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DETERMINATION OF ENERGY LOSSES AND EFFICIENCIES AT VARIOUS INVERSION TEMPERATURE POINTS IN A MULTIPLE LAYERED NON-CONVECTIVE POOL

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Abstract

This survey on the determination of energy losses and efficiencies at various inversion temperature points in a multiple layered non-convective pool was investigated in University of Cross River State, Calabar. In-situ temperature measurement data were generated using four experimental non-convective pools; D1, D2, D3, and Do enclosed in four separate absorbing layers (glazing collectors), having thickness of 0.5 cm. The model uses pools of drums of heights 83.0 cm, perforated at graduated distances, lagged with insulting material (Styropor) of thickness 2.5 cm and filled with water. The absorbing layers were placed from top into the drum depth at an interval distances of 10.0 cm to trap and transmit radiant flux from the sun, while increasing the thermal energy of the content. The daily hourly temperature data were recorded between 7.0 am and 5.0 pm for 24 weeks. The average data were plotted, points of inversion temperature determined, while the energy losses and efficiencies were calculated at inversion temperature points using relevant heat transfer equations. The results show that D1, D2, and D3 had energy losses and efficiencies of 0.000217J, 0.000167J and 0.0000869J and 0.00879%, 0.00676% and 0.00352%, respectively. The implication of this findings is that, thermal storage systems subjected to inversion temperatures cannot function maximally despite the decrease in energy losses, hence the efficiencies do not support optimal storage for non-convective pools with multiple glazing collectors.

Keywords: Energy losses, in-efficiency, Multiple absorbing layers, Temperature Inversion and Non-Convective pools, Thermal Storage System.

1.0 Introduction

There is no doubt that alternative and renewable energy research has produced enormous applications in solar, geothermal, thermosiphon, biomass, biogas, wind and photovoltaic and other areas. Solar and green energy find applications in broader passive and active systems (Bibin et al., 2023). The passive systems span from thermosiphons in terms of temperature control and heating effects, solar ponds technology and solar water heaters (Ho, et al., 2021). In all these applications, the use of glazing collectors or absorbing layers in solving energy problems has produced tremendous advantages which have a direct relationship with the amount solar radiation/ flux received by the glazing collectors and the energy harvested (Kamgba, et al., 2016).

Studies of inversion temperature points in multiple layered non-convective pools showed that, passive solar systems use buoyancy induced force in transferring energy from one point in the pool to another, which eliminate the need for force pumps to create the required force for energy propagation within the system (Mussa, 2024). The buoyancy induced force in a passive system is created by temperature gradient from one location to another. Generally, temperature gradient gives changes in temperature with vertical distance or height in a system. The gradient is either negative or positive if the temperature either increases or decreases with height, respectively (Bandarewa and Shrenet, 2024).

In liquids, energy transport which often leads to temperature gradient, a function of convectional process and buoyancy induced force which is likened to the transient migration and behavour of temperature variation within the atmospheric layer (Kamgba et al., 2016). In line with this phenomenon, a sudden fall in temperature, when there is a positive gradient, results in the loss of energy within that system given by the equation:

$$\frac{dT}{dX} = \frac{dT1}{dX2} - \frac{dT1}{dX1} \quad (1)$$

where dT_1 and dT_2 are changes in temperature and dx_1, dx_2 are changes in heights (Kamgba, et al., 2016).

Moreso, the energy loss at inversion temperature points is given by the equation,

$$Q = MCdT \quad (2)$$

$$Q = MCp(Tc-Ta) \quad (3)$$

Where Q is the energy evolved (J/kg.K)
M = Mas flow rate of the absorber plate(kg/s)
Cp = specific heat capacity at constant pressure (J/kg/K)
Tc = collector temperature (^oC)
Ta = Ambient temperature (^oC)
dT = chance in temperature between collector and ambient (Nama and Ban, 2021).

