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ENERGY AS AN IMPORTANT TOOL IN DISTILLATION PROCESS IN SOLAR STILL: A CASE STUDY WITH RESPECT TO WICK TILTED SOLAR STILL.

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Abstract

The amount of distillate water obtained from a solar still depend solely on the amount of solar radiation utilized in the vaporization of water over the latent heat of vaporization. As the energy is in the form of solar radiation or solar resource. So, without the energy the solar still can not be able to produce distillate water clean and potable to drink devoid of water borne diseases. Hence, all categories of solar still are depending on the solar energy. As the solar energy can rise the temperature of the water inside the solar still and also be able to produce evaporation and later condensation will occur. Thus, the distillate will then trickle down the trough and flow through a channel for collection from the system.

Keywords: Solar still, Solar energy temperature, heat transfer.

INTRODUCTION

Convectional techniques for making water pure can broadly be classified into thermal and membrane based categories [1] . In thermal distillation materials like salts are removed from water by evaporation – condensation processes. This techniques require a large input of energy and is not cost effective for low demands of clean water [2] . According to [3] , improvements in solar distillation technology makes it ideal for distillation of water in remote areas with water demands below 50m^2 per day. Nevertheless, the need to increase the productivity of solar stills at affordable cost especially in developing countries like Nigeria is highly necessary and welcome.

Solar energy is also term solar resource and also solar radiation which is also termed electromagnetic radiation (including infrared, visible and ultraviolet light) released by thermonuclear reactions in the core of the sun. Within a few exceptions (e.g. nuclear energy, geothermal energy), solar energy is the source of all energy used by mankind [4] . Indirect forms include hydroelectricity, ocean thermal, tidal energy, and wind energy: the sun powers the process of photosynthesis that is the original source of energy contained in biomass, peat, coal, and petroleum. Usually, the term solar energy refers to the portion of the Sun's radiant energy harnessed for a specific purpose by man –made devices.

Solar radiation reaches the earth's upper atmosphere at a rate of 1366w/m^2. While traveling through the atmosphere 6% of the incoming solar radiation reflected and 16% is absorbed resulting in peak irradiance at the equator of 1020 w/m^2 . Average atmospheric conditions (clouds, dusty, pollutants) further reduce insulation by 20% through reflection and 3% through absorption. Atmospheric conditions not only reduce the quality of insulation reaching the earth's surface but also affect the quality of insulation by diffusing incoming light and altering its spectrum.

Solar water device is a water cleaning system that cleans water without the use of chemicals, electricity, preventing water borne diseases, environmental consequences, deforestation and carbon dioxide emission . This solar water device can be term as solar still. The solar still can be divided into two categories: 1) Is that of the single-effect type and 2) Is that of the multi-effect type.

HEAT ENERGY TRANSFER

Heat energy transfer is the flow of energy from one point to another due to temperature differences between the points, and it can take place through conduction, convection and radiation. In a solar thermal system, heat energy is distributed from the absorber to other components of the system through one or a combination of these modes of heat transfer. Heat energy transmission in solar collectors may also lead to a loss of useful energy and a reduction in the system efficiency. Consequently, the design, construction and operation of heat exchangers require knowledge about heat transmission mechanisms.

CONDUCTION

Heat conduction is the rate of energy transfer between two points in a medium whereby kinetic energy is transferred between particles or groups of particles [5]. This mode of heat transfer can take place in gaseous, liquid and solid phases of a substance. In addition, heat is conducted in the direction of decreasing temperature. The temperatures in question may vary (transient) or remain constant (steady state) with time.

