REVIEW ON PERFORMANCE OF DOUBLE PASS SOLAR AIR HEATER WITH AND WITHOUT BAFFLES

Mr. Hiren U Tandel*1, Dr. K V Modi2 & Mr. A R Patel3
*1M.E. Student, Mechanical Engineering Department, Government Engineering College, Valsad
2Professor & Head of MED, Mechanical Engineering Department, Government Engineering College, Valsad
3Assistant Professor, Mechanical Engineering Department, Government Engineering College, Valsad

ABSTRACT

In order to enhance rate of heat transfer to flowing air in the duct of a solar air heater (SAH), baffles on the absorber plate is considered to be an effective technique. Investigators reported various baffles geometries in literature for studying heat transfer and friction characteristics of an baffles duct of solar air heaters. In the present paper an attempt has been made to categorize and review the reported baffles used for increasing performance in Double Pass Solar Air Heaters (DPSAHs). Heat transfer coefficient and friction factor correlations developed by various investigators for baffles of solar air heaters have also been reported in the present paper.

Keywords: *Solar Air Heater, Baffles.*

I. INTRODUCTION

Energy is one of the many fundamental resources that our society depends on. Energy is an integral part of modern civilization, and it is mainly used in the form of electrical and thermal energy. The energy is generated by means of fossil fuels like coal, crude oil, nuclear and so on, which are exhaustive in nature and would be culminated in a couple of years. In this regard, researches are being conducted to develop new renewable energies and technologies to utilize them in efficient way. Out of the many forms of renewable energy, solar energy is the most widely available and has the largest potential to fulfil energy demands without polluting the environment. SAH can also be used as an integrated system with the existing conventional dryer system such as bin drier, conveyer drier, tunnel drier and fluidized bed dryers (FBDs) to save the fuel consumption. One of the major problem associated with SAHs is low performance due to (i) low heat transfer rates from the absorber plateto the flowing air and (ii) high heat loss to the environment. The heat transfer rate can be enhanced using various elements, such as artificial roughness [1‐3], extended surfaces [4,5], obstacles [6,7], blocks [8,9]and baffles [10,11]. These elements alter the flow patterns causes to turbulence in the vicinity of heated surface. The losses to the environment can be reduced by using multiple glass covers [12], multi-pass flow [13,14], selective coatings on the absorber plate [15], and honeycomb structures [16,17].There is still a necessity to present a comprehensive of double pass SAHs. Therefore, the present paper reports the comprehensive literature review on double pass SAHs with an aim to emphasize thevarious configurations, and heat transfer enhancement techniques used in double pass SAH. Effects of system and operating parameters have also been discussed.

II. METHOD & MATERIAL

A simple SAH consist of a glass cover, an absorber plate, aback plate and insulations provided on the sides of the duct to reduce the conduction losses to the environment as shown in Fig. 1[18]. Double Pass Solar Air Heater (DPSAHs) can be categorized on the basis of direction of the fluid flow i.e. counter or return flow DPSAH and parallel flow DPSAH. In counter flow type, air flows above and below the absorber plate in opposite direction while in parallel flow type, air flows both above and below the absorber plate in same direction as shown in Fig. 2(a) and (b)[19].

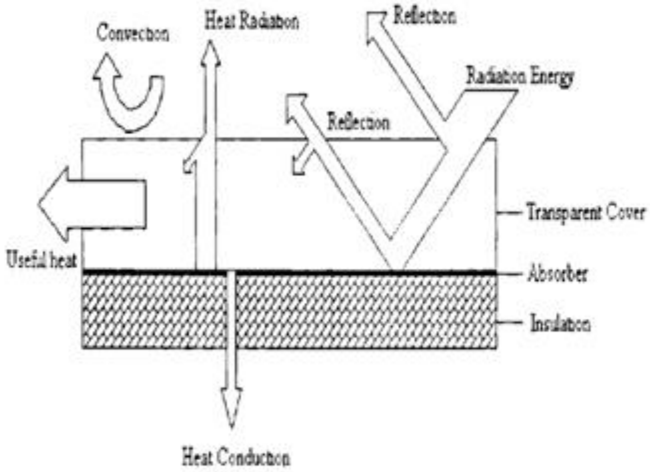

Fig. 1 Fundamentals of a flat plate SAH with flow over the absorber.[18]

