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The Effects of Tempered Glass with Low Iron Oxide (Fe_2O_3) Content on the Efficiency of Solar Air Heater

Yusuf Bilgiç[1], Cengiz Yıldız[2]
[1]*Ph.D Research Assistant, Department of Mechanical Engineering, Fırat University, 23119, Elazig, Turkey*
[2]*Professor, Department of Mechanical Engineering, Fırat University, 23119, Elazig, Turkey*

Abstract:- In this study, the effect of glass cover on the energy and exergy efficiencies of conventional type solar air heater was investigated experimentally. Classic and tempered low iron glass were used as a glass cover. Two of collectors whose dimensions are 900x1900x170mm^3 were used in the experiments. The experiments were conducted at the air flow rates of 0.02, 0.03, 0.04 and 0.05 kg/s. Energy and exergy efficiencies were evaluated regarding to experimental results. As a result of the experiments, it was found that energy efficiency of the collector equipped with tempered glass with low iron oxide content increases by an amount of 4.5%-5.3%. In case of exergy efficiency, an increase was also observed between 0.4 and 0.82 percent.

Keywords:- Solar energy, Solar air heater, Tempered Glass

I. INTRODUCTION

Solar air heaters consist of four parts: transparent cover, absorber surface, and insulation and collector case. The fundamental function of the transparent cover is to prevent heat loss via convection. In addition, it also prevents the collector from harmful external conditions. Various transparent materials are used for the transparent cover. Glass is the most common among these different materials. The ratio of sunlight that can pass through glass is %80-90. Whereas the remaining %10-20 is reflected back. The reason for reflection is the amount of iron oxide (Fe_2O_3) in the glass. Hence, a low iron oxide amount is desired in glass. Another property that is desired in glass is resistance against external factors and thermal stress. Hence, tempering process is applied to glass in order to increase its strength [1].

Kurtbaş and Durmuş [2] have carried out the energy and exergy analyses of a solar air heater. They have used four different types of collectors in their study. They have worked with two different flow rates of 0.028 kg/sec and 0.012 kg/sec. Maximum efficiency was determined for traditional type collector as %16. Whereas maximum efficiency for Type-3 was determined as %67.

Esen [3] has experimentally examined the energy and exergy analyses of 4 types of double flow collectors. Type-1 of these collectors has been used without any obstruction whereas different types of obstructions have been used in the other 3.

Uçar and İnallı [4] have carried out the energy and exergy analyses of 5 types of collectors in their study. They have determined that the highest irreversibility ratio was that of the conventional type collector with 0.236 kW and that the exergy loss was %64.38. Whereas they have also determined that the lowest exergy loss was %43.91 for the collector with a 2^o inclined absorber surface.

Akpınar and Koçyiğit [5] have carried out the exergy and thermal analyses of four different collector types. They have manufactured 3 collectors by placing the fins differently. Whereas the fourth collector was a conventional type collector. They have determined the 1st Law efficiency in Type-II in this study as %82 maximum and the 2nd Law efficiency as %44 maximum.

Gill et.al. [6], have examined a low cost solar air heater experimentally and they have also carried out a cost analysis. They have used three types of collectors with double glass, single glass and one filled with iron shavings. They have observed that the efficiencies of single glass, double glass and bed type collectors in winter season with an air flow rate of 0.02 m^3/s vary as %30.29, %45.05 and %71.68.

Alta et.al. [7] have carried out the experimental thermal analyses for double glass finless collector (Type-I), double glass and finned (Type-II) and finned (Type-III) collectors. They have determined that the efficiencies of Type-II and Type-III to be greater than that of Type-I; the highest irreversibility ratio was determined in Type-I, whereas the lowest irreversibility ratio was determined in Type-II.

Löf and French [8] have examined the strength of solar collectors with tempered glass covers against hail. Hey have stated that the largest area in the studied region covered 540 m2 with panels for which 700 tempered glass covers have been used. They have observed that only 7 of panels were broken after the hail and that 2 of the 54 panels with untempered glass have been broken.

The effect of glass cover on efficiency has been examined in this study. Energy and exergy efficiencies of the collectors have been calculated according to the acquired results.