For transient heat conduction in three dimensions heat flow is based on the theory proposed by [6] and [7]:

$$\nabla^2 T + \frac{\dot{q}}{k} = \frac{1}{\alpha}\frac{dT}{dt} \qquad (1)$$

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Where ∇^2 is the Laplacian.
In Cartesian co-ordinates equation (1) becomes

$$\frac{d^2T}{dx^2}+\frac{d^2T}{dy^2}+\frac{d^2T}{dz^2}+\frac{\dot{q}}{k}=\frac{1}{\alpha}\frac{dT}{dt} \quad (2)$$

Equation (1) can also be expressed in cylindrical or spherical co-ordinates, depending on the geometry of the conductor. It is possible to solve this equation analytically to obtain an accurate spatial distribution of temperature at a given time. Nevertheless, some mathematical models involve systems, of differential equations which can not be solved analytically. In such cases, numerical methods can be used to obtain an approximate solution, but this research all what it takes is to provide the basis of physics theoretically involved. In one dimension equation (2) reduces to:

$$\frac{d^2T}{dx^2}+\frac{\dot{q}}{k}=\frac{1}{\alpha}\frac{dT}{dt} \quad (3)$$

The heat flux in three dimensions can be given by:

$$\dot{q}=-k\nabla T \quad (4)$$

Where ∇T is the temperature gradient (a vector quantity)
In one dimension, heat flux ($\dot{q}$) can be calculated from:

$$q=-k\frac{dT}{dx} \quad (5)$$

It is noted from equation (5) that the rate of heat transfer increases with the coefficient of heat conduction (k) and temperature gradient. Thus, materials with relatively high values of k (such as copper, aluminium, stainless steel and galvanized steel) are suitable for the fabrication of solar absorber plates while those with low values of k (such as plywood, polystyrene, sawdust and cork) are appropriate for insulation to reduce heat loss from a given system to the environment. In addition, k varies with the direction of heat flow and temperature of the conductor [7] . The rate of heat flow (Q) across the slab without heat source can be given by [5]:

$$Q=KA\frac{\Delta T}{x} \quad (6)$$

$$\Delta T=T_1-T_2 \quad (7)$$

Where $T_1 > T_2$

CONVECTION

Heat convection is the rate of energy transfer between two points in a fluid which involves mixing of the fluid by natural of forced mechanisms. In natural convection, the fluid moves due to the density gradient arising from temperature differences. Forced convection occurs when a moving fluid absorbs heat and transport it away by means of an external pump such as Fan. At the fluid-solid boundary, heat is transferred by means of conduction. Heat may be transferred from a hot solid surface to a cold fluid of from a hot fluid to a cold surface. The rate of heat transfer by natural convection can be given by [8]:

$$Q=h_c(T_2-T_1) \quad (8)$$

Where $h_c=\frac{N_u k}{s}, N_u=b(G_rP_r)^d, and\ b\ and\ d\ are\ dimensionless\ parameters.$

It should be noted that the Nusselt number (N_u) is a ratio of convective (h_c) to conductive (k/s) heat transfer coefficients within a fluid. This parameter is dimensionless and it can be calculated from the product of the Grashof (G_r) and Prandth (P_r) numbers. The former parameter is a ratio of buoyancy to viscous force in a fluid while the latter is a ratio of kinetic viscosity (v) to thermal diffusivity ($\acute{\alpha}$). Both of these parameters are also dimensionless and they can be given by [9],[5]:

$$P_r={}^{v}/_{\acute{\alpha}} \quad (9)$$

$$G_r=\frac{gS^3\beta'\varphi^3(\Delta T)}{\mu^2} \quad (10)$$

Equations (9) and (10) show that the product (G_rP_r) is influenced by fluid properties, the difference between the surface and fluid temperatures, and the geometry of the surface in contact with the fluid. Consequently, the coefficient of convective heat transfer is also affected by the same factors.

