Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

THERMO-HYDRAULIC PERFORMANCE OF THE SOLAR AIR HEATER WITH STAGGERED PIECE IN A BROKEN ARC RIBS ON THE ABSORBER PLATE WITH DIFFERENT PITCH

Sunil Kumar Patel, Government Engineering College, Raipur, Sejbahar, Old Dhamtari Road, Chhattisgarh, PIN-492015**,**
Pulkit Kumar Agrawal, Government College of Engineering, Kalahandi, Bandopala Post-Risigaon, Bhawanipatna, Odisha, PIN-766003
Kranti Kumar Dhruw, Government Engineering College, Raipur, Sejbahar, Old Dhamtari Road, Chhattisgarh, PIN-492015

Abstract
The study investigates the thermo-hydraulic performance of a solar air heater with staggered piece in a broken arc ribs on the absorber plate with different pitch. Various roughness geometries for enhancing heat transfer in solar air heater ducts are reviewed and compared. Artificial roughness on the absorber plate increases surface area, promoting turbulent flow and disrupting the viscous sub-layer, thereby enhancing heat transfer coefficient. Results are compared with a smooth plate under similar flow conditions to assess enhancement in heat transfer coefficient and friction factor. The study aims to classify roughness geometries, review their effects on heat transfer, and compare thermo-hydraulic performance of different duct geometries.
Keywords: *Artificial roughness, heat transfer coefficient, solar air heater, thermo-hydraulic performance, viscous sub-layer.*

1 Introduction
1.1 Energy
Tester, who are experimenter who study twist somebody's arm, mobility and force, say that energy is the capability to do job, and work is moving something in opposition to a potential, similar to solemnity. There are various sorts of force in the universe, and that force can do unique things. Energy can be found in several things, and takes various forms. There is a sort of force called dynamic energy in questions that are mobile. There is impressive that experimenter call prospective energy in items very still that will make them move if opposition is vacate. Energy is characterized as the ability or the capability to do effort. Energy is the basic unit to support life and improvement. Power means moves or elating something, warming or illumination something. There are various sources of energy that aid to run the diverse equipment produced by human. There has been a remarkable growth in the concern for energy since the heart of the most current century as an outcome of modern development and people progress. Earth population grew 3.2 times somewhere around 1850 and 1970, per capita utilization of modern energy expanded around twentyfold, and all out world utilization of mechanical and customary energy forms joined expanded more than twelvefold. As ahead of schedule as 4000–3500 BC, the first cruising boats and windmills were created outfitting wind energy. With the utilization of hydropower through water factories or watering systems, things started to move speedier. Fuel wood and fertilizer cakes are even today a noteworthy source of energy in provincial India. solar energy is utilized for drying and warming. With the coming of the Industrial Revolution, the utilization of energy as fossil powers started developing as more businesses were situated up. This happened in stages, from the exploitation of coal stores to the misuse of oil and characteristic gas fields. It has been just a large portion of a century since atomic force started being utilized as an energy source. In the previous century, it got to be obvious that the utilization of non-renewable sources of energy had brought about more natural harm than whatever other human movement. Power created from fossil powers, for example, coal and raw petroleum has prompted high convergences of hurtful gases in the climate. This

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

has thusly prompted issues, for example, ozone consumption and an Earth-wide temperature boost. Vehicular contamination is additionally a grave issue. Because of the issues connected with the utilization of fossil power, option sources of energy have get to be essential and significant in today's reality. These source, for example, the sun and wind, can never be depleted and are hence called renewable. Otherwise called non-traditional sources of energy, they cause less discharge and are accessible. Generally Renewable energy sources incorporate the sun, wind, water, agrarian deposit, fuelwood, and creature waste. Fossil powers are non-renewable sources. Energy produced from the sun is known as sunlight based energy. Hydel is the energy got from water. Biomass – kindling, creature compost, and biodegradable waste from urban areas and yield deposits – is a source of energy when it is smoldered. Geothermal energy is gotten from hot dry rocks, magma, boiling hot water springs, normal fountains, and so on. Sea warm is energy gotten from waves furthermore from tsunamis. The general productivity of energy creation remains greatly low: by and large, more than 90% of energy expended is lost or squandered during the time spent change from crude materials, for example, coal to the last energy administration.

1.1.1 How energy is measured?

One of the fundamental measuring units for energy is known as a Btu or British warm unit. Btu is characterized as the measure of heat energy it takes to raise the temperature of 1 pound of water by 1 degree Fahrenheit, at ocean level. Energy can likewise be measured in joules (pronounced the same way as jewels). One joule is the measure of energy expected to lift 1 pound around 9 inches. It takes 1000 joules to equivalent a Btu. Joule is named after an English physicist named James Prescott Joule who lived from 1818 to 1889. He found that heat is a kind of energy. Around the globe, researchers measure energy in joules as opposed to Btu. It is much like individuals around the globe utilizing the metric system, meters and kilograms. Like in the metric system, you can have kilojoules: "kilo" implies 1000, in this manner, 1000 joules = 1 kilojoules = 1 Btu.