II. EXPERIMENTAL SET UP

The solar air heaters used have dimensions of 900x1900x170 mm. The bottom and side sections have been insulated with 50 mm thick glass wool. The interior of the collector has been painted matte black. A 4 mm classic window glass has been used in one of the collectors as glass cover, whereas 4 mm tempered glass with low iron oxide content (TGLIO) has been used in the other. The iron oxide content of the used TGLIO is less than %0.02.

Whereas in normal glass (NG) this ratio is about %10. Fig.1 shows the schematic diagram of the solar air heater with TGLIO that was used in the experiments.

A 1800 rev/min radial fan with 0.75 kW power that has a maximum air flow rate of 1.8 kg/s has been used to provide air movement in the collectors. ABB brand ACS-150 model 0.75 kW inverter has been used to control the fan speed. The measurement devices used in the experimental setup and their properties have been given in Table I.

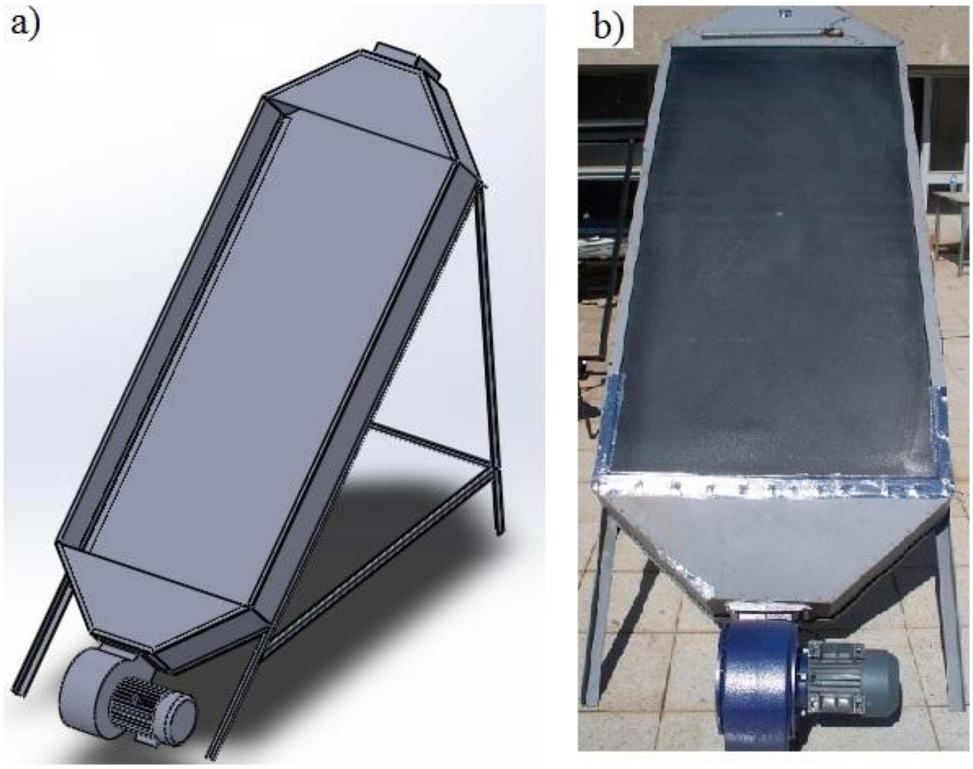

Fig.1 : Experimental setup. a) Schematic, b)Photography

Table.I: The measurement devices used in the experimental setup

Parameter	Measuring Devices	Brand, Model	Sensitivity	Error
Solar Radiation	Solarmetre	Kipp&Zonen CMP3	5-20 μV/W/m²	<20 W/m^2
Temperature	Digital Thermometer	Elimko E-680	0,01 ^oC	±0,1 ^oC
Air Velocity	Hot Wire Anemometer	CEM DT-8880	0,01 m/s	±%1
Wind Velocity	Thermo Anemometer	Prova AVM-07	0,01 m/s	±%3

The experimental setup was assembled on the terrace floor of Department of Mechanical Engineering (Fırat University, Elazığ) . The heaters were placed facing south at an angle of 38 degrees. The experiments were carried out between the hours of 08:00-18:00. The measurements were taken with one hour intervals.