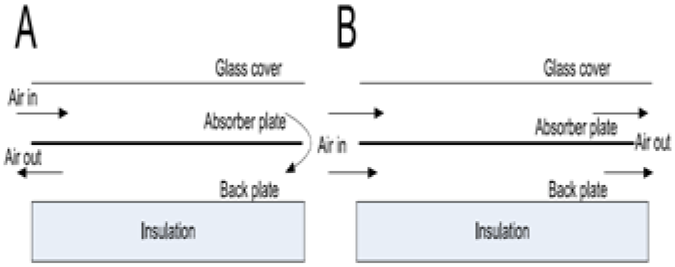

Fig. 2(a) Counter flow DPSAH with single glass cover (b) Parallel flow DPSAH. [19]

III. FACTORSAFFECTING PERFORMANCE OF COLLECTOR:

The performances of a solar collector depend on many factors, including the system and operating parameters of SAH duct. Different researchers investigated the effects of these parameters. The distinguishing factors are categorized and presented in Fig. 3[20].

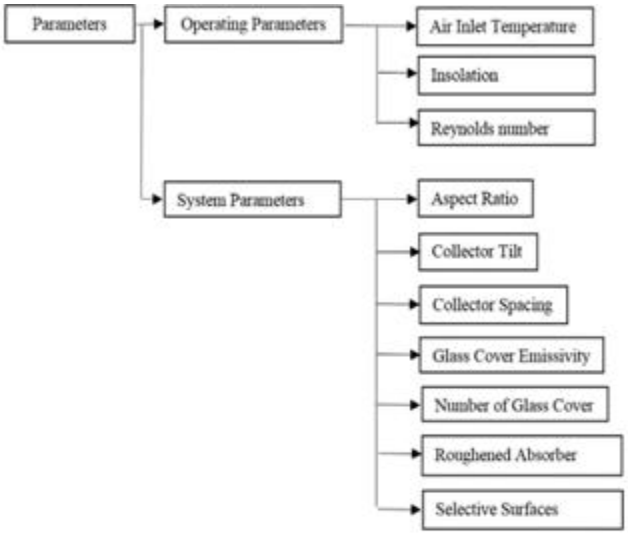

Fig. 3 Performance Factor of Collector [20].

3.1 Operating parameters

3.1.1 Air inlet temperature

Air inlet temperature significantly affects the collector performance. In previous studies, it was shown that collector performance decreases as air inlet temperature increases for similar operating and design parameters [21–22].

3.1.2 Insolation

The intensity of solar radiation greatly affects the thermal performance of a solar air collector. For a given fluid inlet temperature, ahigher intensity of insolation results in higher thermal efficiency. Theeffect of incident insolation on collector efficiency has been discussedby Wijeysundera et al.[23].

3.1.3 Reynolds number

The Reynolds number is determined in terms of the mass flow rate of a fluid. An increase in the Reynolds number of air increases the convective heat transfer coefficient, which causes to better thermal performance. In addition, the collector plate temperature decreases with the mass flow rate of air and, thus decreases heat losses to the environment. At same time, pressure drop also increases causing to high pumping power requirement, which is inadmissible. The adverse effects of the Reynolds number on the convective heat transfer coefficient and pressure drop penalty requires optimization of system parameters, thereby, maximum possible effective efficiency can be achieved.

3.2 System parameters

3.2.1 Duct aspect ratio

The duct aspect ratio (W/H) is the ratio of duct width to duct height. The selection of the duct aspect ratio is depended upon many factors and mainly depended on output temperature requirement. Generally, a high duct aspect ratio causes a high heat transfer rate with a rapid increase in factor increases rapidly, which does not ensure that it would provide higher thermo hydraulic performance [24].

3.2.2 Collector tilt

In order to capture the maximum amount of solar energy, the tilt angle of the collector is optimized based on many factors such as location, path of sun, weather and so on. Generally, the recommended collector tilt angles for summer and winter operation are φ-(10–15°) and φ+(10–15°), respectively. For the entire year, a tilt angle of approximately 0.9 time of latitude has been recommended for maximum solar energy collection [25].

