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Influence of Obstacles with Wing Delta Shape on Flat-Plate Air Solar Collector Efficiency

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Abstract: We present results of our investigation on flat-plate air solar collector equipped with chicanes wing delta shape fixed on non-selective absorber. The absorber was composed of aluminum plate covered with copper. The transparent cover of collector was realized in polycarbonate. This inexpensive device permitted the optimization of collector efficiency by the wing delta chicanes disposed in strips of 10, 13 and 26. Inclination angles used were 10, 20, 30 and 140°. Collector efficiency increased with increasing of slants of chicanes and also with increasing number of the strips. The best efficiency about 81% was obtained with 26 strips at slant 140°.

Key words: Flat-plate air solar collector, non-selective absorber, wing delta obstacle, slant, strips, collector efficiency

INTRODUCTION

The numerous flat-plate air solar collectors fabricated and studied showed that the different shapes of the absorber and materials used in its design influenced the efficiency of these collectors. Different techniques using absorber have been used like an absorber with double pass made of retraining aluminium barrel (Alvarez *et al*., 2004), an absorber in wire braid shape with stitches indicated by M4b (Mittal and Varshney, 2006).

Out-flow of the fluid inside flat-plate air solar collectors also showed that obstacles placed in mobile air stream have influence on its efficiency (Gbaha *et al*., 2007; Suleyman, 2007; Yousef-Ali, 2005; Gbaha, 1989; Flechon *et al*., 1984).

The present research reports collector efficiency with wing delta shape fixed on absorber. Collector efficiency was studied as function of chicanes inclination angles and also as function of the number of strip of these chicanes. The collector used is working in air drawing setting (Furbo and Jivan Shah, 2003).

MATERIALS AND METHODS

The testing bench is made of a collector positioned before a Vortex fan in an open loop. A vertical alcohol manometer and a propeller fitted with anemometer permitted measurements of losses of charges within the collector and the flow of air drawn to be taken.

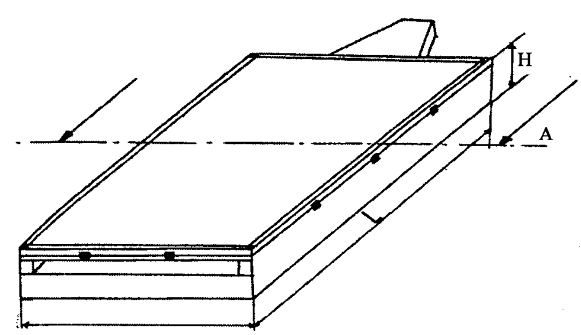

Fig. 1: Flat-plate air solar collector

The different air solar collectors designed were rectangular with a shape ratio of two. The frames were made of wood with an aluminium support and a transparent cover (Fig. 1, 2) (Gbaha *et al*., 2007).

In this device, the absorber was non-selective. It was composed of aluminium plate covered with copper and had a rough surface. This plate in dull black paint offered surface of 1.28 m^2. Transparent cover was realized in polycarbonate. Chicanes were obstacles cut up in aluminium sheets with thickness varying between 0.1 and 0.3 mm. Obstacles with wing delta shape were fixed either on absorber or on hardboard plate.

A hardboard plate covered with reflective aluminium sheet was placed on internal side of the rear insulator for the reduction of losses on the rear of the collector.

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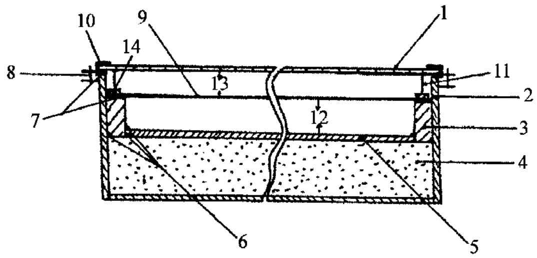

Fig. 2: A-A cross section of flat-plate air solar collector

1 : Transparent cover;
2 : Box (wood or metal);
3 : Wood (compressed);
4 : Insulator (polystyrene);
5 : Hardboard plate (chicane support);
6 : Mastic flow for airtightness;
7 : Rubber joints;
8 : Frog-type hook;
9 : Absorber (metal plate or copersun sheet);
10 : Frame, transparent aluminium support cover;
11 : Adjustable screw for airtightness between the absorber and its support;
12 : Thickness of mobile air stream;
13 : Thickness of fix air layer;
14 : Absorber frame.

