Chapter 2

Literature survey

Conventional SAH mainly consist of a panel, insulated hot air duct and air blower in active systems. The panel consists of an absorber plate and transparent cover which affects the SAH efficiency. A major heat losses from conventional SAH are found to be top losses, whereas, heat losses from the bottom and sides are negligible owing to adequate insulation. In order to minimize the heat losses (top losses) and to improve the efficiency, dual glassing was recommended [Prasad et al. 2009, Alta et al. 2010]. Yeh and Lin [1996] stated that in conventional SAH, the area available for heat transfer is lesser than the projected area of the absorber, as it becomes unnecessarily hot leading to higher heat losses. The same was confirmed by Lin et al. [2006], Akpinar and Koçyiğit [2010] and Benli [2013], who stated that, the convective heat transfer rate in flow channel is augmented by increasing the heat transfer surface area and turbulence inside the channel. Increase in absorber plate projected area enhances the heat transfer rate and, consequently, pressure drop across the SAH and the power consumption for air flow through the SAH increases [Esen 2010]. Ozgen et al. [2009], Ramani et al. [2010] and Aldabbagh et al. [2010] suggested dual-pass mode to restrict heat losses, enhancement in heat transfer rate and efficiency without increasing heater size or cost.

From the above discussion, it can be concluded that the flow configuration, absorber plate and its geometry play a vital role in deciding the thermal performance of a SAH. Hence, in the following sections, major contributions by different researchers on flat plate SAHs including all the variants are discussed.
2.1 Flat absorber SAHs

In 1995, Yeh and Lin investigated the effect of the collector aspect ratio on the energy efficiency of flat plate SAHs theoretically and experimentally with varied flow rates and reported that energy efficiency increases with the mass flow rate and collector aspect ratio. While, Naphon and Kongtragool in 2003 applied mathematical models for predicting the heat transfer characteristics of flat plate SAH with various flow configurations and found that single flow dual-pass flat plate SAH exhibit higher thermal performance. In the mean time, Forson et al. [2003] conducted theoretical and experimental investigation with single-pass dual duct flat plate SAH and reported that the mass flow rate dictates the overall efficiency of SAH. The thermal performance of flat plate SAH employing electrical field was attempted by Kiatsiriroat et al. [2007] who reported better heat transfer rate at the high radiation intensity and lower mass flow rate. Employing external recycle improves the thermal efficiency in flat plate SAHs was reported by Yeh and Ho [2009]. During the same period, Gupta and Kaushik [2009] from India developed a procedure to determine optimum aspect ratio (length to width ratio of the absorber plate) and optimum duct depth (the distance between absorber and bottom plates) for maximum exergy delivery in flat plate solar air heater and concluded that if the inlet temperature of air is low, maximum exergy output is achieved at lower mass flow rate. Few years later, Jafarkazemi and Ahmadifard [2013] evaluated the energy and exergy performance of flat plate solar collector and reported reduction in energy efficiency and increase in exergy efficiency with augment in inlet temperature.

2.2 Roughened absorber SAHs

The first citation on roughened absorber SAH was by Prasad and Saini [1998], who investigated the effect of relative roughness height and pitch on heat transfer and
friction factors in transverse ribs. Karwa et al. [2001] carried out an experimental investigation to determine the thermal performance of SAHs with chamfered repeated rib-roughness on the airflow side of the absorber plates, and achieved substantial enhancement in thermal efficiency over SAH with smooth absorber plate. Bhagoria et al. [2002] used wedge shaped ribs to enhance the heat transfer coefficient and reported a maximum heat transfer enhancement at a wedge angle of $10^\circ$. In addition, they obtained an increase in friction factor with wedge angle. Sahu and Bhagoria [2005] investigated the effect of different pitches having $90^\circ$ broken wire rib roughness in SAH and reported enhancement of thermal performance by 1.25-1.4 times. Jaurker et al. [2006] investigated the effect of rib-grooved and ribbed artificial roughness on heat transfer and friction characteristics of SAH, who concluded that the thermo-hydraulic performance of rib-grooved artificial roughness was higher than ribbed one. An experimental study was also carried out by Varun et al. [2009], who investigated the efficiency of SAH with transverse and inclined ribs as artificial roughness elements on the absorber and reported combination of roughness geometry provides better performance over the transverse ribs. Gupta and Kaushik [2009] in their article published correlated the performance of artificial roughness absorber SAH with smooth absorber SAH. They concluded that exergy is more for SAH with roughness at lower mass flow rate. Remarkable efforts are made by Karwa and Chauhan [2010], Karmare and Tikekare [2010] and Prasad [2013] to study the effect of rib roughness over the absorber plate on thermal performance of SAHs. They indicated that the artificial roughness break the viscous sub-layer and increases the heat transfer rate with the penalty of undesirable increase in pressure drop due to increased friction. In 2013, Benli concluded that the heat transfer coefficient and the pressure drop changes with configuration of absorber surface while experimentally
analysing the energy and exergy of varied absorber surface viz., corrugated, trapeze, reverse corrugated, reverse trapeze and a base plate.