Furthermore, the efficiency of various glazing collectors can be estimated thus;

Efficiency

$$= \frac{\text{'}Q'\,Evolved\ Energy\ from\ absorber\ plate}{Solar\ Radiation\ x\ Absorber\ Plate\ used}\ x\ 100\% \quad (4)$$

$$E = \frac{Q}{IxA}\ x\ 100\% \quad (5)$$

$$E = \frac{MCp\Delta T}{I\ x\ A} \quad (6)$$

(Stanquest, 2020)

Where ŋ = Collector Efficiency (%)
I = Incident Solar Radiation (w/m^2)
A = Area of the Absorber Plate (m^2)
The storage level of any non-convective pool is a function of the amount of energy gained by the surface collector and subsequent distribution in the system (Bondarewa and Sherenet,2024). Note that liquids are stratified based on layers and the thermal energy within them which is a function of the transient temperature profile modified by the dynamics and geometric condition (Sunirant and Dan, 2021).

The loss of energy within the layers is brought about the reverse in convectional flow direction of the liquid and hence or otherwise, there is partial discharge of thermally stored energy given by (Engel and Reld, 2006) in the equation

$$\frac{dT}{dx} = 0 \quad (7)$$

Thus, equation (7) implies that, during this period of standby, there is no solar intake from the heat exchange loop or the overburdened loop of cooler fluid layer over warmer layer. This condition is called inversion temperature (Stanquet, 2020)

The inversion temperature results to great energy lost in the process, to ascertain the volume of energy lost across different inversion temperature points, a quick calculation is carried out with the mass, volume of water and the specific heat capacity (Chen and Xu, 2021).

However, the idea of the multiple glazing collector design is to increase the efficiency and the heating effect by reducing losses in the system, but the reverse is the case when the thermal energy is observed to decrease with increased number of glazing collectors (Kamgba, et al.,2016).

2.0 Material and methods

A four model non-convective pools were made up of four drums of diameter measuring 57.0 cm and height of 83.0 cm. Eleven mercury in-glass thermometers were inserted at perforated graduated heights and varied distances from the base of the drums toward the top, beginning from 7.0 cm to 63.0 cm. The procedure was followed by painting the inner surface of the drums with black oxide paint and lagging them with insulators (styropo) of thickness 2.50 cm and introduction of water up to 60.0 cm.

The glaze collectors (absorbing layers) of thickness 0.5 cm were introduced, with pool- 1, 2 and 3, each with its separate glazing, while pool -4 having no glazing for control purposes was filled with water, as well.

The glazing collectors in pool two and three were inserted at separation distances of 10.0 cm each. The research was conducted in an opened area to receive maximum insolation. The non-conductive pools were placed on insulating surfaces 6 inches above the ground level for avoidance of thermal interaction with re-radiation from the ground.

The values of temperature for eleven thermometers each inserted in pool 1 to 4 were monitored and recorded at an hourly interval between 7.0 am to 5.0 pm daily for weeks. Temperature data tabulated were plotted against heights and points of inversion determined for various non-convective pools as illustrated in fig 1-2. Also the values of the energy loss at inversion points were calculated using appropriate equations.

Fig. 1 : Experimental designs of four non-convective pools (Kamgba, et al.,2016)

