Calculation of efficiency tubular solar collectors

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Abstract. One of the basic characteristics of a solar power plant, as well as any power installation, is efficiency which can be calculated by known techniques or it is defined experimentally, on a parity it is useful for made thermal energy and total intensity of sunlight. Settlement and experimental daily efficiency have satisfactory convergence within 7 % that testifies to reliability of settlement formulas. It speaks the successful constructive decision, application of mirror reflectors and cellular structure of a transparent covering that confirms an initial hypothesis.

[Kunelbayev M.M., Dauletkulova A.U., Zhamyhanov B.T., Hanzharova B.S., Kokazhaeva A.B. **Calculation of efficiency tubular solar collectors.** *Life Sci J* 2014;11(12s):471-473] (ISSN:1097-8135). http://www.lifesciencesite.com.101

Keywords: efficiency, tubular solar collector, total intensity of sunlight, warmly productivity of a solar power plant

Introduction

The source of thermal energy required by most distillation processes can range from 70-120°C which can ideally be produced by evacuated tube collectors which can easily achieve this range and have the added advantage of a high performance. With the recent advances in vacuum technology, evacuated tube collectors can be reliably mass produced. Their high temperature effectiveness is essential to the proper operation of distillation systems. In the first years of the twentieth century it was recognized that the creation of vacuum between the absorber and the cover of a solar collector would result in a substantial improvement in collector efficiency due to reduction in heat loss through convection and conduction. In 1909 [1], proposed several evacuated-tube concepts for solar energy collection, two of which are still sold commercially today. Using a selective absorbing surface in evacuated collectors would also reduce substantially the radioactive losses and improve the overall efficiency of the collector. For a survey of evacuated collectors, see Graham (1979). Tubular collectors, with their inherently high compressive strength and resistance to implosion, afford the only practical means for completely eliminating convection and conduction losses by surrounding the receiver with a vacuum on the order of 10^{-4} mm Hg [2,3]. The performance of evacuated tube collectors may be improved by introducing a small level of concentration - 1.5 to 2.0 - by forming a mirror from part of the internal concave surface of a glass tube. This reflector can focus radiation on an absorber plate inside the tube. External concentrators of radiation may also be coupled to an evacuated collector for improvement of performance over the simple evacuated tube.

Since the convection is related to the Rayleigh number [3,4],which is proportional to the square of the absolute pressure, modest reduction in pressure (e.g. to 0.1 atm) effectively eliminates convection. Gas conduction, on the other hand, is independent of pressure and Fourier Law applies. As the pressure is reduced into the free molecular flow region (i.e. $<10^{-4}$ Torr), gas conduction becomes insignificant. Evacuated collectors are generally produced with an initial pressure of 10^{-4}-10^{-3} Torr by a combination of evacuated bake-out and gettering. Because glasses, particularly borosilicate glasses, are not impermeable to gas molecules in the air, helium in the air was reported to build up inside evacuated glass tubes over a long period of time. And since helium is an excellent conductor compared to the heavier gasses, the heat loss may increase substantially above its initial level.

Thermal analysis of most evacuated tube collectors can be carried out under steady state condition using the well known Hottel-Whiller-Bliss equation [5,6]. Following the analysis of [5,6] the useful energy gain of most flat plate collectors can be expressed by the equation

$$Qu = AcFR\,[S - UL\,(Ti - Ta\,)] \qquad (1)$$

Methodology

One of the main characteristics of the solar heating system, as well as any power plant is the efficiency which can be calculated by known methods or determined experimentally, as the ratio of useful heat energy produced and total solar radiation. However, the formula for calculating efficiency requires verification, because developed manifold includes new design elements.

The average for each hour of collector efficiency can be determined from the expression [7]:

$$\eta = \frac{Q_n}{E \cdot S_\kappa}, \qquad (2)$$

where:

E - flux density of solar radiation on the surface of the collector; Qp - hourly value of useful energy; $S_к$ - collector area;

Bandwidth efficiency is not equal to the daily average value of efficiency and is defined as:

$$\eta_{cym} = \frac{\sum Q_n}{S_\kappa \cdot E} \qquad (3)$$

where

Qp - full of useful energy obtained in the reservoir for the night;

According to the heat balance equation for steady-state conditions [8], the amount of useful energy obtained from solar collectors is defined as the difference between the amount of incident solar energy and the amount of energy is lost to the environment:

$$Q_{\text{ï}} = S_{\text{ê}} \cdot \left[\text{Å} \cdot (\tau\alpha)_{\text{â}} - U_L \cdot (\text{Ò}_2 - \text{Ò}_1)\right], \quad (4)$$

where

$S_к$ - absorber area (absorbing surface);