2.3 Finned absorber SAHs

A better thermal efficiency in a dual flow SAH having fins, was reported by Yeh et al. in 2002, where the cross sectional area and mass flow rate of upper and lower flow channels is equal. In 2004, Moumni et al. conducted an energy analysis and flow characteristics of finned SAH both experimentally and theoretically and reported better thermal performance while employing fins. Two years later, Ucar and Inalli [2006] conducted energy and exergy analyses with staggered absorber sheets and attached fins concluded largest irreversibility is occurring at the conventional SAH, where thermal efficiency is smallest. Meanwhile, Youcef-Ali and Desmons in 2006 and Peng et al. in 2010 unconnectedly recommended providing fins for enhancing the thermal performance. Alta et al. [2010] investigated three different types of SAHs (two having fins and the other without fins, one of the heaters with fins had single glass cover and the others had dual glass covers) and concluded that, dual glass covers and fins are more effective and the rise in air temperature is higher based on energy and exergy output. One year later, Ho et al. [2011] obtained higher thermal performance in an upward type dual-pass SAH with fins along with external recycling. In a subsequent publication Ho et al. [2012] reported SAH with fins and baffles was economically viable than dual pass SAH with fins based on the ratio of efficiency and power consumption increment.

2.4 Absorber with obstacles SAHs

In 2008, Esen compared the results of dual flow SAH with and without obstacles. The influences of parameters viz., obstacles in absorber plate, mass flow rate of air and absorber plate level in duct on the energy and exergy efficiencies of
SAH were examined. Later, Ozgen et al. [2009] attempted dual flow SAH with aluminium cans, reported higher thermal performance owing to enhancement of heat transfer area. The energy and exergy analysis of flat plate SAH with several obstacles positioned at different angles was experimentally studied by Akpınar and Koçyiğit [2010]. They also correlated those results with SAH without obstacles and found that the energy and exergy efficiency of SAHs significantly depends on the solar radiation, surface geometry of SAHs and the extension of the air flow line. In addition, they reported that exergy loss of SAH decreased depending on the increase of the energy efficiency.

2.5 Corrugated absorber SAHs

Karim and Hawlader [2006] compared the thermal performance of flat plate, v-corrugated and finned air collectors. They concluded that v-groove collector is the most efficient collector and the flat plate collector is the least efficient one. They also found that the v-groove collector has 7-12% higher efficiency than flat plate collectors. Notable efforts are made by Liu et al. [2007] and Gao et al. [2007] in studying the thermal performance of cross corrugated SAHs and compared the results with a flat plate and v-grooved absorber plate. These studies show that the thermal performance of cross corrugated SAH is superior to v-grooved and flat plate SAHs. El-Sawi et al. [2010] investigated both theoretically and experimentally flat plate, v-grooved and chevron pattern absorber SAHs and concluded that, chevron pattern absorber SAH performance was better than flat plate and v-grooved absorber SAH. El-Sebii et al. [2011] investigated the thermal performance of dual flow finned and v-corrugated plate SAH both theoretically and experimentally and concluded that dual flow v-corrugated plate SAH was 9-12% more efficient than dual flow finned plate SAH.
2.6 Porous bed absorber SAHs