1.1.2 Classifications of Energy Resources

1.1.2.1 On the Basis of Usability of Energy

- ***(a)* *Primary Resources***: These resources are for the most part accessible in crude form and are in this way known as crude energy resources. By and large, this type of energy can't be utilized all things considered. These are found, investigated, removed, handled and are changed over to a form as needed by consumer. Illustrations of essential energy resources are coal, unrefined petroleum, daylight, wind, running stream, vegetation, uranium, and so forth.
- ***(b)* *Intermediate Resources***: These are acquired from essential energy by one or more step of change and are utilized as vehicle of energy
- ***(c)* *Secondary Resources***: The type of energy which is at long last supplied to a purchaser for use is known as optional or usable energy, e.g., electrical energy, solar energy (as steam or high temp water), compound energy (as hydrogen or fossil fuel), and so on.

1.1.2.2 On The Basis of Traditional Utilization

- ***(a)* *Conventional***: Energy which are as a rule customarily utilized for a long time and were in like manner use around the oil emergency of 1973, are called traditional energy resources, e.g., fossil fuels, atomic and hydro resources.
- ***(b)* *Non-conventional***: Energy which are considered for extensive scale use after the oil emergency of 1973, are called non- traditional energy resources, e.g., sun powered, wind, biomass, and so on.

1.1.2.3 On The Basis of Long Term Accessibility

- ***(a)* *Non Renewable***: Resource which are limited and don't get recharged after their utilization are called non-renewable, e.g., fossil energizes, uranium, and so forth.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

(b) Renewable: Resource which are replenished by nature over and over and their supply is not influenced by the rate of their utilization are called renewable, e.g., sunlight based, wind, biomass, sea (warm, tidal and waves), geothermal, hydro, and so forth.

1.1.2.4 On The Basis of Business Application

(a) Commercial energy Resource: The optional usable energy forms, for example, power, petrol, diesel, and so forth are key for business exercises and are classified as business energy asset.

(b) Non business energy: The energy got from nature and utilized specifically without going through the business outlet are called non business asset.

1.1.3.5 On The Basis of Starting Point

(a) Fossil Fuel energy
(b) Nuclear energy
(c) Hydro energy
(d) Solar energy
(e) Wind energy
(f) Biomass energy
(g) Geothermal energy
(h) Tidal energy
(i) Ocean warm energy
(j) Ocean wave energy

1.2 Solar Energy and Its Applications

Solar energy is the light and radiant heat from the Sun that impacts Earth's atmosphere and climate and supports life. For sun based energy as a hotspot for renewable energy, gaze upward photovoltaic (solar power) or solar energy. Sun based advancements are extensively described as either passive Solar or active solar relying upon the way they catch, change over and disseminate solar energy. Active sunlight based methods incorporate the utilization of photovoltaic boards and solar heat authorities to outfit the energy. Inactive solar procedures incorporate arranging a building to the Sun, selecting materials with ideal warm mass or light scattering properties, and outlining spaces that normally flow air.

Applications: -

- Cooking
- Product drying
- Refining of water
- Concoction procedure heat
- Warming and cooling of building
- Water heating
- Refrigeration
- Photovoltaic force change
- Sunlight based heater
- Warm power transformation

1.2.1 Concentrating Solar Power

Concentrating solar based energy (CSP) plants are utility-scale generators that deliver power utilizing mirrors or lenses to effectively think the sun's energy. The four central CSP advances are explanatory troughs, Dish-Sterling motor systems, focal recipients, and concentrating photovoltaic system s (CPV).

1.2.2 Solar Thermal Electric Power Plants

Solar heat energy includes outfitting sunlight based energy for pragmatic applications from solar warming to electrical energy era. Sunlight based heat authorities, for example, solar boiling hot water boards, are normally used to create solar heated water for household and light mechanical applications.

This energy system is additionally utilized as a part of building design and building configuration to control warming and ventilation in both active Solar and uninvolved solar outlines.

1.2.3 Photovoltaic

Photovoltaic or PV innovation utilizes solar based cells or solar photovoltaic clusters to change over energy from the sun into power. Sun based cells create direct current power from the sun's beams, which can be utilized to power hardware or to revive batteries. Numerous pocket adding machines fuse a solitary Solar cell, yet for bigger applications, cells are by and large gathered together to frame PV modules that are thusly orchestrated in sunlight based exhibits. Sun based clusters can be utilized to power circling satellites and other shuttle and in remote regions as a source of force for roadside crisis phones, remote detecting, and cathodic security of pipelines.

