Thermal Analysis of a Flat-Plate Solar Collectors in Parallel and Series Connections

Huseyin Gunerhan

Department of Mechanical Engineering, Faculty of Engineering

Ege University, 35100 Bornova, Izmir, Turkey

huseyin.gunerhan@ege.edu.tr

Abstract

In this study, thermal analysis for solar collectors in series and parallel connection was conducted, taking into consideration a model for flat-plate solar collectors with fluid. A model of thermal analysis made up of dimensionless numbers was set up and by the help of computer software, generally accepted graphics for the dimensionless temperature, dimensionless solar radiation, coefficient of thermal efficiency were obtained. Making use of these graphics, numbers of collectors can be determined for the desired values of flow rate and temperature.

Keywords - energy; flat-plate solar collectors; thermal analysis

1. Introduction

Flat-plate solar collectors with fluid, one of the applications of solar energy, are cheaper than other systems because they do not need complex technologies. In general, they are made up of one or two permeable covers, pipes connected to an absorbing surface, insulating material, and a protective cover [1, 2].

Numbers of collectors are determined according to the desired output temperature of the fluid in series connections, and desired flow rate of fluid for parallel connections. Heating and cooling, and hot water requirements of houses, heating of green houses, heating of swimming pools, hot water requirements of industry can be met by using series-parallel connected flat-plate solar collectors with fluid in series-parallel connection (Figure 1). In Turkey, Aegean, Central, Mediterranean, and South Eastern Anatolia regions are appropriate for solar energy applications due to their high solar energy potentials, and 40% of the industry is established in these regions. Main sectors of industry such as food, textile and chemistry, and others such as cellulose, paper, wood, and soil are among developed branches of industry in Turkey. Approximately 65% or the energy consumed in industry is in the form of processed heat, and about 35% of this is obtained by using hot water below the temperature of 300°C. Hot water up to 120°C can be produced by solar collectors, and this hot water can meet all or some part of hot water requirements of housing and industry.

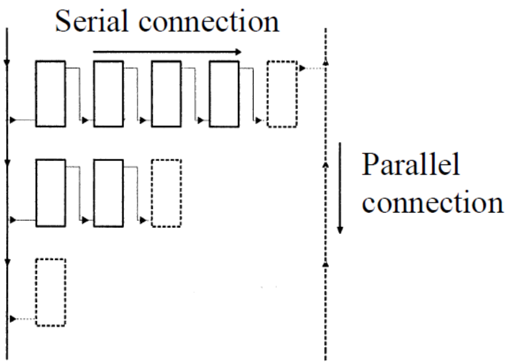

Fig. 1 Solar collector in serial-parallel connection

2. Thermal Analysis

In the light of the following assumptions analysis were conducted taking into consideration the fin theory. For a model of flat-plate solar collector with fluid, the element collecting the solar energy and transferring it to the water to be heated consists of pipes connected to the absorbing surface. Here absorbing surface-pipe coupling gives the theory nearest to the fin theory [2, 3, 4].

Assumptions:

- For the heat transfer calculations, steady state is taken into consideration
- Absorbing surface is in the form of flat flat-plate and pipes connected to the surface are located parallel to each other, and the water introduced from the bottom is collected from the top
- Solar radiation coming onto the glass cover is uniform and in steady state
- Environmental conditions are the same for all parts of the collector
- Temperature changes around the pipes are taken into consideration; circulation in the pipes is uniform
- Heat loss due to permeable covers and insulation is one-dimensional
- Sky is black body
- For fixed length of collector, the heat at the middle line of the absorbing surface between the two pipes is at the maximum level according to the heat at the other lines, and half of the flat-plate is accepted as a fin of which the point is heated.

Useful heat gain to be obtained from the collectors, Q_u is given by equation (1) [3].

$$Q_u = A_c [S - U_L (T_i - T_a)] \quad (1)$$

Mean temperature of fluid T_{fm} is given by equation (2), mean surface temperature of absorbing surface T_{pm} is given by equation (3) and temperature of outgoing fluid T_{fo} is given by equation (4) [3].

$$T_{fm} = T_i + Q_u (1 - F_2) / (A_c U_L F_R) \quad (2)$$
$$T_{pm} = T_i + Q_u (1 - F_R) / (A_c U_L F_R) \quad (3)$$
$$T_{fo} = (T_i - T_a - S / U_L) \exp[-A_c U_L F_1 / (\dot{m} c_p)] + T_a + S / U_L \quad (4)$$

The equalities given in equations (1, 2, 3, 4) are the dimensional ones that provide base for thermal analysis.

3. Calculations of Dimensionless Solar Radiation, Dimensionless Temperature and Thermal Efficiency Coefficient

To be able to conduct general thermal analysis for liquid solar flat-plate collectors with fluid, there appeared need for dimensionless numbers and incidence of solar radiation on absorbing surface and input and output temperatures of the fluid were brought into dimensionless state. Thus equalities with general acceptance were obtained.