Natural convection can be divided into three regions: a) turbulent natural convection (d=1/3) , b) Laminar natural convection (d=1/4) and c) a region with $d < 1/4$. When a fluid flows under forced convection, a boundary layer is created between the fluid and the surface (say s flat surface) in contact with the fluid. Flow within the boundary layer close to the leading edge of the surface is laminar forced convection. As flow continues along the surface, there is a rise in the thickness of the boundary layer to a critical level. Therefore, turbulent forced convection sets in. So, forced convection can be laminar or turbulent. At a very low fluid velocity, flow remains laminar in long tubes or channels with small hydraulic diameter and it is said to be fully developed laminar flow developed laminar flow. At a high fluid velocity or in a tube with large diameter, transition to turbulent flow takes place and flow is fully developed turbulent. These flow regions are employed in the computation of the coefficient of convective heat transfer (h_c) , and [] and [] provide a summary of models used for this computation. For instance, h_c for natural convection can be given by :

$$h_c=b\frac{k}{S}\left(\frac{S^3\varphi^2\beta'g\Delta T}{\mu^2}\right)^d\left(\frac{\mu c_\rho}{k}\right)^d \quad (11)$$

Where S=height, length, diameter and 0.5 x diameter for vertical plates or pipes, horizontal plates, horizontal pipes and spheres respectively.

For forced convection, h_c can be calculated from:

$$h_c=b\frac{k}{S}\left(\frac{Sm'}{\mu}\right)^e\left(\frac{\mu c_\rho}{k}\right)^d \quad (12)$$

It is noted from equation (11) that the coefficient of natural convection is independent of the characteristic length (S) when d=1/3. For forced convection, h_c is independent of the geometry of a cavity when the exponent e=1 in equation (12).

RADIATION:

Here can be divided into two :

a) Optical View Factor

An optical view factor influences the exchange of radiation between two given surfaces and it depends on the geometries of the surfaces in question. For isothermal and diffuse surfaces, the view factor (w_{i-j}) is defined as the proportion of energy leaving surface (i) that is incident on the surface (j) , [11]. Moreover, the energy leaving surface (i) may reach other surfaces surrounding it. So, using the law of conservation of energy, this yield:

$$w_{i-1} + w_{i-2} + w_{i-3} + \cdots \ldots . + w_{i-j} = 1 \quad (13)$$

$where\ (2), (3), (4), \ldots . (j)$ are surfaces that surround surface (i).If a surface views itself, then $w_{i-j} > 0$.

In addition, the following relationships are also useful for calculation of radiation exchange amongst surfaces [10]:

$$w_{1-(2,3)} = w_{1-2} + w_{1-3} \quad (14)$$

$$w_{(2,3)-1} = (A_2 w_{2-1} + A_3 w_{3-1})(A_2 + A_3) \quad (15)$$

$$A_1 w_{1-2} = A_2 w_{2-1} \quad (16)$$

It should be noted that surface (1) views a combination of surfaces (2) and (3) in equation(14) while surfaces (2) and (3) jointly view surface (1) in equation (15),equation(16) expresses the reciprocity of view factors, which is particularly necessary for computation of radiation exchange between surfaces with finite and infinite areas. This equation is required in the calculation of radiation exchange between a solar collector (with finite area) and the sky (with infinite area).

b) Radiation Heat Transfer

Heat radiation is the transfer of thermal energy through electromagnetic waves [12];[7]. This mode of heat transfer does not require a medium for propagation, unlike heat conduction and convection.

Consequently, the use of a vacuum to reduce heat loss only eliminates convective and conductive heat losses. In fact, the presence of a medium between a radiator and receiver provides impedance to radiation heat transfer. The amount of energy emitted by a radiator depends on the nature of the material microscopic structure and temperature of the radiator and its surroundings. A blackbody, for instance, absorbs all the radiation incident on it. Its emissive power to a hemispherical region above it is given by [13],[10],[14]:

$$\dot{E_{bb}} = \lambda \sigma T^4 \quad (17)$$

$$\dot{E_{bb\lambda}} = \frac{c_1 \lambda^{-5}}{e^{c2/(\lambda T)} - 1} \quad (18)$$

Where $c_1 = 3.742x10^{-16} wm^2$, $c_2 = 0.014388mk$ are respectively the first and second Planck's constants.