III. THERMAL ANALYSIS

Energy efficiency can be calculated as the ratio of the available heat to the solar radiation on the collector [2,3,4,5].

$$Q_c = \dot{m} C_p (T_o - T_i) \quad (1)$$

$$\eta_{en} = \frac{Q_c}{(IA_C)} \quad (2)$$

$$\eta_{en} = \frac{\dot{m} C_p (T_o - T_i)}{(IA_C)} \quad (3)$$

According to these assumptions, the energy and exergy equalities of the system are as below [2,3,4,5].

$$\sum \dot{E}_i = \sum \dot{E}_o \quad (4)$$

$$\sum \dot{E}x_i - \sum \dot{E}x_o = \sum \dot{E}x_{dest} \quad (5.a)$$

$$\dot{E}x_{heat} - \dot{E}x_{work} + \dot{E}x_{mass,i} - \dot{E}x_{mass,o} = \dot{E}x_{dest} \quad (5.b)$$

General exergy equality can be expressed as below using Eq. (5.b) .

$$\sum \left(1 - \frac{T_e}{T_s}\right) \dot{Q}_s - \dot{W} + \sum \dot{m}_i \psi_i - \sum \dot{m}_o \psi_o = \dot{E}x_{dest} \quad (6)$$

The input (ψ_i) and output specific exergy (ψ_o) can be written as such;

$$\psi_i = \left(h_i - h_e\right) - T_e \left(S_i - S_e\right) \quad (7)$$

$$\psi_o = \left(h_o - h_e\right) - T_e \left(S_o - S_e\right) \quad (8)$$

If Equation (7) and (8) are placed inside equation (6);

$$\left(1 - \frac{T_e}{T_s}\right) \dot{Q}_s - \dot{m}\left(h_o - h_i\right) - T_e\left(S_o - S_i\right) = \dot{E}x_{dest} \quad (9)$$

Is obtained.

The solar energy absorbed by the absorber surface is as follows:

$$\dot{Q}_s = I(\tau\alpha)A_c \quad (10)$$

The enthalpy and entropy changes of the air in the collector;

$$\Delta h = c_p \left(T_{f,o} - T_{f,i}\right) \quad (11)$$

$$\Delta s = c_p \ln \frac{T_{f,o}}{T_{f,i}} - R \ln \frac{P_o}{P_i} \quad (12)$$

When Equations (10),(11) and (12) are placed in equation (9)

$$\left(1 - \frac{T_e}{T_s}\right) I(\tau\alpha) A_c - mc_p \left(T_{f,o} - T_{f,i}\right) + mc_p T_e \ln \frac{T_{f,o}}{T_{f,i}} - mRT_e \ln \frac{P_o}{P_i} = \dot{E}x_{dest} \quad (13)$$

Is obtained.

Exergy loss (irreversibility) can be calculated as below:

$$\dot{E}x_{dest} = T_e S_{gen} \quad (14)$$

Dimensionless exergy loss [2,3,4,5];

$$\dot{E}x_D = \frac{\dot{E}x_{dest}}{Qc} \quad (15)$$

Is thus obtained.

Whereas exergy efficiency [2,3,4,5] is expressed as;

$$\eta_{ex} = 1 - \frac{T_e S_{gen}}{\left[1-\left(T_e / T_S\right)\right]\dot{Q}_S} \quad (16)$$

IV. RESULTS AND DISCUSSION

In this study, the effect of classical glass and low iron content tempered glass as transparent cover for solar air heaters on energy and exergy efficiencies have been experimentally examined. 2 collectors were used in the experiments. The experiments were carried out with air flow rates of 0.02 kg/sec, 0.03 kg/sec, 0.04 kg/sec and 0.05 kg/sec during the dates of 31.08.2012 and 07.09.2012 at the city of Elazığ in Turkey under equal weather conditions. The experiments were repeated for two days for all flow rates.

Fig.2 shows the average radiation values for the 8 days during which the experiment was carried out. The radiation value was measured as 285 W/m^2 at 08:00 in the morning as 832 W/m^2 at13:00 and as 61 W/m^2 at 18:00.