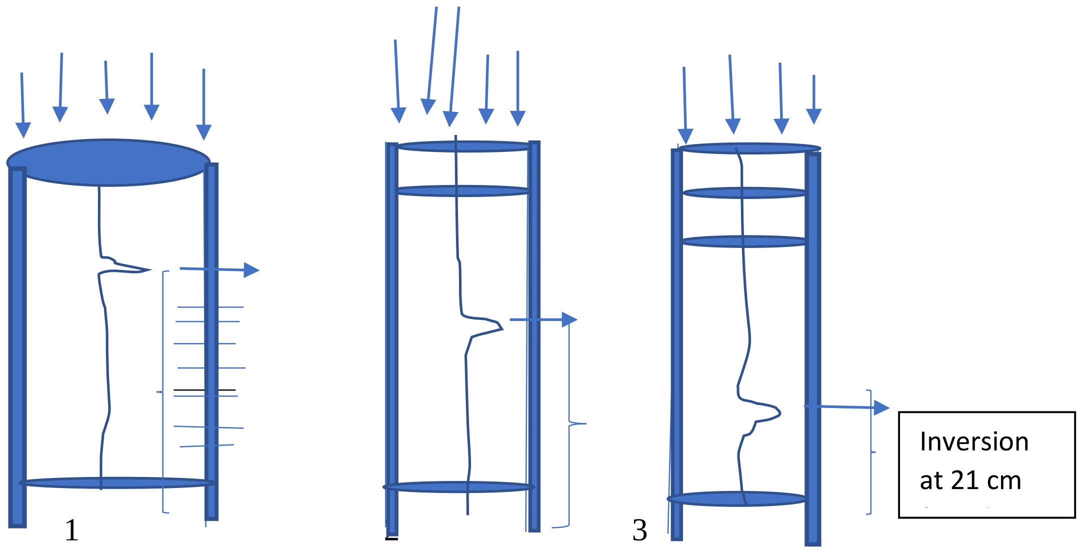

Fig. 2: Sketches of three non-convective pools with 1, 2 and 3 glazing collectors showing points of inversion temperatures at different heights from the base.

3.0 Results and discussion

The results of the study are presented in Table 1 and Fig.3

Table 1: Average Daily Temperature distribution with Height and Flux for two Weeks in four non-Convective Pools at 1pm .

T_a = 35.2 ^oC, Solar Flux = 432.4w/m^2

Height (cm)	D_1Temperature (^{o}C)	D_2Temperature (^{o}C)	D_3 Temperature (^{o}C)	D_0 Temperature (^{o}C)
7.0	30.1	29.9	29.4	29.0
14.0	30.1	31.0	30.0	27.5
21.0	31.2	29.5	21.0	27.0
28.0	31.1	32.6	31.0	26.8
35.0	29.0	20.9	31.2	27.0
42.0	30.9	32.0	32.0	28.0
45.0	32.0	31.0	33.0	28.9
49.0	22.0	33.0	33.5	29.3
52.0	34.0	33.1	33.9	31.0
56.0	36.9	36.8	36.0	31.3
63.0	48.5	45.0	40.4	33.0

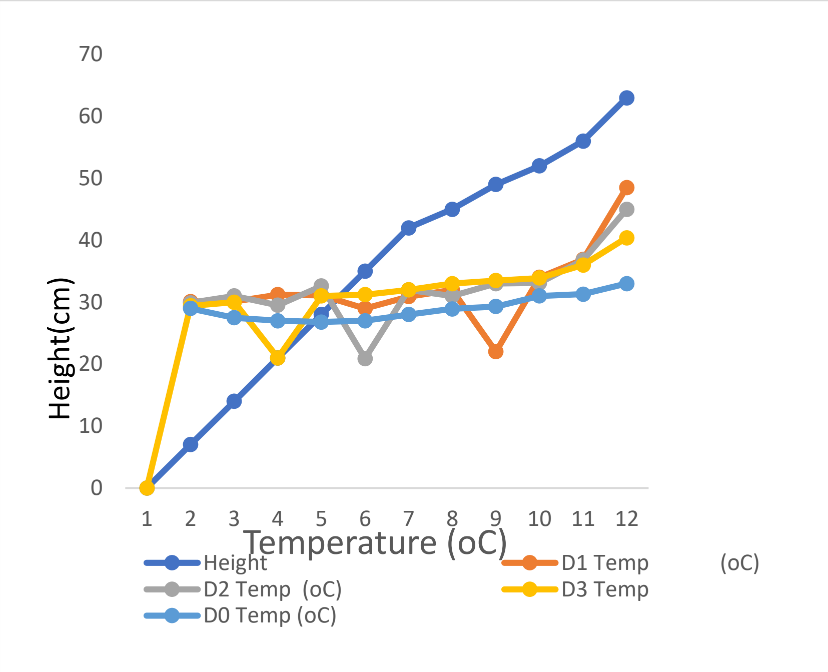

Fig. 3. A plot of temperatures against heights for four non-convective pools

The results of the study as presented on table 1 and plotted on fig. 2 show points of inversion temperature at different heights against different glazing collectors.