1.2.4 Solar Heating Systems

Solar hot water systems use daylight to heat the water. The systems are made out of sunlight based heat collectors and a storage tank, and they may be dynamic, inactive or cluster system s.

1.2.5 Passive Solar Energy

It concerns building outline to keep up its surroundings at an agreeable temperature through the sun's every day and yearly cycles. It should be possible by (1) Direct pick up or the situating of windows, sky facing windows, and screens to control the measure of direct sunlight based radiation coming to the inside and warming the air and surfaces inside of a building, Indirect pick up in which solar radiation is caught by a piece of the building envelope and after that transmitted by implication to the building through conduction and convection; and (3) Isolated addition which includes latently catching Solar heat and afterward moving it inactively into or out of the building by means of a fluid or air straightforwardly or utilizing a warm store. Sunspaces, nurseries, and sunlight based wardrobes are elective methods for catching segregated heat pick up from which warmed air can be taken.

1.2.6 Solar Lighting

It is also called day lighting, this is the utilization of characteristic light to give brightening to balance energy use in electric lighting system s and lessen the cooling load on HVAC systems. Day lighting elements incorporate building introduction, window introduction, outside shading, saw tooth rooftops, clerestory windows, light retires, and light tubes. Building patterns progressively perceive day lighting as a foundation of reasonable outline.

1.2.7 Sun based Cars:

A sun based auto is an electric vehicle controlled by energy got from solar boards on the surface of the auto which change over the sun's energy specifically into electrical energy. Solar autos are not right now a reasonable type of transportation. Despite the fact that they can work for constrained separations without sun, the solar cells are for the most part exceptionally delicate. Improvement groups have centered their endeavors on advancing the productivity of the vehicle, however numerous have sufficiently just space for maybe a couple individuals.

1.2.8 Solar Power Satellite

A sun based force satellite (SPS) is a proposed satellite inherent high Earth circle that uses microwave power transmission to shaft solar energy to a vast reception apparatus on Earth where it can be utilized as a part of spot of routine force sources. The upside of putting the solar collector in space is the unhindered perspective of the sun, unaffected by the day/night cycle, climate, or seasons. Then again, the expenses of development are high, and SPSs won't have the capacity to contend with customary sources unless low dispatch expenses can be accomplished or unless a space-based assembling industry creates and they can be assembled in circle from off-earth materials.

1.2.9 Solar Updraft Tower

A solar updraft tower is a proposed kind of renewable-energy force plant. Air is warmed in a vast roundabout nursery like structure, and the subsequent convection causes the air to rise and escape through a tall tower. The moving air drives turbines, which create power. There are no sunlight based

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

up-draft towers in operation at present. An examination model worked in Spain in the 1980s, and Enviro-mission is proposing to build a full-scale force station utilizing this innovation as a part of Australia.

1.2.10 Renewable Solar Power Systems with Regenerative Fuel Cell Systems

NASA has since quite a while ago perceived the exceptional points of interest of regenerative energy component (RFC) system s to give energy stockpiling to solar force systems in space. RFC system s are remarkably qualified to give the important energy stockpiling to sun based surface power systems on the moon or Mars amid long stretches of dimness, i.e. amid the 14-day lunar night or the12-hour Martian night. The way of the RFC and its inalienable configuration adaptability empowers it to viably meet the necessities of space missions. Also, throughout executing the NASA RFC Program, analysts perceived that there are various applications in government, industry, transportation, and the military for RFC system s too.