Chicanes strips with wing delta shape of apex $\beta = 60°$ and rope of 4 cm (Fig. 3-5) were arranged on internal face of the absorber. These wings were inclined at angles varying from 10° to 140° in the air out-flow direction within the collector.

From the works of Deroyon *et al.* (1973) and Minair (1987), obstacles with wing delta shape whose angles are not privileged were arranged with the aim of creating favourable whirlwinds for heat exchanging between fluid and absorber. The wings delta of apex $\beta = 60°$ and rope of 40 mm were used.

Temperatures of entrance, exit and point of measurement of the air mass flow were measured with thermocouples (couple thermo resistant: iron/constantin) disposed at these places.

A Philips brand recorder with twelve ways recorded different registered values. Instantaneous global lighting was obtained through a pyranometer Kipp and Zonen type, fitted with an integrator of the same brand.

For a given sunshine (generally by clear sky) and for a period where global irradiance is quasi constant (variation of more or less 2% of the nominal value), all these parameters were carried out simultaneously.

The useful energy gain of a flat-plate air solar collector is given by the following relation (Duffie and Beckman, 1991):

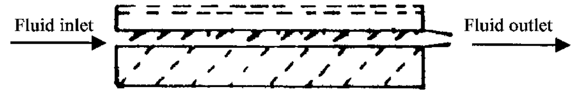

Fig. 3: Out-flow of air attacking the tip of the wings delta

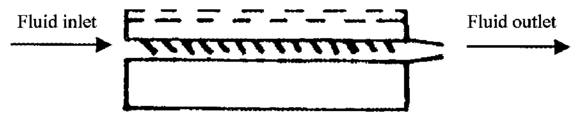

Fig. 4: Out-flow of air attacking the basis of the wings delta

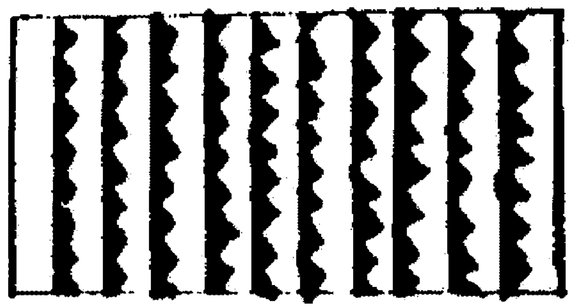

Fig. 5: Disposition of strips of wings delta chicanes

$$Qu = AF'[(\tau\alpha)G - U_L(T_f - T_a)] \quad (1)$$

$$T_f = \frac{T_o + T_i}{2}$$

The efficiency is expressed as:

$$\eta = F'[(\tau\alpha) - U_L \frac{T_f - T_a}{G}] \quad (2)$$

with

$$U_L = U_b + U_t \quad (3)$$

and

$$F' = [1 + \frac{U_L}{h_1 + [(1/h_2) + (1/h_r)]^{-1}}] \quad (4)$$

$$h_r = \sigma \frac{(T_1^2 + T_2^2)(T_1 + T_2)}{1/\varepsilon_1 + 1/\varepsilon_2 - 1} \quad (5)$$

The different measurements permitted the calculation of collector efficiency thereafter by using the relation of Gard and Hrishikesan (1988):

$$\eta = \frac{\dot{m} C_p}{A} B \qquad (6)$$

$$B = \frac{T_o - T_i}{G} \qquad (7)$$

Where, B represents temperature gap brought back to the received incident solar flux by the collector per unit of surface.

Measurements were made on several collectors manufactured in the same way and presenting the same features with the same conditions of experimentation.

Chicanes with wing delta shape of apex $\beta = 60°$ and rope of 40 mm, were disposed in strips of 10 and tilted respectively at 10°, 20°, 30° and 140°. The choice of these inclinations was guided by the visualization of out-flow of the smoke in contact with these obstacles.