E - total flux density of solar radiation in the plane of the collector;

T_1 - ambient; T_2 - average temperature of the absorbent panel collector. In practice, to calculate Qp Wheeler equation is used.

$$Q_{\text{ï}} = F_R \cdot S_{\text{ê}} \cdot \left[\text{Å} \cdot (\tau\alpha)_{\text{â}} - U_L \cdot (\text{Ò}_3 - \text{Ò}_1)\right] \quad (5)$$

where F_R - heat removal rate equal to

$$F_R = \frac{G_\kappa \cdot C_p}{S_\kappa \cdot U_L} \cdot \left[1 - \exp\left(-\frac{U_L \cdot F \cdot S}{G_\kappa \cdot C_p}\right)\right]. \quad (6)$$

The initial data for the calculation of heat loss through the Mylar cover (LP) for a specific collector are the following:

d_1,м	d_2,м	d_3,м	d_4, м	T_1,°C	T_4,°C	λ_1 W/(m·grad)	λ_2 W/(m·grad)	λ_3 W/(m·grad)	α_1 W/(m·grad)	α_2 W/(m·grad)
0,036	0,05	0,080	0,080	28	53	0,22	0,260	0,185	297	25,7

Calculation of heat losses for the tube collector shall make simplistic as pipe insulation multilayer screen according to the formula:

$$U_L = \frac{t_4 - t_1}{\frac{1}{\pi \cdot d_1 \cdot \alpha_1} + \frac{1}{2{,}273 \cdot \lambda_1}\lg\frac{d_2}{d_1} + \frac{1}{2{,}273 \cdot \lambda_2}\lg\frac{d_3}{d_2} + \frac{1}{2{,}273 \cdot \lambda_3}\lg\frac{d_4}{d_3} + \frac{1}{\pi \cdot d_4}} \qquad (7)$$

Substituting the appropriate values in the collector this formula to calculate and determine that U_L = 4,9 W/m^2. hour. Initial data for calculation of efficiency is:

U_L W/m²·grad	W,м	d_2, м	α_2 W/m²·grad	$(\tau\alpha)_e$	$S_к$ м²	G kg/s
4,9	0,1	0,04	300	0,89	1,68	0,018

Theoretical analysis

To calculate the efficiency, it is necessary to determine the coefficients FR, for tubular solar collector recommended by well-known equations [9,10].

$$F' = 1/[1+(U_L/h)] = 0{,}98. \qquad (8)$$

$$F_R = \frac{G \cdot C}{U_L} \cdot \left(1 - \exp\left(\frac{U_L \cdot F'}{G \cdot C_p}\right)\right) = 0{,}806. \quad (9)$$

Hour shift energy consumption of the water tank in the experiment is given by:

$$Q_б = c(m_в \Delta T_в + m_c \Delta T_c + m_н \Delta T_н), \quad (10)$$

where c - specific heat of water is equal to 4.19 kJ / (kg·°C);

m_u, m_m, m_l - mass of water, respectively upper, middle and lower zone of the tank, which is equal to 51 kg;

ΔT_w, ΔT_c, ΔT_L -hour water temperature difference in the respective zones of the accumulator tank.

At a flow rate $G = v \cdot \frac{\pi d^2}{4}$ = 0,00128 kg / s calculation results performance solar heat and power solar collector are presented in accordance with Figure 1.

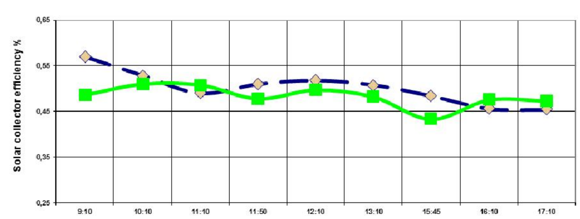

Figure 1. Dependence of calculation hour efficiency of a heliocollector from heating time

Methods

Theoretical calculation of the average daily efficiency of TC shows that:

$$\eta_{теор.} = \frac{6655}{7579 \cdot 1{,}68} = 0{,}49\,. \qquad (11)$$

The average efficiency from the experimental data in accordance with Figure 2 is:

$$\eta_{экс.} = \frac{\sum Q_n}{S_{тк} \cdot E_{экс.}} = \frac{6266}{1{,}68 \cdot 7579} = 0{,}47\,. \quad (12)$$

Conclusions

Calculated and experimental daily efficiency are satisfactory convergence [3] within 7%, indicating that the reliability of the calculation formulas. This is explained by the best design solution, using mirror reflectors and honeycomb transparent coating, which confirms the initial hypothesis.

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7/29/2014