1.3 Solar Air Collectors

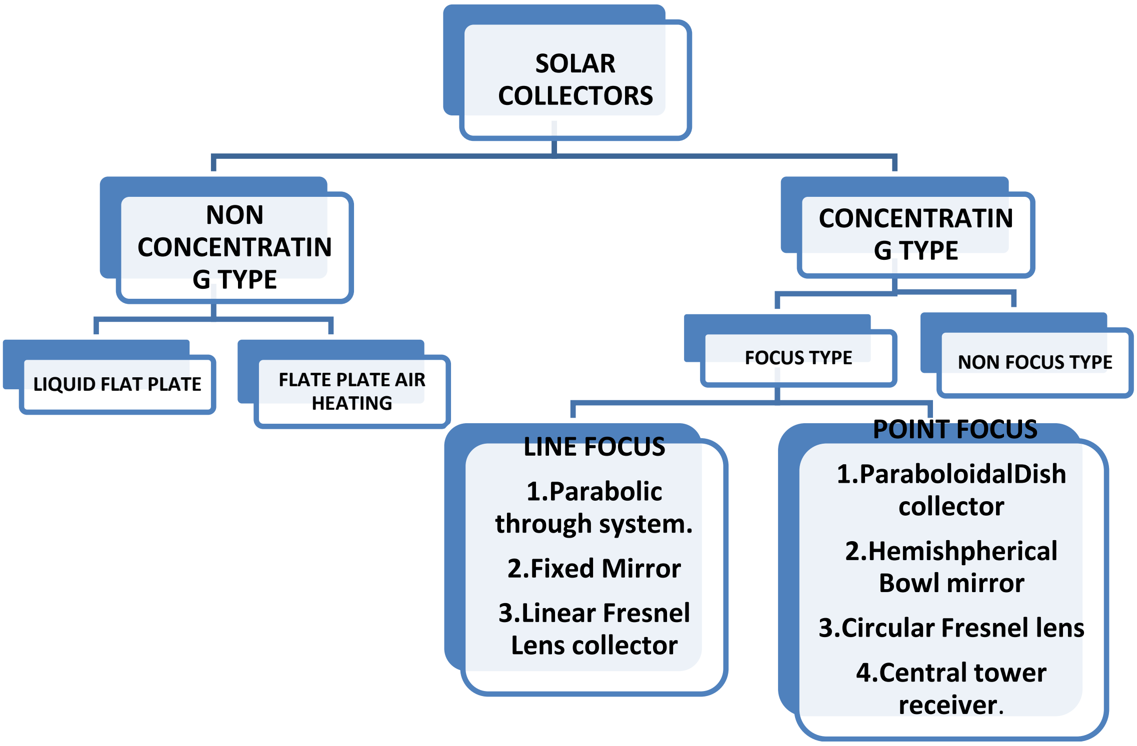


Fig 1: Type of solar collectors

Sun based collectors are an uncommon sort of Heat exchanger which change solar radiation into heat and transfer that heat to a medium (water, solar liquid, or air). At that point solar heat can be utilized for heating water, to go down warming systems and so forth. The efficiency of solar collectors is characterized as the remainder of usable heat energy versus got solar energy. Other than heat loss there is optical losses also.

The critical execution records of solar collector are:

a. Collector Efficiency
b. Concentration ratio
c. Temperature range

The execution of solar collectors is assessed on the premise of these elements. Collector's efficiency is characterized as the proportion of the energy really assimilated and exchanged to the heat transport liquid by the collector to the energy episode to the collector. Concentration Ratio is characterized as the proportion of the region of gap of the system to the territory of collector. The opening of the system is the anticipated territory of the collector confronting the pillar. Temperature extent is the scope of temperature to which the heat transport liquid is warmed up by the collectors.

1.3.1 Fluid Flat Plate Collector

A level plate collector comprises of a safeguard, a straightforward spread, an edge, and protection. Typically an iron-poor sun based security glass is utilized as a straightforward spread, as it transmits an extraordinary measure of the short-wave light range.

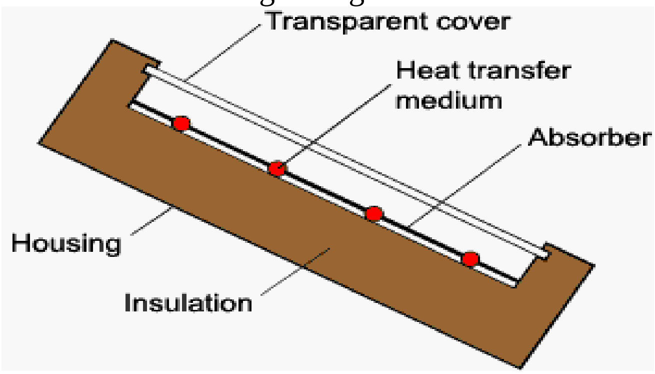


Fig. 3: Fluid level plate collector

At the same time, just almost no of the heat discharged by the absorber gets away from the spread (nursery impact). Furthermore, the straightforward spread keeps wind and breezes from diverting the gathered heat (convection). Together with the edge, the spread shields the absorber from unfavorable climate conditions. Common casing materials incorporate aluminum and electrify steel; here and there fiberglass-strengthened plastic is utilized. The protection on the back of the absorber and as afterthought dividers diminishes the heat losses through conduction. Protection is generally of polyurethane froth or mineral fleece; however, in some cases mineral fiber protecting materials like glass fleece, rock fleece, glass fiber or fiberglass are utilized. With a specific end goal to lessen heat lose inside of the casing by convection, the air can be pumped out of the collectors' tubes. Such authorities then can be called emptied tube collectors. They must be re-cleared once every one to three years.