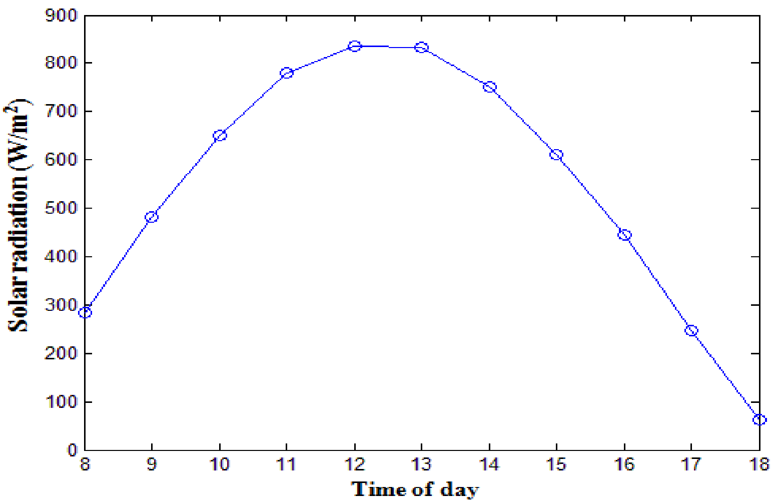

Fig.2: The solar radiation as a function of day times

Fig.3 shows the change in time of the available heat amount that has been calculated using Eq. (1). The highest available heat was obtained in the heater in which TGLIO was used at m=0.06 kg/s. The available heat varies between 30,5 J/s and 498,9 J/s for this case. Whereas the average available heat is 321 J/s. The lowest available heat was observed in the heater in which NC was used at a flow rate of m=0.02 kg/s. The available heat varies between 24.5 J/s and 335 J/s for this case. The average available heat has been determined as 217 J/s.

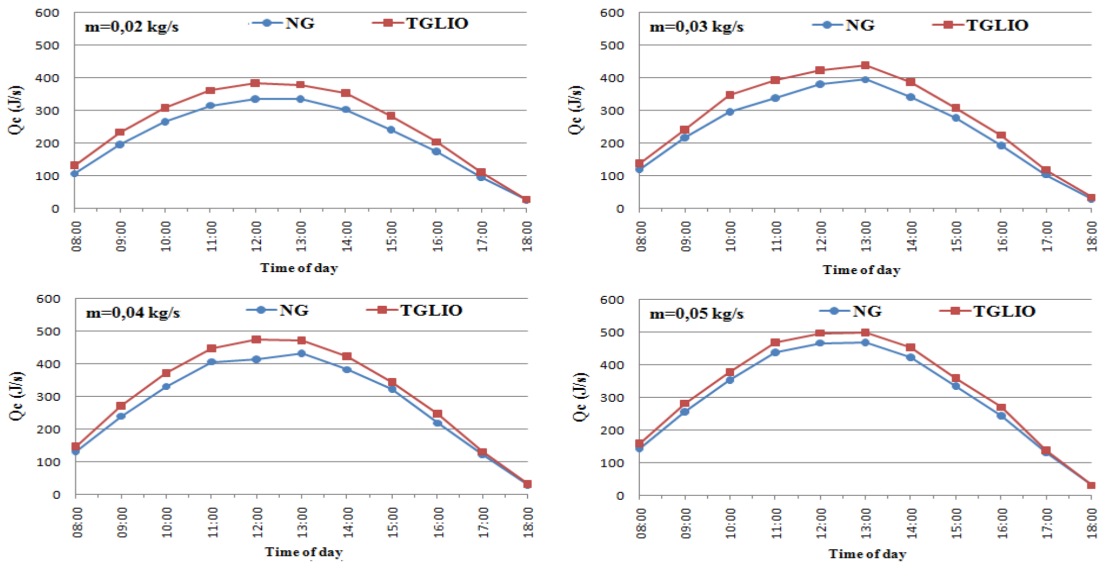

Fig.3: The useful heat rate as a function of day times

Fig.4 shows the change in time of the energy efficiencies that have been calculated using Eq (3). Similar to available heat, energy efficiency was also observed to be highest in the heater with TGLIO at a flow rate of m=0.05 kg/s. The average energy efficiency for this case was %43.5. Whereas energy efficiency average was determined as %38.2 in the heater with NC at a flow rate of m=0.05 kg/s. The lowest energy efficiency was calculated as %29.3 on average at a flow rate of m=0.02 kg/s. The average efficiency was determined as % 33.8 in the TGLIO used solar heater at the same flow rate as.