RESULTS AND DISCUSSION

Fluid flow: The utilization of wings delta as chicanes in flat-plate solar air collector is only justified for inclinations because they can introduce burstings of whirlwinds. The out-flow organized with incidence angle of 10° exploded itself when inclination reached 20° then real torchlights of whirlwinds appeared beyond 20° of inclination.

A detachment of the tablecloth was seen on the wing and then whirlwinds were created and occupied the entire wing. When the wings delta inclination reached 140°, the return of the smoke on the horizontal plan playing the absorber role was observed.

Thus, we noted that for slants higher than 20°, whirlwinds went higher. It could favour heat exchange.

Efficiency results: The obtained results came from profiles where obstacles with wing delta shape were fixed on absorber in order to make small wings.

Figure 6 shows efficiency curves of collector as function of B for chicanes with wing delta shape placed in strips of 10.

We observed that for wings delta tilted to 10°, collector efficiency was higher than the ones without chicanes; however this efficiency remained lower than those corresponding to the elevated slants. It could be due to the fact that for this slant out-flow fluid was organized with weak nets of fluid, thus reducing exchanging surface between fluid and small wing joint of the collector.

Table 1 indicates variation of collector efficiency with chicanes inclination angles for the temperature gap brought back to the received incident solar flux by the collector per unit of surface of 40 K (kW)β^1 m^2.

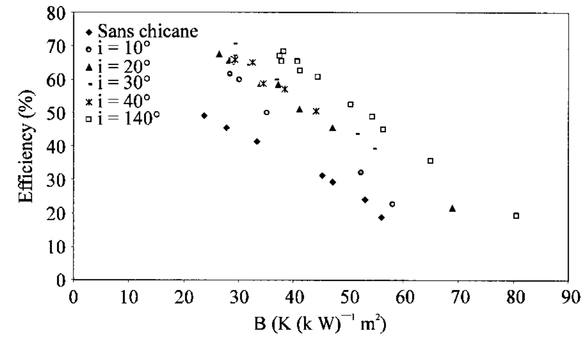

Fig. 6: Collector efficiency as function of B at different chicanes inclination angles

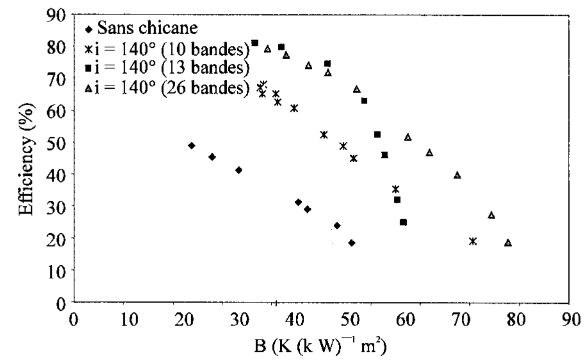

Fig. 7: Collector efficiency as function of number of strips

Table 1: Efficiency values at different inclination angles

Inclination (°)	10	20	30	40	140
Efficiency (%)	48	52	56	55	63

Collector efficiency increased with increasing of slants at respectively 63% and 140° (Table 1). The lower value of efficiency (48%) was given for i = 10°. For slants 30° and 40°, efficiencies were practically identical. The most favourable profile corresponds to collector equipped with chicanes tilted to 140°.

Influence of strips on efficiency has been studied by measurements made with collectors provided with chicanes of 13 and 26 strips.

Figure 7 gives collector efficiency as function of B at different strips for slant at 140°.

We observed that for profiles of obstacles containing 13 and 26 strips, collector efficiency was about 80% for usual B (40 K $(kW)^{-1}$ m^2). At high mass flow of fluid, causing weak temperature gaps, efficiency of 13 and 26 strips remained practically the same and moved toward optical efficiency. On average and at low mass flow, out-flow of fluid through these obstacles did not show significant improvement of efficiency for 13 strips. However, the one of 26 strips was distinctly higher than all efficiencies obtained. This improvement could be due to the return of fluid on the absorber, the dead zone reduction with step of 57 mm corresponding to 26 strips of chicanes and to the effect of small wing.