A real surface absorbs part of the radiant energy which it receives. So, its emissive power to a hemispherical surface above it is given by:

$$E = \varepsilon \sigma (\dot{T_i^4} - T_j^4) \quad (19)$$

$$E_\lambda = \dot{\varepsilon_\lambda} \dot{E_{bb\lambda}} \quad (20)$$

$$\varepsilon = \frac{1}{\sigma T^4} \int_0^\infty \varepsilon_\lambda \dot{E_{bb\lambda}}\, d\lambda \quad (21)$$

If ε_λ is independent of λ, then $\varepsilon = \varepsilon_\lambda$and a surface with such a characteristic is known as gray body. In practical calculations, surfaces are usually assumed to be gray because of the unavailability of information about the relationship between $\varepsilon_\lambda$and λ. It should also be mentioned that the energy from a non-black surface comprises the radiant and reflected components and this energy leave the surface specularly or diffusely. The reflected radiation follows one direction from a specular reflector but it goes in different directions from a diffuse reflector.

If solar irradiance on surface (i) G_{gp} , then the amount of solar power reflected diffusely from surface (i) can be given by [15]:

$$G_{i-j} = w_{i-j} \rho_i G_{gp} \quad (22)$$

Equation (22) shows that the amount of solar radiation reflected to a receiver is influenced by both the reflectance and view factor of the surfaces. To calculate the amount of radiation energy transferred between two surface, the following assumptions are often made [5]: a)surfaces are gray or black b)radiation and reflection are diffuse c) $\alpha = \varepsilon\ and\ \alpha$ does not depend on the temperature of the source of the incident radiation and d) surfaces are separated by a non- absorbing medium. For two given surfaces, the net radiation heat transfer can be given by [16]:

$$Q = \frac{\sigma(T_i - T_j)}{\frac{1-\varepsilon_j}{A_i \varepsilon_i} + \frac{1-\varepsilon_j}{A_j \varepsilon_j} + \frac{1}{A_i w_{i-j}}} \quad (23)$$

The net radiation heat transfer between two surfaces can also be expressed in a linear form by defining a coefficient of radiation heat transfer:

$$Q = A_i h_{r,i-j} (A_i - A_j) \quad (24)$$

$$h_{r,i-j} = \frac{\sigma(T_i^2 + T_j^2)(T_i + T_j)}{\frac{1-\varepsilon_i}{\varepsilon_i} + \frac{A_i(1-\varepsilon_j)}{A_j \varepsilon_j} + \frac{1}{w_{i,j}}} \quad (25)$$

If the two surfaces are rectangular and parallel to each other, then $w_{i-j} \approx 1\ and A_i = A_j$. Consequently, equation (25) reduces to:

$$h_{r,i-j} = \sigma \varepsilon_{i,j} (T_i^2 + T_j^2)(T_i + T_j) \quad (26)$$

$$\varepsilon_{i,j} = \frac{1}{\varepsilon_i} + \frac{1}{\varepsilon_j} - 1 \quad (27)$$

FIGURE 1: Above show the wick tilted solar still

EXPERIMENTAL RESULTS:

EFFICIENCY OF A WICK TILTED SINGLE SLOPE SOLAR STILL

T_{amb} C^0	T_{cover} C^0	T_{abs} C^0	Wind speed m/s	Humidity %	Energy utilized in the vaporization of water in the wet wick , Q_e	Amount of incident solar energy on the still , Q_t	Time Hours	Efficiency $\eta=Q_e/Q_t$ %
33	58	73	2.5	33	0.774	1.096	1.42	70
43	49	64	2.5	19	1.940	2.56	1.32	75
43	54	73	4.7	28	2.912	3.648	1.25	79.8
42	46	74	3.0	53	2.800	3.2	1.14	87
34	55	73	2.5	38	1.552	2.208	1.42	70.28
28	46	67	5.7	59	1.504	2.016	1.34	74.6
38	57	73	2.8	33	1.548	2.182	1.41	70.94
39	49	67	4.2	25	5.92	7.68	1.29	77.08
31	59	75	2.6	30	12.648	14.592	1.15	86.6
32	52	70	3	31	12.00	16.00	1.15	75
41	45	73	2.7	52	11.312	13.248	1.17	85.38
33	56	71	2.5	33	11.528	14.112	1.22	81.68
34	55	72	2.5	38	12.032	16.128	1.34	74.60
42	45	73	2.9	52	13.536	19.636	1.45	68.93
42	47	73	3.0	53	2.822	3.288	1.17	85.83
41	44	72	2.6	51	6.192	8.726	1.41	70.96
43	45	73	2.5	53	21.68	30.72	1.42	70.57
39	48	67	4.2	25	4.512	6.048	1.32	74.60
43	46	73	2.6	53	44.112	56.448	1.28	78.15
31	58	74	2.5	30	5.824	7.296	1.25	79.8
33	53	71	3.0	32	6.00	8.00	1.33	75.00
41	44	72	2.6	51	5.656	6.624	1.17	85.38
32	55	70	2.4	37	5.764	7.056	1.22	81.68
33	54	71	2.5	38	7.016	8.064	1.15	87.00
41	44	72	2.8	51	8.268	9.818	1.19	84.20
41	46	73	3.0	52	1.411	1.644	1.17	85.82
40	43	71	2.5	50	3.096	4.363	1.41	70.96
40	44	72	2.5	52	12.84	15.36	1.20	83.59
38	47	66	4.1	24	2.756	3.124	1.13	88.22
42	45	72	2.5	52	25.056	28.224	1.13	88.77
32	57	72	2.5	33	1.546	2.192	1.42	70.529
43	48	64	2.5	19	3.88	5.12	1.32	75.78
42	55	73	5	29	5.824	7.298	1.25	79.80
43	47	74	3	53	5.6	6.4	1.14	87.50
35	56	75	2.5	39	4.656	6.624	1.42	70.28
28	47	68	2.5	39	3.008	4.032	1.34	74.60
39	58	74	2.9	34	4.644	6.546	1.41	70.94
38	48	67	4.2	25	11.84	15.36	1.30	77.08
31	59	76	2.6	30	25.296	29.184	1.15	86.67
30	50	69	3	31	6.00	7.00	1.17	85.70
40	45	73	2.7	52	5.656	6.724	1.19	85.39