1.3.2 Flat Plate Air Heating Collector

It is like the fluid level plate collector with an adjustment in design of the absorber and the tube (riser), as demonstrated as follows. The estimation of heat transfer coefficient between the absorber plate and the air is low. Here and there harshness or longitudinal balances are given in the entry of wind current. The key uses of these collectors are drying for horticulture and mechanical purposes, and space warming.

In some cases, harshness or longitudinal blades are given in the section of wind current. The foremost utilizations of these authorities are drying for farming and modern purposes, and space warming.

Fig. 4: flat plate air heater collector

Favorable circumstances more than a fluid level plate collector-

- It is minimal, straightforward in development and obliges little upkeep.
- Erosion is totally killed.
- Spillage of air from the conduit is less extreme.
- Possibility of solidifying of working liquid is additionally killed.
- The pressure inside the collector does not turn out to be high.

1.3.3 Parabolic Trough System

Illustrative parabolic are gadgets that are formed like the letter "u". The troughs concentrate daylight onto a beneficiary tube that is situated along the central line of the parabolic. Infrequently a straightforward glass tube conceals the beneficiary tube to diminish heat lose. Explanatory troughs frequently utilize single-hub or double hub following. In uncommon occurrences, they may be stationary. Temperatures at the beneficiary can achieve 400 °C and produce steam for creating power. In California, multi-megawatt force plants were constructed utilizing allegorical troughs joined with gas turbines

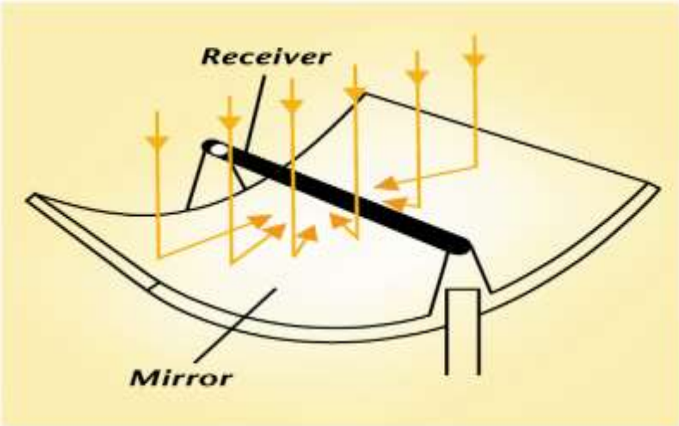


Fig. 5: Explanatory parabolic system

1.3.4 FIXED MIRROR SOLAR CONCENTRATOR

The concentrator contains of altered replicate strips masterminded on a round reference barrel with a following beneficiary tube as demonstrated below in fig. due to on hand hassle in assembling a huge replicate in a solitary piece in a tube shaped allegorical shape, long constrained reflect strips are utilized as part of this concentrator. The recipient tube is made to pivot approximately the point of interest of arch of the reflector module to tune the sun. The image width at the absorberis in an excellent international similar to the predicted width of a mirror element; the point of interest percentage is quite nearly the same as the quantity of replicate strips.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

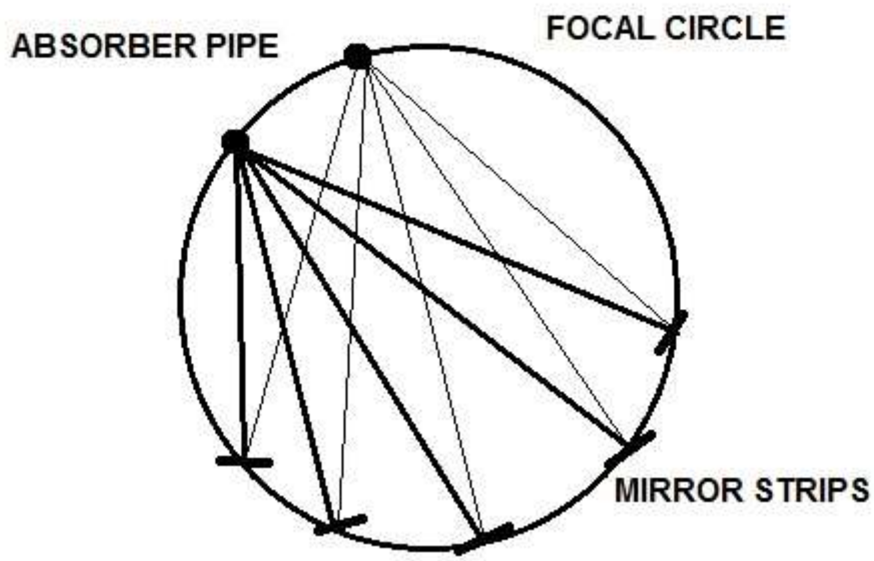


Fig. 6: Altered mirror sunlight based concentrator

1.3.5 LINEAR FRESNEL LENS COLLECTOR

Sun concentrator direct Fresnel lens has been produced for gathering parallel mild to an opening shape. The solar concentrator direct Fresnel lenses are mentioned its Plano side to stand the solar (parallel light supply), and the Fresnel surface to face photovoltaic cells or warmth creditors tube (pay attention) as portrayed inside the chart beneath.

