamental equation of state for helmholtz free energy their results gave a good correlation with the annex 18 research group of IEA. The exergetic evaluation of the thermal performance was also carried out by Gang et al, (2012). In their experiment first and second laws of thermodynamic were employed for optimum determination of the work potential performance. Ma et al, (2010); Liang et al, (2011) and Dufie, (1980) used the energy balance to evaluate the thermal performance of an evacuated tube solar water heater.

The high rate of socio political development plays a lot on the need for an improved performance of solar water heater to meet up the domestic and industrials processes. Improving on solar water heater performance required mend operation process which takes into critical analyses of the performance parameters. In doing that, this study analyses the various thermodynamic property parameters using thermodynamic relation of Clausius Clapeyron analysis.

2. Material and Methods

Using Maxwell knowledge of thermodynamic relation the p-v- T surface for water in Solar water heater is analysed based on continuous and discontinuities that occurred during the process. Hence, according to Winterborne, (1997) the relationships apply over the major regions of the surface, but not across the boundaries is expressed for a continuous surface z = z(x, y).

$$dz = \left(\frac{dz}{dx}\right)_y dx + \left(\frac{dz}{dy}dy\right)_x \qquad 1$$

$$dz = Mdx + Ndy \qquad 2$$

Given: $M = \left(\frac{dz}{dx}\right)$, $N = \left(\frac{dz}{dy}\right)$

Following this particular relation as explained by Maxwell and Clausius Clapeyron thermodynamic relations for entropy, volume, pressure and temperature is express as follows;

$$\left(\frac{ds}{dv}\right)_T = \left(\frac{dp}{dT}\right)_v \qquad 3$$

Where; s = entropy; v = volume; p = pressure; T = Temperature

For a change of state in which a constant temperature and pressure is observed

$$\frac{ds}{dv} = \frac{s_2 - s_1}{v_2 - v_1} \qquad 4$$

Thus,

$$\frac{dp}{dT} = \frac{s_2 - s_1}{v_2 - v_1} \qquad 5$$

During phase changes therefore, the ratio of change of enthalpy, h, of a system to change in entropy is expressed as;

$$\frac{\partial h}{\partial s} = T \qquad 6$$

$$\therefore h_2 + h_1 = T(s_2 - s_1) \qquad 7$$

Substituting equation (5) to equation (7)

We have;

$$\frac{h_2 + h_1}{v_2 - v_1} = T\frac{dp}{dT} \qquad 8$$

Following the proposition of first law of thermodynamic, the energy efficiency was not ascertained unlike the second law which expresses the production of entropy in a system as the difference between the sum of stream entropy flows and entropy flows by heat transfer leaving the system and the sum of stream entropy flows and entropy flows by heat transfer entering the system.

$$\sum_{\text{out of system}} \left(\text{ns} + \frac{\text{Q}}{\text{T}_\text{s}}\right) - \sum_{\text{into system}} \left(\text{ns} + \frac{\text{Q}}{\text{T}_\text{s}}\right) = \Delta\text{S}_{\text{irr.}} \qquad 9$$

n =molar flow rates; Q =heat transfer T_s =System temperature; $\Delta S_{irr.}$ = entropy production in a system or irriversible entropy.

In addition to this its gives the analysis of available energy which is further expressed as;

For stream available functions the expression is as follows;

$$\text{b} = \text{h} - \text{T}_\text{o}\text{S} \qquad 10$$

b= stream available function

Therefore, lost work, LW, is expressed as;

$$\text{LW} = \text{T}_\text{o}\Delta\text{S}_{\text{irr.}} \qquad 11$$

The system efficiency according to second law is the ratio of minimum works of separation to equivalent actual work of separation and therefore expressed as;

Therefore knowing the inlet and outlet temperature of a system of solar water heater the nature of it phase behaviour could actually be predicted using the analogy of the pressure and density model presented by Aasa and Ajayi, (2012).

For the pressure model;

$$P(T) = 0.0001T^2 - 0.006T + 0.1738 \qquad 12$$

And the density model;

$$\rho(T,P) = 1.0118 - 0.0004T - 0.0177P \qquad 13$$

These models are going to be used in evaluating the various thermodynamic properties of the system.