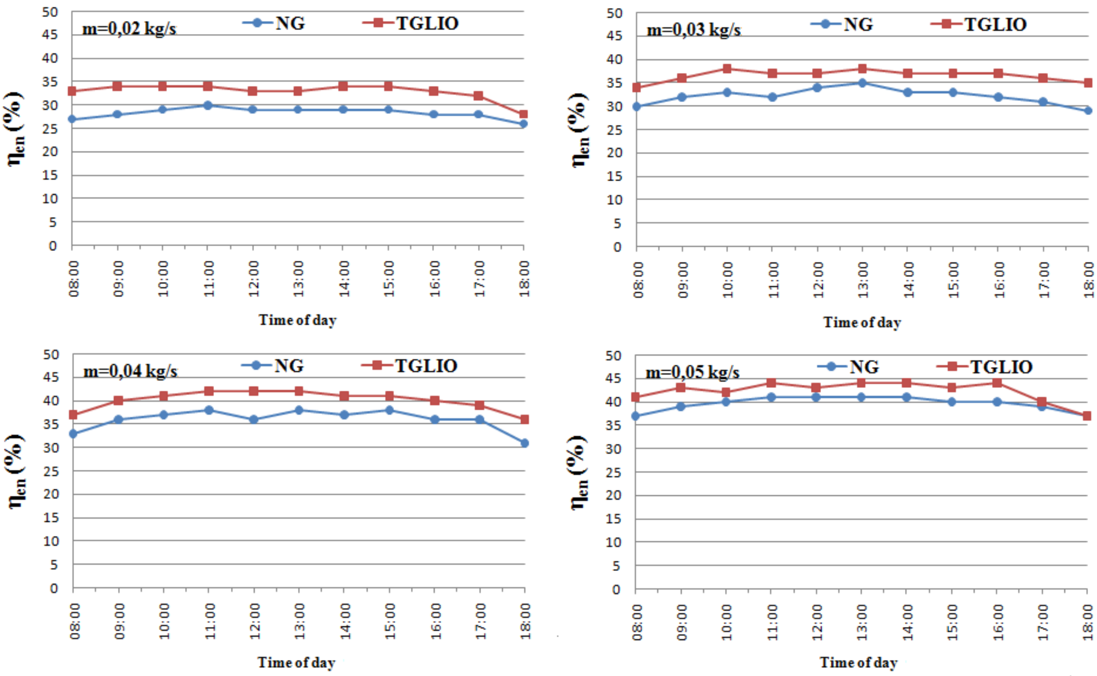

Fig.4: The energy efficiency as a function of day times

The change with time in exergy efficiency calculated using Eq (16) has been shown in Fig.5. The source temperature used in the calculation (Ts) is the temperature of the absorber surface. The highest exergy efficiency was observed in the heater with TGLIO at a flow rate of m=0.02 kg/s. The average exergy efficiency for this case was %6.95. Whereas the average exergy efficiency for the heater with NC at this flow rate was % 6.13. It has been observed that the exergy efficiency was lowest with a value of % 4.1 in the heater with NC at an air flow rate of m=0.05 kg/s. Whereas the efficiency was observed as % 4.5 in the heater with TGLIO.