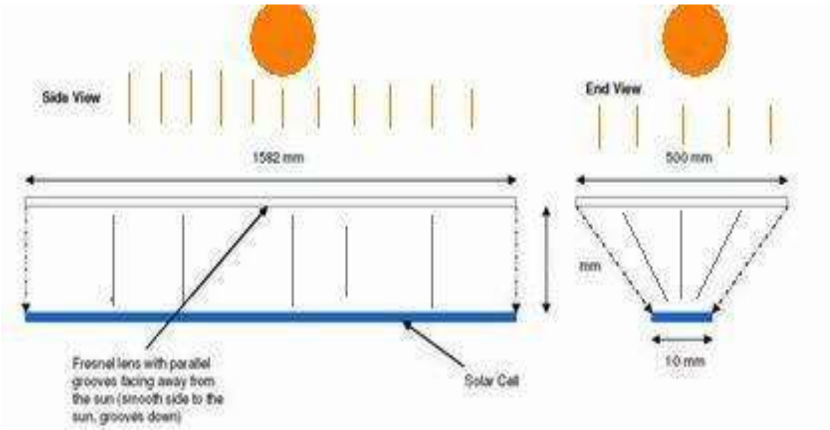


Fig. 7: Straight Fresnel lens collectors.

1.3.6 PARABOLOIDAL DISH COLLECTOR

Using illustrative dishes is a very a whole lot tried manner to address listen sun radiation, and became an early experimental tool at numerous regions round the world. The optical proficiency of allegorical dishes is notably better than that of trough, LFR or force tower gadget s for the reason that the replicate is constantly pointed straightforwardly on the sun, at the same time as the trough, LFR and pressure tower have a diminishment in expected variety because of a frequent low point of fee of the solar radiation. A schematic is indicated in determine.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

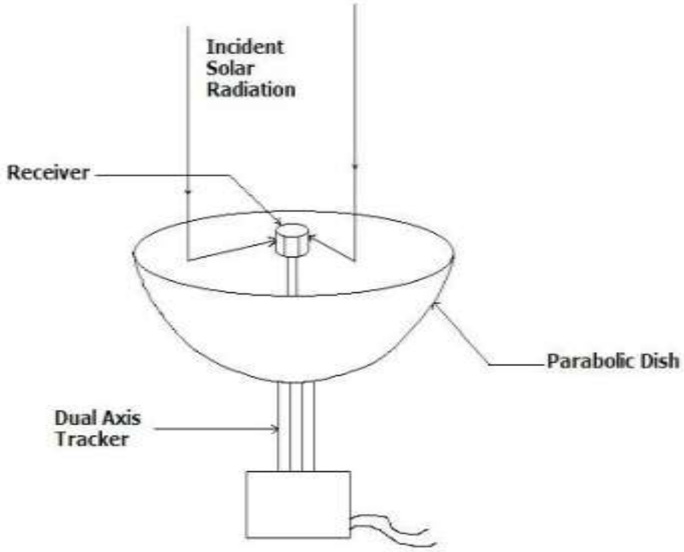


Fig. 8: Paraboloid dish collector.

1.3.7 HEMISPHERICAL BOWL MIRROR

The hemispherical dish is every other case of direct valuable optics. Assorted to the trough or lens, two-pivot following is obligatory. The hemispherical dish is constantly altered, and the beneficiary the focal point of the circle with the sun. The central line is confined to the decrease a massive portion of the variety with the aid of the optical residences of the dish. Due to the fact a few beams achieve the central line with standout reflection and others oblige severe reflections, the energy is not uniform along the length of the imperative line.