3. Results

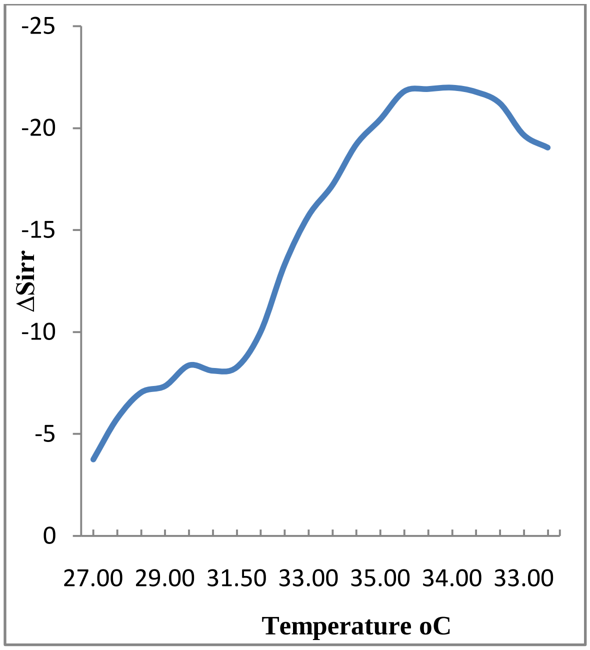

Fig. 1: Plot of Entropy minimization against Temperature variations

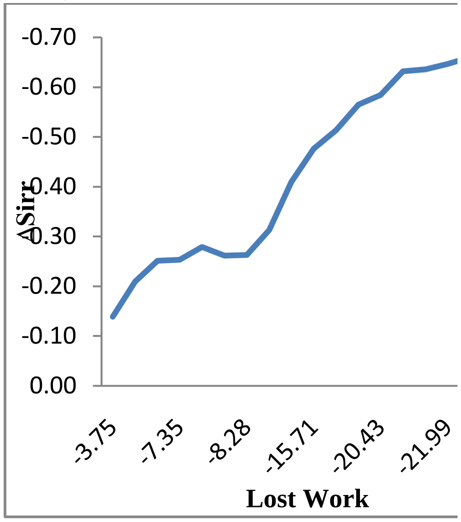

Fig.2: Plot of Entropy minimization against Lost Work

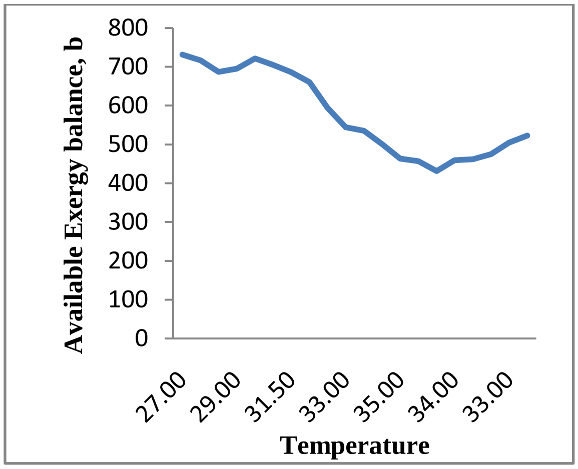

Fig. 3: Plot of Available Exergy balance against Temperature

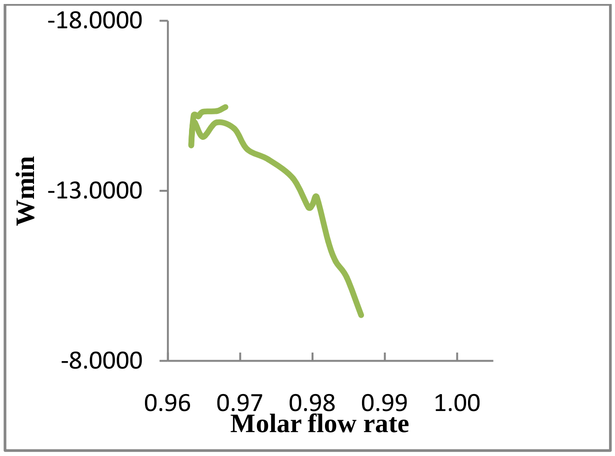

Fig. 4: Plot of Minimum work against Molar flow rate

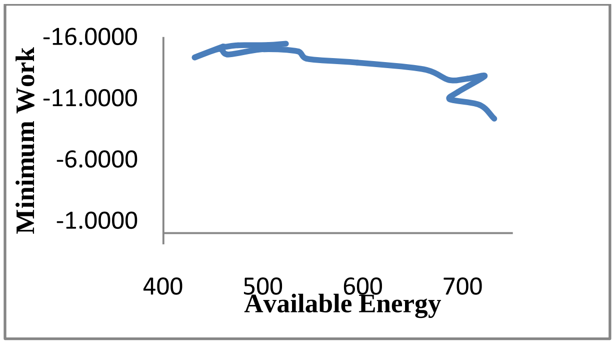

Fig. 5: Plot of Minimum against available Exergy

4. Discussions

Figures 1-5 present the plots of various analyses carried out for the system characterization of density model present by Aasa and Ajayi, (2012). Figure 1 analysis the change in the entropy irreversibility as temperature of the fluids is improved. The plot shows that the irreversibility decreases as the fluid flows absorbs heat energy, this is explained by the negative values display by the change in the irreversibility.

Plot 2 further strengthens the rate of change of the irreversibility and lost work, the graph shows that at maximum heat absorbs by the fluid in the system; the entropy generation and the lost work is minimum. This gives implication for optimum available energy (Exergy) of the system.

In addition to this, figure 3 analyses the available energy as system temperature of the system changes it was noticed that maximum energy was obtained at the top of the day when the highest heat absorption take place. Therefore considering the level of heat absorption and the exergetic nature of energy obtained it could be stated that the higher the heat radiation heat the higher the absorb heat and consequently the available energy.

Figure 4 explains the minimum work done and the amount of mass flow rate effects. A minimum work is done at maximum mass flow of the fluid; this implies low lost work at the optimum absorption because virtually all the heat is absorbed. The density which is responsible for the flow process occurs at its peak and a maximum flow rate at minimum work done is realised.

Finally, figure 5 explains work done in respects of the available energy. A maximum available energy of 731.4J was achieved at the least work done of 9.34J and a minimum available energy of 431.43J was achieved at a maximum work of 14.34J.

5. Conclusions

Thermodynamic relationships between properties have been developed which are independent of the particular fluid. This has been used to evaluate derived properties from primitive ones and to extend empirical data. Therefore an optimum available energy of 731.4J was achieved at the least work done of 9.34J and a minimum available energy of 431.43J was achieved at a maximum work of 14.34J. Also, at a optimum lost work of 14.34J a mass flow rate of corresponding density of 0.9633Kg/m^{3}s was obtained and at 10.45J lost work, 0.9833Kg/m^{3}s.

To sum it up, using the thermodynamics characterization relations of Clausius Clapeyron and basic experimental data of solar water heater (temperature) various performance evaluations have been accessed. Hence, analysis for optimum design operation can now be achieved by simply taking temperature, a domineering parameter, of solar water heater experiment and empirical data have been stretched.

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