3.2.3 Collector spacing

Design of the collector is depended mainly on the requirement of output air temperature and heating capacity. Additionally, other factors are also taken into account, such as operating conditions; tilt angle and air inlet temperature. Therefore, optimized spacing between collector and glass cover is not fixed, however, typical value of spacing is used in the range of 1–6 mm.

3.2.4 Glass cover emissivity

Low-emissivity glass covers help to reduce the heat losses to the environment, leading to improved collector performance. Heat losses can be reduced up to 50% by using low emissivity glass covers [25].

3.2.5 Number of glass covers

Thermal losses can be reduced using large number of glass cover, although, insolation reaching to absorber plate is also decreased due to decrease in overall transmittance-absorption product (ια). Selections of number of covers depend on the absorber temperature. For selective surface, one cover is sufficient for optimum performance. Two covers are recommended for non-selective surfaces [23].

3.2.6 Roughened absorber

Roughness creates flow turbulence near surfaces and promotes flow mixing in low-turbulence regions, which effectively enhances the convective heat transfer coefficient and lowers the absorber plate temperature leading to lower thermal losses. Roughness also causes

3.2.7 Selective surfaces

Characteristics of selective surface are to absorb maximum insolation without exhibit much more radiative losses. Selective surface is obtained by coating the layer of such materials which have high value of absorptivity and low value of emissivity without affecting the life of collector. Black chrome on bright nickel is considered to be as the best selective surface which has 0.96 absorptivity and 0.07 emissivity.

IV. PERFORMANCE OF DPSAH

The double pass solar air heater are of mainly two types depending on the fluid flow direction namely counter or return flow double pass solar air heater and parallel pass double duct solar air heater.

4.1 Performance of Simple DPSAH:

The analysis of parallel pass arrangement i.e. Fig. 1(c) heat collected in the lower and upper channel per unit area is defined as;

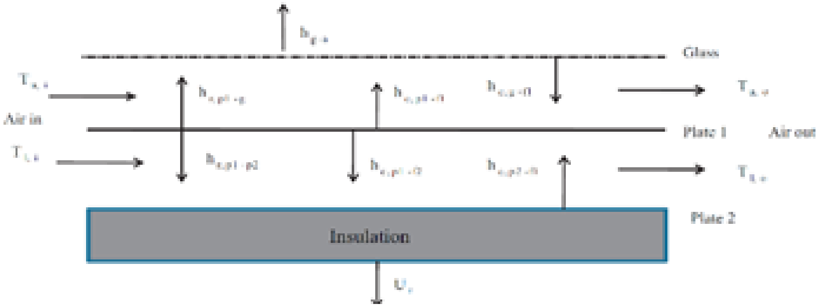

Fig. 4Schematic diagram of parallel pass double duct solar air heater [26]

$$q_1 = h_{c,p-l}\left(T_p - T_l\right) + h_{c,l-b}\left(T_b - T_l\right) \ldots (1)$$

$$q_2 = h_{c,g-u}\left(T_p - T_u\right) + h_{c,u-p}\left(T_p - T_a\right) \ldots (2)$$

$$Q_l = m_l C_p\left(T_{l,fo} - T_{l,fi}\right) \ldots \ldots . \ldots (3)$$

$$Q_u = m_u C_p \left(T_{u,fo} - T_{u,fi} \right) \ldots \ldots . \ldots (4)$$

$$Q_t = Q_l + Q_u \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . . (5)$$

$$\eta = \frac{Q_t}{AS}$$

4.2 Double-pass flat plate solar air heater with Baffles:

With the first law of thermodynamics and based on the Naphonand Kongtragood’s model [27], Naphon developed a mathematical model for double-pass flat solar air heater with longitudinal fins. Using the assumption proposed in the case of double pass solar air heater with porous media, the following equations have been developed:

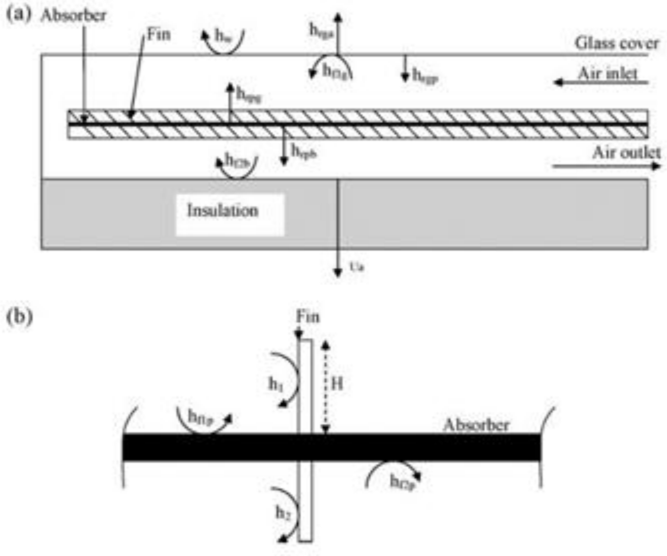

Fig. 5(a) Schematic diagram of the solar heater (b) Schematic diagram of fin section [27].

For the glass cover:

$$\propto_g S = h_w \left(T_g + T_a \right) + h_{cf1cg} \left(T_g + T_{f1} \right) + T_{rgp} \left(T_g + T_p \right) + h_{rag} \ldots (6)$$

For the First Pass of Air:

$$mC_f \frac{dT_{f1}}{dx} = h_{cf11g} \left(T_g - T_{f1} \right) + h_{cf1p} \left(T_p - T_{f1} \right) + \frac{N}{A_{frontal}} \int_{z=0}^{z=H} 2Lh_1 \left(T_{v1} - T_{f1} \right) dz \ldots . . (7)$$

For Upper Fin:

$$\frac{N}{A_{frontal}} \int_{z=0}^{z=H} 2Lh_1 \left(T_{v1} - T_{f1} \right) dz = \frac{N}{A_{frontal}} \left(-kA \frac{T_{v1}}{dz} \right)_{z=0} \ldots \ldots \ldots \ldots \ldots (8)$$

For Absorber plate:

$$I \propto_p \tau_c = h_{f1p} \left(T_p - T_{f1} \right) + h_{f2p} \left(T_p - T_{f2} \right) + h_{r,cp} \left(T_p - T_c \right) + h_{r,cp} \left(T_p - T_b \right) + \frac{N}{A_{frontal}} \left(-kA_{s,f} \frac{dT_{v1}}{dz} \right)_{z=0} + \frac{N}{A_{frontal}} \left(-kA_{s,f} \frac{dT_{v2}}{dz} \right)_{z=0} \ldots . (9)$$

For lower fin:

$$\frac{N}{A_{frontal}} \int_{z=0}^{z=H} 2Lh_2 \left(T_{v2} - T_{f2} \right) dz = \frac{N}{A_{frontal}} \left(-kA \frac{T_{v2}}{dz} \right)_{z=0} \ldots . (10)$$

For Second Air Stream:

$$mC_f \frac{dT_{f2}}{dx} = h_{f2p} \left(T_p - T_{f2} \right) + h_{f2p} \left(T_p - T_{f2} \right) + \frac{N}{A_{frontal}} \int_{z=0}^{z=H} 2Lh_2 \left(T_{v2} - T_{f2} \right) dz \ldots . . (11)$$

For bottom plate:

$$0 = h_{f2b} \left(T_b - T_{f2} \right) + h_{r,pb} \left(T_b - T_p \right) + U_a \left(T_b - T_a \right)$$

Table 1A summary of various investigations based on the double-pass SAH using extended surfaces