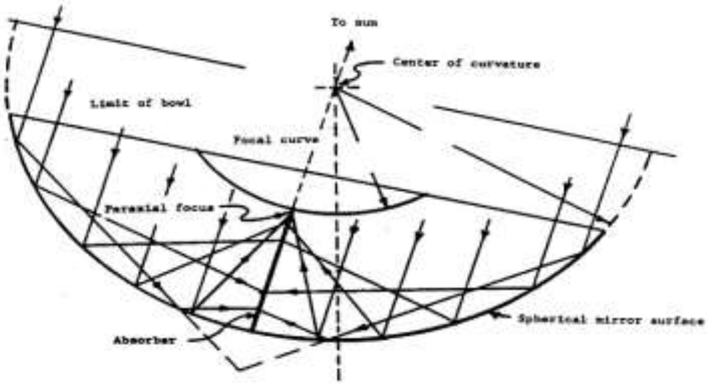


Fig. 9: Hemispherical bowl mirror

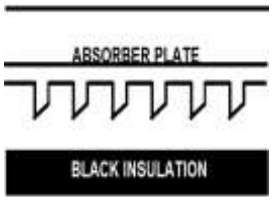
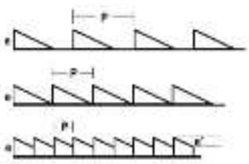
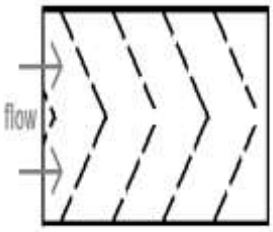
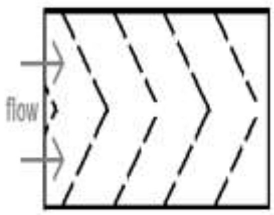
1.3.8 CENTRAL TOWER RECEIVER

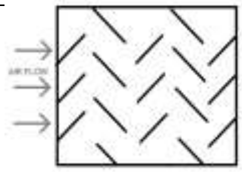
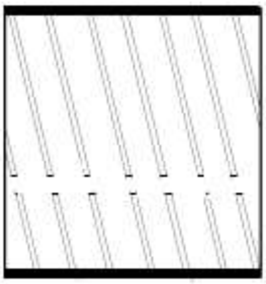
A heliostat makes use of a subject of dual axis sun trackers that direct solar electricity to a large absorber located on a tower. Thus far the handiest software for the heliostat collector is power generation in a system referred to as the power tower. A electricity tower has a field of large mirrors that follow the solar's route across the sky. The mirrors pay attention daylight onto a receiver on pinnacle of a high tower. A laptop maintains the mirrors aligned so the reflected rays of the solar are always aimed toward the receiver, where temperatures nicely above 1000°C can be reached. High-pressure steam is generated to produce power.

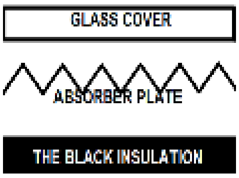
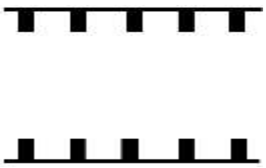
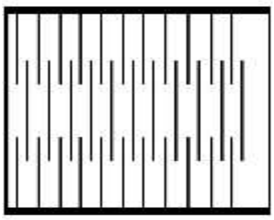
2 Literature Reviews

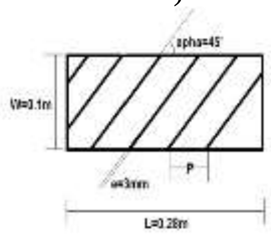
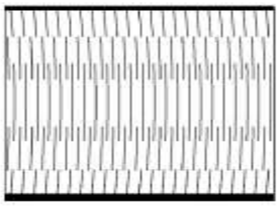
Table 1: Literature Reviews according to various case studies

AUTHOR	ROUGHNESS	REYNOLDS NUMBER	e/D	p/e	A	FINDINGS
R.S. Gill V.S. Hans J.S.Saini Sukhmeet Singh	STAGGERED PIECE IN BROKEN ARC SHAPE	2000-16000	0.043	10	30	The corresponding enhancements over that of smooth duct are 3.06 and 2.50 times respectively. The thermo-hydraulic performance of duct roughened with present rib roughness has been considerably enhanced and was found to be highest for relative staggered rib size of 4.
V.S. Hans R.S.Gill Sukhmeet Singh a	BROKEN ARC SHAPE	2000-16000	0.043	10	30	The corresponding values over that of smooth duct were 2.63 and 2.44 times respectively. Experimental results of heat transfer and friction in flow have also been correlated in terms of flow and roughness geometry parameters.
A.M.LanjewaR, J.L.Bhagoria,M.K.AgrawaL	DOUBLE ARC SHAPE	4000-14000	0.029	10	45	Enhance of Nusselt no 66.99 to 115.24 percent for double arc up.and for down arc 105.57 to 162.45 percent
Sanjay Yadav, Maneesh Kaushal, Varun Siddhartha	ARC SHAPE	1000-40,0000	0.015-0.03	12-24	45-75	The exergetic efficiency of a solar air heater was calculated analytically using developed correlations and the results were compared with that of a smooth flat-plate solar air heater. Design plots were also prepared in order to facilitate the designer for designing such type of roughened solar air heater within the investigated range of system and operating parameters