The return of fluid toward the absorber seems to be relatively lower for 13 strips. The number of wings delta was only 234 for these 13 strips and therefore it was observed that there was a reduction of small wing effect in comparison with one of the 26 strips containing 468 wings delta.

As the transparent cover of the device was in polycarbonate, the global transmission coefficient was 86%. The absorber being in dull black paint, its absorption coefficient was 95%. From these values, optical efficiency was calculated to be 81.7% whereas the measured optical efficiency was 81% for the studied collectors.

Efficiency improvement of 26 strips profile, moving toward optical efficiency at high mass flow could be explain by conjugated effects of air out-flow through wings delta, presence of whirlwinds in mobile air stream and utilization of aluminium sheet covering hardboard plate side of the rear insulator. For the same gap of usual temperature (40 K $(kW)^{-1}$ m^2), the best efficiencies cited in the literature were 45% (Abdullah *et al.*, 2003), 65% (Mittal and Varshney, 2006), 72% (Alvarez *et al.*, 2004). Azharul and Hawlader (2006) using a V-groove absorber registered efficiency of 70% for the same gap of temperature. Previous studies using transversal chicanes obtained efficiency of about 68% for the same value of B (Gbaha *et al.*, 2007).

Figure 7 shows that some curves of efficiency as function of B were non linear as expected. For the values of B lower than 30 K $(kW)^{-1}$ m^2, the curves reached asymptote representing optical efficiency of the collector. This result was in agreement with the one reported by Benz and Beikircher (1999) using selective surfaces and steam water as fluid.

Curves efficiency for 13 and 26 strips of wings delta (Fig. 7), can be described by the following equation from the manual TRNSYS 16 (Klein and Beckman, 2005):

$$\eta = F'\left[\eta_0 - U_{L1}\frac{(T_o - T_i)}{G} - U_{L2}\frac{(T_o - T_i)^2}{G}\right]$$

Parameters U_{L1} and U_{L2} of the above equation will be assessed in further research.

CONCLUSIONS

Flat-plate air solar collectors equipped with obstacles with wing delta shape showed that the optimization of efficiency could be obtained by judicious disposition of chicanes. The device permitted to reach higher efficiency than those obtained without chicanes. Collector efficiency increased with increasing of slants of chicanes. The best efficiency was obtained at slant 140°. Efficiency also increased with increasing number of the strips. Thus, efficiency improvement was obtained with 26 strips. Collector efficiency measured was about 81%. This performance obtained by inexpensive device was seen to be sometimes higher than those obtained with costly processes.

NOMENCLATURE

A = Area of absorber plate surface (m^2)
C_p = Specific heat of air (J kg^{-1} K^{-1})
F' = Efficiency factor of solar collector
G = Global irradiance incident on solar air heater collector (W m^{-2})
h_1 = Convection heat transfer coefficient between the absorber plate wall and the fluid (W m^{-2} K)
h_2 = Convection heat transfer coefficient between the back channel and the fluid (W m^{-2} K)
h_r = Radiation heat transfer coefficient (W m^{-2} K)
Q_u = Useful energy gain of solar collector (W)
T_1 = Absorber plate mean temperature (K)
T_2 = Mean temperature of the back channel (K)
T_a = Ambient temperature (K)
T_f = Fluid mean temperature (K)
Ti = Inlet fluid temperature (K)
To = Outlet fluid temperature (K)
U_L = Global heat loss coefficient (W m^{-2} K)
U_{L1} = First order global heat loss coefficient (W m^{-2} K)
U_{L2} = Second order global heat loss coefficient (W m^{-2} K^{-2})
U_b = Heat loss coefficient from the bottom of the duct to the ambient air (W m^{-2} K)
U_t = Heat loss coefficient from the absorber plate to the ambient air (W m^{-2} K)

Greek symbols

α = Absorber plate absorption coefficient
ε_1 = Emissivity of the inner wall of the absorber plate
ε_2 = Emissivity of the back plate wall
η = Collector efficiency (%)
σ = Constant of Stefan-Boltzmann
τ = Transparent cover transmittance

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