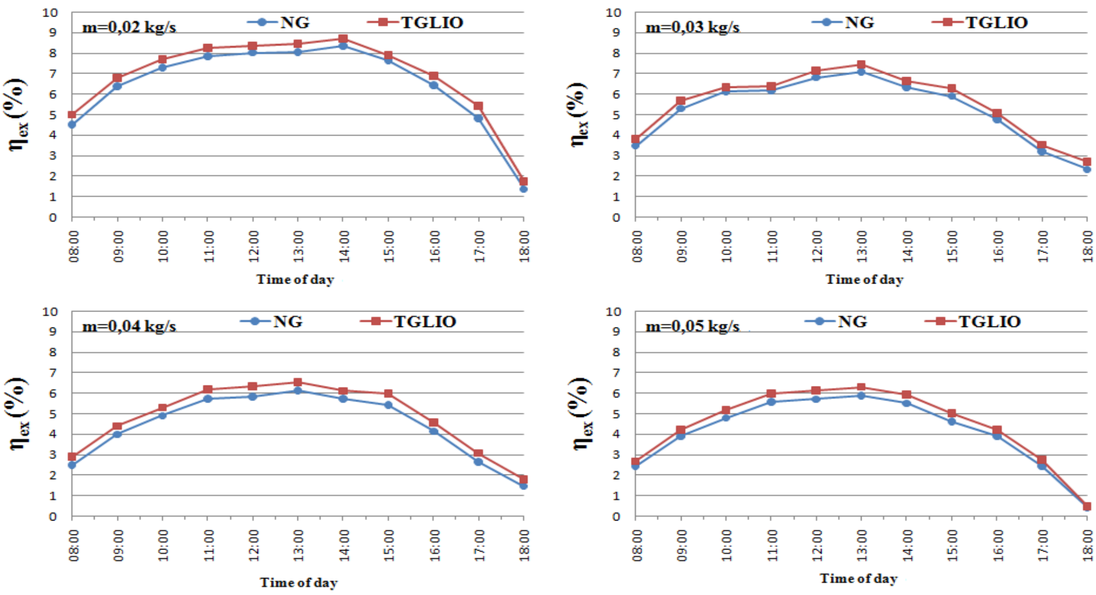

Fig.5: The energy efficiency as a function of day times

Dimensionless exergy ratio was calculated using Eq (15). According to the acquired results, Fig.6 shows the change in dimensionless exergy ratio with time for each flow rate. The lowest dimensionless exergy ratio was observed in the heater with TGLIO at an air flow rate of m=0.05 kg /s. The dimensionless exergy ratio average for this case was determined as 0.1924. Whereas the highest dimensionless exergy ratio average was calculated as 0.2325 in the heater with NC at an air flow rate of m=0.02 kg/s.