Year	Author	Study Type	Flow	System	Result
1997	Metwally et al. [28]	Experimental	Parallel	Corrugated absorber, multi-layer mesh	Efficiency was enhanced by 75% in comparison to smooth collector
2002	Yeh et al. [29]	Both	Parallel	Fins attached to absorber	Highest efficiency was reported for equal mass flow rate of air in bothpasses.
2005	Naphon [30]	Theoretical	Counter	Longitudinal fins	Thermal efficiency increased with number of fins and fin height
2009	Ho et al. [31]	Both	Counter	Baffled absorber	Collector efficiency increased with increase in recycle ratio and mass flow rate
2009	Ozgen et al. [45]	Experimental	Parallel	Aluminium cans	Optimum efficiency was found for mass flow rate of 0.05 kg/s.
2009	Yeh and Ho [21]	Theoretical	Counter	Fins	Enhancement in efficiency increases with increase in reflux ratio
2011	Ho et al. [32]	Theoretical	Counter	Fins	Efficiency was improved by 80% using recycle operations.
2011	Fudholi et al. [33]	Theoretical	Parallel	Longitudinal fins	Maximum efficiency was increased upto 75%
2013	Fudholi et al. [34]	Both	Counter	Finned absorbed	Optimum efficiency was obtained as 77% at a mass flow rate of 0.09 kg/s.
2006	Karim and Hawaldar [35]	Both	Parallel	Fins and V-corrugated absorber	Efficiency of V-corrugated was improved by 5–11% with respect to smooth duct.
2011	Ei-Sebaii et al. [14]	Both	Parallel	V-corrugated absorber	Efficiency of V-corrugated was improved by 11–14% with respect to smooth duct.
2015	Mahmood et al. [36]	Experimental	Counter	Transverse fins with wire mesh	Maximum efficiency was reported as 62.50%.
2012	Sharma et al. [37]	Experimental	Counter	Ribs in V shape	Nusselt number was found to be a strong function of roughness parameters.
2013	Sharma et al. [38]	Experimental	Counter	V ribs roughness	Maximum enhancement in Nusselt number and friction factor was 1.7 and 1.9, respectively.
2014	Rawat and Juarker [39]	Experimental	Counter	V ribs roughness	Maximum efficiency was reported as 93%.
2013	Dogra [40]	Experimental	Counter	Transverse ribs	Maximum thermal and thermo-hydraulic efficiency were ported at relative pitch of 10°.
2014	Kumar et al. [41]	Experimental	Counter	Inclined continuous ribs	Maximum efficiency was reported as 93.5%.
2015	Singh et al. [42]	Experimental	Counter	Transverse ribs	Maximum enhancement in Nusselt number and friction factor was 1.28 and 1.17,

					respectively.
2016	Dehariya and Juarker [43]	Experimental	Counter	Desecrate Square ribs	Maximum efficiency was reported as 93%.
2016	Ravi and Saini [44]	Experimental	Counter	Multi V ribs in desecrate form	Maximum enhancement in Nusselt number and friction factor was 3.4 and 2.5, respectively.

V. CONCLUSION

Key results of different researches have also been summarized for ready reference. Based on the literature review conducted in this paper, following conclusions have been drawn.

1. Double pass SAH has better efficiency which is about 10–15% higher than that of the single pass arrangement operating at similar flow conditions. Furthermore, counter flow with recycle operation configuration perform best.
2. Substantial experimental and analytical research has been conducted on extended surfaces such as fins, wires, and corrugated absorbers and considerable heat transfer enhancements have been obtained along with pressure drop penalties.
3. Very few studies are available on artificial roughness and more work is required to investigate this technique because it offers superior hydraulic performance.
4. A considerable amount of research has been conducted on heat transfer and pressured drops in packed beds consisting of packing elements of different materials. The absorption of insolation in a porous matrix occurs layer by layer, which is more effective and results in the reduction of the temperature at the top layer of the porous matrix. Therefore, the energy loss from the top of the collector is reduced.
5. Considerable amount of research work has been carried out on heat transfer and pressured drop in packed beds having different packing elements of different material. Absorption of insolation in porous matrix is layer by layer which is more effective resulting in the reduction of top layer temperature of porous matrix and therefore, the energy loss from the top of the collector is reduced.
6. Double pass counter flow solar air collector with porous matrix in the lower passage significantly improved thermal performance of double pass SAH.

There are lots of scopes for future study of double pass SAHs are available which includes the study of various roughness on both sides of absorber, integration of heat storage with absorber, usage of perforated fins and obstacles etc.

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