Thakur et al. [2003], studied the effect of porosity on the heat transfer rate covering a wide range of geometrical parameters of wire screen matrix (wire diameter 0.795-1.4 mm, pitch 2.5-3.19 mm, number of layers 5-12) and reported a decrease in porosity which increases the volumetric heat transfer coefficient. Ozturk and Demirel [2004] evaluated the energy and exergy efficiencies of SAH having it flow channel packed with raschig rings. They observed that the energy and exergy efficiencies of the packed-bed SAH increased as the outlet temperature of heat transfer fluid increased. Naphon [2005] numerically analysed the heat transfer characteristics and performance of dual-pass flat plate SAH with and without porous media and stated that variation in efficiency from 38% to 59% for the bed without porous media, whereas, it ranges from 42% to 70% with porous media for mass flow rates between 0.03 and 0.07 kg/s respectively. El-Sebaii et al. [2007] used limestone and gravel as packed bed materials and reported a thermal efficiency of 65% at a mass flow rate of 0.05 kg/s, while the pressure drop was 400 N/m². Further, they recommended operating the system with a packed bed at a mass flow rate lower than 0.05 kg/s in order to attain lower pressure drop and high thermal efficiency. A thermal performance investigation of dual glass, dual-pass SAH with a packed bed (limestone and gravel), based on mass flow rate and porosity was carried out by Ramadan et al. [2007]. Ramadan et al. reported better thermal performance while employing gravel as packed bed material. Prasad et al. [2009] presented an investigation on a packed bed SAH using wire mesh as a packing material for air flow rate ranging from 0.0159 to 0.0347 kg/s. They reported that the efficiency of packed bed SAH with a porosity of 0.599 increases from 53.3% to 68.5% compared with conventional SAH. Moreover, they opined that the efficiency increases with decreasing the porosity of the
bed. The performance of single and dual-pass SAH with fins and steel wire mesh as absorber was studied by Omojaro and Aldabbagh [2010] who found that the efficiency of dual-pass was higher than single-pass by 7-9%. El-khawajah et al. [2011] attempted a novel design of employing dual-pass SAH with wire mesh and fins instead of absorber plate and reported better thermal performance than conventional SAH. The counter and parallel flow packed bed SAHs was investigated by Dhiman et al. [2012]. The results showed that the thermal efficiency of counter flow packed bed SAH is 11-17% more than parallel flow packed bed SAH. Economic analysis on dual pass SAH with and without wire mesh was carried out by Ho et al. [2013] and reported that the dual pass SAH with wire mesh is economically feasible based on the ratio of efficiency and power consumption increment. El-khawajah et al. [2015] employed wire mesh and fins instead of the absorber plate in single-pass SAH and reported maximum thermal efficiency and outlet temperature for conditions exhibiting more fins along with wire mesh.

2.7 Motivation

From the above it is obvious that the heat transfer between the absorber surface of SAH and flowing air can be improved by (1) increasing the turbulence, employing artificial roughness on the absorber surface, (2) increasing the heat transfer surface area, using longitudinal fins on the absorber surface and (3) increasing both absorber surface area and turbulence by providing wire mesh on the absorber surface. Though numerous works were carried out in the past, it is observed from the literature survey that experimental and theoretical work aimed to enhance the thermal performance with minimum pressure drop under various flow configurations and absorber plate geometries of SAH are found to be rare. In the present investigation, an attempt is made to improve the thermal performance of SAH with modified flow
configurations and absorber plate design. There are three transforms attempted in the flow configuration (a) single-pass (b) dual-pass and (c) dual-pass with fins. The absorber plates are modified with roughened surface, finned surface and wire mesh surface. An economic analysis was also conducted for the optimised configurations

2.8 Research methodology

![Flow chart of research methodology](image)

Figure 2.1 Flow chart of research methodology

Figure 2.1 illustrates the research methodology adopted in this study. An extensive literature survey of articles related to SAH highlights the significance of the problem stated. SAH with different absorber plate geometries were fabricated and tested at various flow configurations, mass flow rate and radiation intensities. Theoretical models are developed for each condition and the results correlate with the experimental findings.