In order to achieve the changes of coefficients of dimensionless solar radiation, dimensionless efficiency of thermal and temperature coefficients to stay between 0 and 1, numbers of maximum dimension were needed. Maximum extraterrestrial solar radiation was accepted to be 1400 W/m², with ±3% tolerance of error, and maximum solar radiation that might incident on the absorbing surface S_{max}, were defined in equation (5), and maximum temperature of out coming water from collector T_{om}, was defined in equation (6). Using these already defined equations, dimensionless solar radiation S′, was given in equation (8), dimensionless temperature θ, in equation (9). Coefficient of thermal efficiency η was given in equation (10) [3, 5]. Dimensionless numbers given in equations (8, 9, 10) change between 0 and 1.

$$S_{max} = 1400 \text{ W/m}^2 \quad (5)$$
$$T_{om} = 120°C \quad (6)$$
$$S = G_t \, 1{,}02 \, \tau \, \alpha \quad (7)$$
$$S' = S / S_{max} \quad (8)$$
$$\theta = (T_{fo} - T_i) / (T_{om} - T_i) \quad (9)$$
$$\eta = \dot{m} c_p \Delta T / (G_t A_c) \quad (10)$$

Basic data given in equations (1, 2, 3, 4, 5, 6, 7, 8, 9, 10) and in Table 1 were evaluated in computer software and graphics composing of dimensionless numbers were obtained. Dimensionless temperature, dimensionless solar radiation and change in collector numbers are given in Figure 2. Dimensionless solar radiation changes between 0.0 and 0.9, dimensionless temperature, on the other hand, changes in percentage between 0 and 100. Coefficient of mean of thermal efficiency varying in percentage, dimensionless solar radiation and controlling of number of collectors are given in Figure 3.

Table 1. Basic Data for Computer Simulation Program

Angle of inclination of the collector = 35°
Coefficient of heat transfer for absorbing surface = 300 W/(mK)
Number of pipes = 11 pcs
Flow rate of the fluid in series line = 0.04 kg/s
Velocity of wind = 2.5 m/s
Exterior diameter of pipe = 0.0172 m
Interior diameter of pipe = 0.0148 m
Thickness of the absorbing surface = 0.0015 m
Gross length of the collector = 1.9330 m
Gross width of the collector = 0.9410 m

Investigation of Figures (2, 3) suggests that as dimensionless temperature value increases in constant value of dimensionless solar radiation, number of collectors to be used in series line increases, in constant temperature value, on the other hand, as the value of dimensionless solar radiation increases, number of collectors decreases. And as the number of collectors increases, coefficient of mean thermal efficiency decreases.

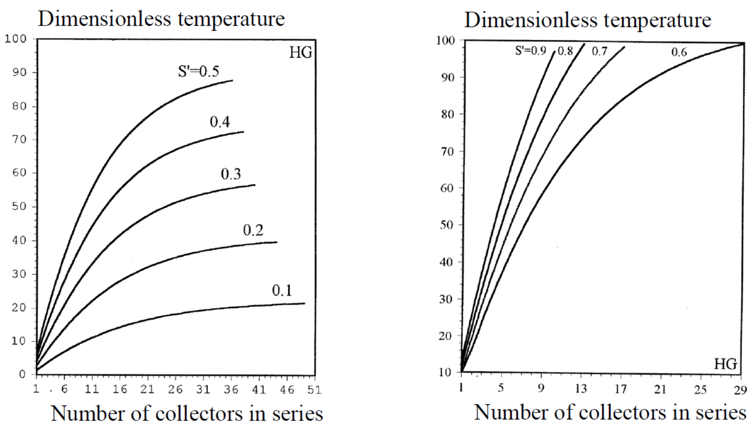

Fig. 2 Change in dimensionless temperature-number of collectors

4. Conclusions

Using Figure 2 and taking into consideration the degrees of dimensionless solar radiation, one can determine the number of collectors at the line for the desired fluid temperature, and the number of collectors at the parallel line for the desired flow rate. In this study, flow rate passing through a collector was taken as 0.04 kg/s. As it is seen in Figure 3, as the number of collectors increases, coefficient of mean thermal efficiency decreases. Using Figure 2 and 3, and considering the necessary economic evaluations, user can make the most appropriate design.

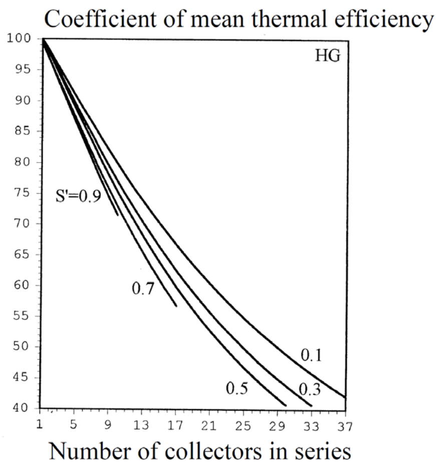

Fig. 3 Change in coefficient of mean thermal efficiency-number of collectors

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Nomenclature

A_c Collector Area [m²]

F_R Collector Heat Removal Factor [-]

F_1 Fin Efficiency Factor [-]

F_2 Collector Flow Factor [-]

G_t Solar Radiation [W/m²]

Q_u Useful Heat Gain [W]
S Absorbed Solar Radiation [W/m²]
S' Dimensionless Solar Radiation [-]
S_{max} Maximum Solar Radiation [W/m²]
T_a Ambient Temperature [°C]
T_{fm} Mean Temperature of Fluid [°C]
T_{fo} Temperature of Outgoing Fluid [°C]
T_i Inlet Temperature [°C]
T_{om} Maximum Temperature of Fluid [°C]
T_{pm} Mean Absorber Plate Temperature [°C]
U_L Collector Overall Heat Loss Coefficient [W/m²K]
c_p Specific Heat [J/kgK]
$\dot{m}$ Flow Rate [kg/s]
α Solar Absorptivity [-]
η Coefficient of Thermal Efficiency [-]
θ Dimensionless Temperature [-]
τ Solar Transmissivity [-]