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ABSTRACT

Flat-plate solar collectors have potential applications in HVAC system, industrial thermal process, and solar engineering. Flat-plate collectors are the most economical and popular in solar domestic heating water system since they are permanently fixed in positions, have simple construction, and require little maintenance. The design of a solar energy system is generally concerned with obtaining maximum efficiency at minimum cost. The aim of this thesis is to develop a design tool for predicting the performance of a flat-plate solar collector.

A very detailed thermal analysis of a flat-plate solar collector was carried out to predict the thermal performance. The analysis is based on the established theory about flat-plate solar collector: the radiation absorption, heat loss from the collector, and temperature distribution on the plate. The calculation of useful energy and top heat loss from the collector is based on the aperture area to make a more accurate prediction of collector performance. The net-radiation method was employed to obtain the radiation component of top heat loss from the general collector cover system. The correlation for natural convection heat transfer between the covers and between the plate and cover was selected with the consideration of the low conductivity of plastics. The semi-gray radiation model was adopted to determine the optical properties of the collector cover and absorber plate.

Results comparing the design tool calculations with experiments showed good agreement. The collector tests were performed by Florida Solar Energy Center. The

calculations based on the information from test reports yielded an accurate prediction of the thermal performance of flat-plate solar collectors.

Based on the analysis, a flat-plate solar collector design program (CoDePro) has been developed. The program is arranged so that detailed information about the collector can be specified with an easy-to-use graphic interface. Compiled versions of CoDePro have been distributed to solar engineers from its development level, and it has been modified according to their suggestions. CoDePro has an ability to evaluate the collector performance with high accuracy and can be used as a design tool for flat-plate solar collectors.

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NOMENCLATURE

A_c	Gross collector area
A_e	Edge area of collector
A_p	Aperture area
b_0	Incidence angle modifier coefficienct
C_b	Tube-plate bond conductance
C_p	Specific heat of working fluid
D	Outer diameter of tube
D_i	Inner diameter of tube
F	Fin efficiency of straight insulated-fins with rectangular cross section
f	Darcy friction factor
F_R	Collector heat removal factor
F'	Collector efficiency factor
F''	Collector flow factor
G_T	Total intensity of incident solar radiation on tilted collector surface.
h_{fi}	Forced convection heat transfer coefficient inside of tubes
h_w	Wind convection coefficient
I	Intensity of incident radiation
K	Minor loss coefficient
K_{ta}	Incidence angle modifier
k	Thermal conductivity
k_b	Thermal conductivity of back insulation
k_e	Thermal conductivity of edge insulation
L	Characteristic length
L_b	Thickness of back insulation
L_e	Thickness of edge insulation
L_{eq}	Equivalent length

m	Parameter of the fin-air arrangement
$\dot{m}$	Total collector mass flow rate
n	Number of tubes
n_1	Refractive index of medium 1
n_2	Refractive index of medium 2
Nu	Nusselt number
P	Pressure
Pr	Prandtl number
Q	Heat transfer rate
q	radiation flux
Q_c	Heat transfer rate due to convection
Q_r	Heat transfer rate due to radiation
Q_b	Back heat loss from collector
Q_e	Edge heat loss from collector
Q_u	Useful gain from collector
Q_{loss}	Overall heat loss from collector
Q_t	Top heat loss from collector
r	Reflection of radiation
R_b	Geometric factor
Ra	Rayleigh number
Re	Reynolds number
S	Absorbed radiation per unit area of absorber plate
S_c	Absorbed radiation per unit area based on the gross collector area
T	Temperature
t	hour from midnight
T_a	Ambient temperature
T_b	Fin base temperature
T_f	Local fluid temperature
T_{fm}	Mean fluid temperature

T_{dp}	Dew point temperature
T_i	Fluid temperature at collector inlet
T_o	Fluid temperature at collector exit
T_{pm}	Mean plate temperature
T_s	Sky temperature
U	Mean fluid velocity inside of tubes
U_L	Overall loss coefficient of the collector based on the gross collector area
U'_L	Overall loss coefficient of the collector based on the aperture area
V	Wind speed
W	Distance between the centers of adjacent tubes

GREEK

a	Absorptance
b	Collector slope
b_v	Volumetric coefficient of expansion of air
D	Difference
d	Thickness of absorber plate
e	Emittance
h	Instantaneous efficiency of solar collector
n	Kinematic viscosity
q	Angle of incidence of solar radiation
q_1	Angle of incidence
q_2	Angle of refraction
$q_{d,e}$	equivalent angle of incidence for diffuse radiation
$q_{g,e}$	equivalent angle of incidence for ground-reflected radiation
r	Reflectance

r_f	Density of working fluid
s	Stefan-Boltzmann constant
t	Transmittance
t_a	Transmittance of material due to absorption of radiation
$(t a)$	Transmittance-absorptance product

Subscript

b	Beam radiation
c	Cover
$c1$	Cover 1 (inner cover)
$c2$	Cover 2 (outer cover)
d	Diffuse radiation
g	Ground-reflected radiation
i	Incidence radiation
n	Normal incidence
p	Absorber plate
r	Reflected radiation
$\perp$	Perpendicular component of radiation
$\parallel$	Parallel component of radiation