It is obvious that from the graphs that the temperature rises from 7.0 am and at 1.0 pm, there is a sharp fall exhibited by different non-convective pools at different heights from the base, which is in agreement with Kamgba et al., 2016. The sharp drop in temperature may be attributed to transient energy flow loss in the thermal system due to the behavour of the glazing collectors in line with Musa (2024). To determine the loss, and efficiency of the storage system, the following parameters were employed:

The average solar power as at 1 pm = 432.4 w/m^2
Specific heat capacity of the glazing collector = 0.84 J/jmK
Specific heat capacity of water = 4.18J/gmK
Effective Area of the absorber plate used 57.0 cm^2 converted to m^2 = 0.0057m^2
Approximate mass of effectiveness of absorber plate used for multiple glazing

W = 8.4,

Acceleration due to gravity, g = 10ms^2

$$W = M \times g \qquad (8)$$

$$M = \frac{W}{g} = \frac{8.6}{10}$$

M = 0.86kg

But mass flow rate,

$$\frac{mass}{rate} = \frac{0.86}{12x60x60} \qquad (9)$$

Mass flow rate = 1.99x10^{-5} kg/s (Chen and Xu, 2021)

Hence, to estimate the energy evolved by the Solar absorber for different glazing collectors one, two and three at varied distances of 10, 20 and 30 cm respectively, useful energy gained (energy evolved) for a solar thermal energy leaving the collector is usually described in terms of the rate of energy being added to a heat transfer field passing through the receiver or absorber plate (Ekechukwu and Northon, 1999).

Energy loss $Q = MC_p(T_c - T_{amb})$ J/kg.k (10)

For one- glazing,

$Q = 1.99x10^{-5}$ x 0.84 (48.2 – 35.2)
Q = 0.000217j
For two- glazing,
$Q = 1.99x10^{-5}$ x 0.84(45 – 35.2)
Q = 0.000167j
For three- glazing,
$Q = 1.99x10^{-5}$ x 0.84(40.4 – 35.2)
Q = 0.0000869j

We therefore estimate energy efficiency of glazing with separations of 10 cm, 20 cm and 30 cm respectively by using equation (4) above as follows:

$$Efficiency = \frac{{}^{\prime}Q^{\prime} Evolved\ Energy\ from\ absorber\ plate}{Solar\ Radiation\ x\ Absorber\ Plate\ used}\ x\ 100\% \quad (11)$$

For one glazing

$$Ŋ = \frac{Q}{IxA}\ x100\%$$

$$Ŋ = \frac{0.000217}{432.5\ x\ 0.0057} = 8.79 \times 10^{-5} \times 100\% \quad (12)$$

$$Ŋ = 8.79 \times 10^{-3}\%$$

For two glazings

$$Ŋ = \frac{0.000167}{432.5\ x\ 0.0057} = 6.76 \times 10^{-5} \times 100\% \quad (13)$$

$$Ŋ = 6.76 \times 10^{-3}\%$$

For three glazing

$$Ŋ = \frac{0.0000869}{432.5\ x\ 0.0057} = 3.518 \times 10^{-5} \times 100\% \quad (14)$$

$$Ŋ = 3.52 \times 10^{-3}\%$$

The values of energy losses as shown in equation (10) for one, two and three glazing collectors are: 0.000217j, 0.000167j and 0.0000869j respectively.

Moreso, the efficiencies of 1, 2 and 3 glazing collectors are as shown in equations: 12, 13 and 14 as: 0.00879%, 0.00676% and 0.00352% respectively. The result implies that the energy loss decreases as the number of glazing collectors increase, as well as the efficiencies of the glazing collectors. The results also show that the loss of energy in the non-convective pools is proportional to temperature gradient and the number of glazing collectors which is in line with Banjan et al.,1981. Hence, the greater the number of glazing collectors, the lesser their efficiencies and the more the energy losses in the system. The implication of this findings is that, thermal storage systems subjected to inversion temperatures cannot function maximally in energy conservation and use.

4.0 Conclusion

Result of the research on transient energy profile in a non-convective pool subjected to multiple glazing shows values of energy losses and efficiencies at different levels of temperature inversion. The losses varied with the number of glazing collectors as well as the temperature gradient, a clear view of the solar flux received and transmitted. There is significant variation in energy losses and glazing efficiencies as we move from glazing one to three and from 10 cm to 30 cm separations between the glazing collectors. The results show that energy losses and efficiency decrease with increased in the number of glazing collectors. The implication is that despite the minimal losses experienced, the efficiency of energy preservation in the thermal storage system is does not increase further.

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