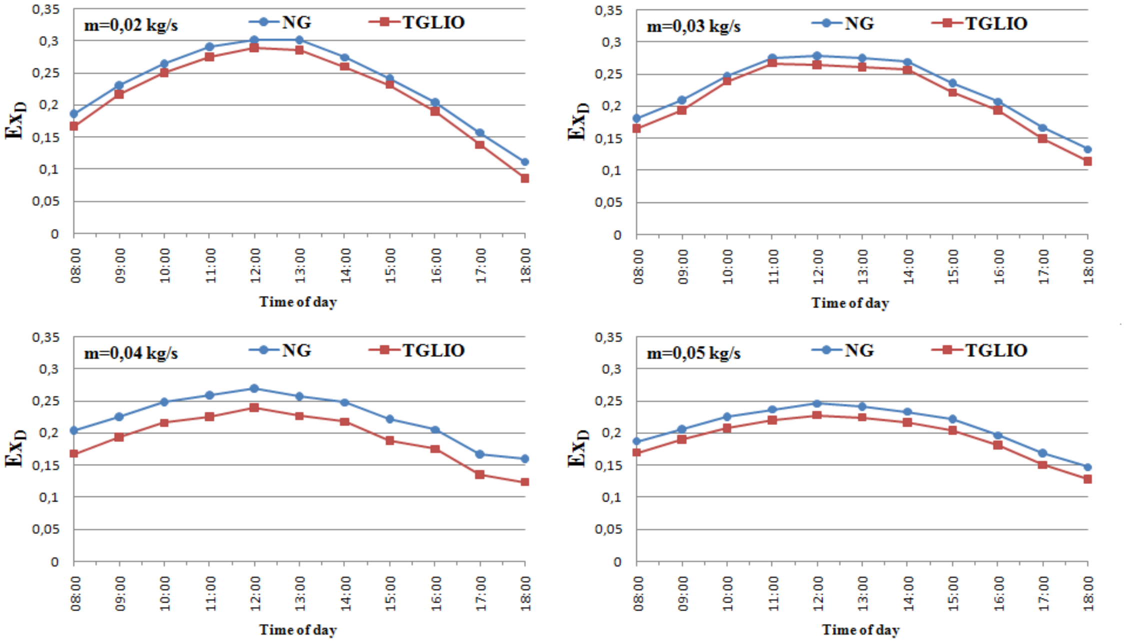

Fig.6: The dimensionless exergy ratio as a function of day times

Experimental results put forth that low iron content tempered glass is more efficient thermally in comparison with normal glass. Another property of TGLIO is that it shatters into tiny pieces upon breaking. The status of the glasses dropped to a concrete floor from a height of 3 meters has been shown in Fig.7.

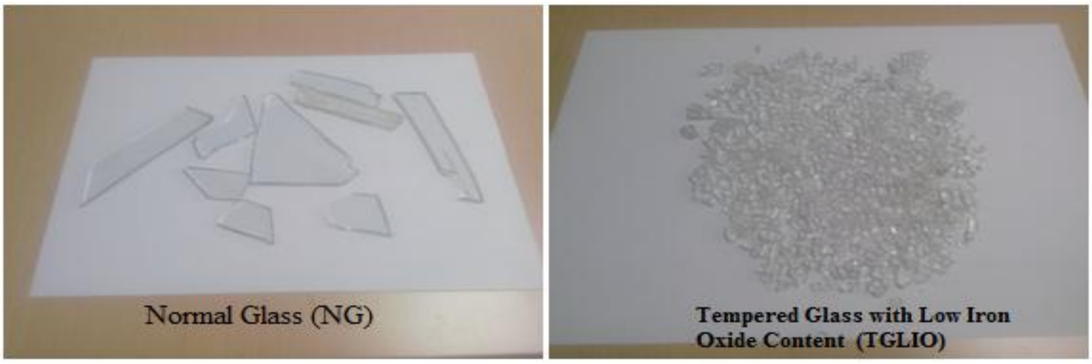

Fig.7: Normal and Tempered glass shards

V. CONCLUSIONS

In this study, the effects of classical glass and low iron content tempered glass as transparent covers in solar air heaters on energy and exergy efficiencies have been examined experimentally.

As a result of the experiments, it was found that energy efficiency of the collector equipped with tempered glass with low iron oxide content increases by an amount of 4.5%-5.3%. In case of exergy efficiency, an increase was also observed between 0.4 and 0.82 percent.

It was observed that the available heat, energy efficiency and exergy efficiency of heaters with TGLIO were higher. The main reason for this is that the radiation reflecting from the glass covers decreases as the iron-oxide (Fe_2O_3) amount decreases. In addition, tempered glass is more resistant to external weather conditions in comparison with normal glass. Another feature of TGLIO is that the glasses do not break as blocks upon impact. This glass shatters into tiny pieces. This is important in terms of safety.

NOMENCLATURE

A	Surface are (m^2)
Cp	Specific heat (J/kg K)
$\dot{E}$	Energy rate (W)
$\dot{E}x$	Exergy rate (W)
$\dot{E}x_D$	Dimensionless exergy loss (dimensionless)
$\dot{E}x_{dest}$	Rate of irreversibility (W)
h	Enthalpy (J/kg)
I	Solar radiation (W/m2)
m	Mass flow rate (kg/s)
P	Fluid pressure (Pa)
R	Universal gas constant (J/kg K)
Q_c	Useful heat rate (W)
Q_s	Incident energy in the collector area (W)
s	Entropy (J/kg K)
S_{gen}	Entropy generation rate (W/kg K)
T	Temperature (^oC)
$\dot{W}$	Work rate or power (W)
α	Absorptivity (dimensionless)
η_{en}	Energetic efficiency (dimensionless)
η_{ex}	Exergetic efficiency (dimensionless)
τα	Effective transmission (dimensionless)
ψ	Specific exergy (J/kg)

A. *SUBSCRIPTS*

a	Air
c	Collector
e	Environment
f	Fluid
i	Inlet
o	Outlet
gen	Generation

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