33	56	72	2.5	33	8.528	11.112	1.30	76.75
32	55	70	2.5	38	10.032	14.126	1.41	71.017
41	44	72	2.8	51	14.536	19.636	1.35	74.022
42	47	73	3	53	5.644	6.576	1.17	85.82
40	44	71	2.6	52	7.192	8.726	1.21	82.24
43	45	73	2.5	53	19.68	28.72	1.46	68.52
38	47	66	4.2	25	9.024	12.098	1.34	74.59
43	46	73	2.6	53	22.056	28.224	1.28	78.146
31	58	74	2.5	30	11.646	14.592	1.25	79.81
33	53	71	3	32	12.00	16.00	1.33	75.00
41	44	72	2.6	51	11.312	13.248	1.17	85.39
32	55	70	2.4	37	11.528	14.112	1.22	81.39
33	54	71	2.5	38	14.032	16.128	1.15	87.00
41	44	72	2.8	51	6.266	7.818	1.25	80.15
42	46	73	3	52	4.233	4.932	1.17	85.58
40	43	72	2.5	50	6.192	8.728	1.41	70.94
40	44	71	2.5	52	11.84	13.36	1.18	88.62
38	46	66	4.1	24	5.512	6.248	1.13	88.22
42	45	73	2.5	52	12.526	14.112	1.13	88.76
33	58	73	2.5	33	3.096	4.384	1.42	70.62
43	49	64	2.5	19	9.7	12.6	1.30	76.98
43	54	73	4.7	28	14.56	18.24	1.25	79.82
42	46	74	3	53	14.00	16.00	1.14	87.5
34	55	73	2.5	38	7.76	11.04	1.42	70.28
28	46	67	5.7	59	7.52	10.08	1.34	74.60
38	57	73	2.8	33	7.74	10.90	1.41	71.00
39	49	67	4.2	25	29.6	38.4	1.30	77.08
31	59	75	2.6	30	6.324	7.296	1.15	86.67
32	52	70	3	31	6.00	8.00	1.33	75.00
41	45	73	2.7	52	9.312	11.248	1.21	82.79
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42	47	73	3	53	3.822	4.288	1.12	89.13
41	44	72	2.6	51	7.192	9.726	1.35	73.95
43	45	73	2.5	53	16.68	25.72	1.54	64.90
39	49	67	4.2	25	9.024	12.098	1.34	64.90
42	45	73	2.6	53	22.056	28.224	1.28	78.15
30	57	74	2.5	30	11.648	14.592	1.25	79.82
34	54	72	3	33	12.00	16.00	1.33	75.00
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28	48	68	2.5	39	2.008	3.032	1.51	66.23
38	57	74	2.9	34	3.644	5.546	1.52	65.70
38	48	68	4.2	25	12.84	16.36	1.27	78.48
32	60	77	2.6	30	12.648	14.592	1.15	86.68
30	49	70	3	31	4.656	5.724	1.22	81.34
40	46	74	2.7	52	6.657	7.725	1.16	86.18
32	57	73	2.5	33	7.528	10.112	1.34	74.45
33	55	71	2.5	38	9.032	13.126	1.45	68.81
41	45	72	2.8	52	12.536	17.636	1.41	71.08
42	47	73	3	53	6.644	7.576	1.14	87.70
40	45	72	2.6	52	6.192	7.726	1.25	80.14
43	46	73	2.5	53	9.84	14.36	1.46	68.52
37	48	67	4.2	25	10.024	13.098	1.31	76.53
44	47	74	2.6	53	11.056	14.112	1.28	78.35
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41	45	72	3	52	3.233	3.932	1.22	82.22
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40	44	71	2.5	52	10.84	12.36	1.14	87.70
39	47	67	4.1	24	6.512	7.2488	1.11	89.85
41	44	72	2.5	52	11.526	13.112	1.14	87.90
32	55	70	2.4	36	11.528	14.112	1.22	81.69
31	52	71	2.5	38	13.032	14.128	1.08	92.24
41	44	72	2.7	50	6.266	7.818	1.25	80.15
40	44	71	3	51	2.233	2.932	1.31	76.16
40	43	72	2.5	50	6.192	8.723	1.41	70.94

Average efficiency, $\eta = \frac{Q_e}{Q_t} = 79.174\%$, Approximate efficiency, η= 79%

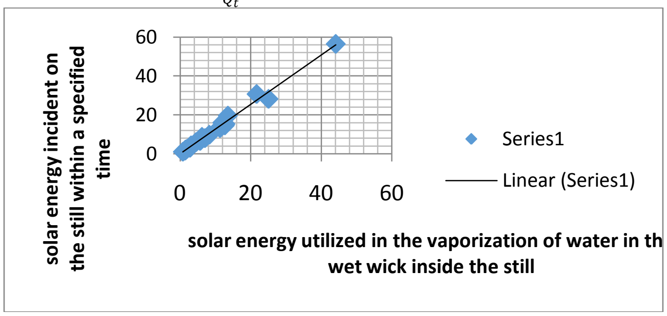

FIGURE: A graph of solar energy utilized in the vaporization of water in the wet wick against the solar energy been incident on the still within a specified time

CONCLUSION

I was able to concluded that the energy is the major tool in the separation of clean water from the dissolved solid matter or contaminants and without the energy the solar still of any type can not function without the energy with respect to the wick tilted solar still and the efficiency obtained was 79%.In addition, in my research above it has shown that the importance of energy in the processing of separation of clean water from dissolved solid matter or contaminants is unavoidable.

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