(i) R. Karwa, S.C. Solanki and J.S. Saini	 Integral chamfered rib	3750-16350	0.019, 0.025, 0.044	4.58,7.09	15˚	Helical rib yields greater heat transfer compared to transverse rib.
(ii) Dr. J.L. Bhagoria, J.S. Saini and S.C. Solanki		3000-18000	0.015, 0.033	5.67,7.57,10.0, 12.1	Wedge angleØ = 8˚, 10˚,12˚,15˚ And α= 90˚	Maximum heat transfer occurs at 10˚wedge angle and at relative roughness pitch of 7.57
(iii)R.Karwa and Kalpanachauhan		2800-15000	0.0467-0.05, and B/S =3	10	60˚ and 90˚	Enhancement in St.no.65-90%, 87-112%,102-137%,110-147%,93-134%,102-142%.Enhancement in friction factor(f)2.68-2.94,3.02-3.42,3.40-3.92,3.32-3.65,2.35-2.47, and2.46-2.58 For Transverse, inclined V-up V down continuous and V-up V down discrete resp.
(iv) K.B. Muluwork,S.C. Solanki and J.S. Saini		2000-15500	e/D= 0.02 B/S = 3-9 S'/S = 1.7	P/e =10 P'/P= 0.6	60˚	St. no. Increases between 1.32-2.47 in the range of system & operating parameters

(v) Dr.A. Lanjewar , Dr.J.L. Bhagoria and Dr.R.M. Sarviya	 	2300-14000	0.03375	10	30˚ ,45˚,60˚ and 75˚	Nusselt number increases and friction factor decreases with increasing Reynolds number. W-down ribs give better thermo-hydraulic performance than W-up and V-ribs. Maximum thermo-hydraulic performance for W-down ribs is 1.98 while it is 1.81 for W-up ribs in the range of parameters investigated
(vi) S.V. Karmare , A.N. Tikekar		4000-17000	0.035-0.044	1.5-36	45° - 60°	Optimum performance obtained for roughness e/D=0.044 and Enhancement of nusselt number was found to be 187%
(vii) Thakur Sanjay Kumar, Vijay Mittal, N. S. Thakur and Anoop Kumar			0.0249, 0.0311, 0.0374, 0.436, 0.0498	8,12,16	60	The temperature rise parameter higher than 0.038 K/m2W, 60°inclined discrete ribs arrangement Provides the higher value of effective efficiency. The set of relative roughness pitch of 12, relative roughness height of 0.0498 and relative gap position of 0.35 shows the maximum effective efficiency and minimum entropy and entropy generation number for the temperature rise parameter nearly about 0.058 K/m2W.
Mukesh Kumar Sahu, Radha Krishna Prasad	ARC SHAPED WIRE RIBS.	5000-40000	0.02130.0422	10	30-60	The maximum enhancement in exergetic efficiency of roughened solar air heater as compared to smooth absorber plate solar air heater has been found as 56% corresponding to relative roughness height (e/D) ¼ 0.0422. The design plots, exhibiting the optimum combination of roughness parameters, can be used to design arc shaped wire rib roughened solar air heater.

(viii) A.A. El-Sebaii , S. Aboul-Enein , M.R.I. Ramadan , S.M. Shalaby ,B.M. Moharram		--	--	--	--	The outlet temperature of the DPVCPSAH is 5% higher than that of the DPFPSA ,The DPVCPSAH is 11to14% more efficient than the DPFPSAH. The thermal efficiencies of the DPFPSAH and DPVCPSAH increase with increasing ‘m’until a typical value of 0.04 kg/s, beyond 0.04 kg/s.
(ix)J.C. Han		7000-90000	0.021-0.063	10 to 40	90	Max value of f & St at p/e=10
(x)R.P. Saini	Curved shaped wire	2000-17000	0.0213-0.0422	10	α/90=0.33 to 0.66	Maximum enhancement in Nu obtained as 3.8 times and f=1.75 times at α/90=0.33,e/d=0.042
(xi) M.M sahu and J.L.bhagoria	Briken 90 ribs 	3000-12000	0.0377	10	--	-Nusselt no. increases , attains a maximum for the roughness pitch of 20 mm. -pitch 20 mm gives the highest efficiency of 83.5%. -the heat transfer coefficient is increased by 1.25-1.40 times as compared to smooth rectangular duct.

(xiii)Giovanni Tanda	rectangular channel with 45 angled rib turbulators on one/two walls) 	8000-40000	p/e= 6.66, 13.6 and 20.0		α =45°	Nusselt number values typically decrease along the span wise direction because of the secondary flow induced by rib inclination. Heat transfer augmentations, relative to the smooth channel with the same mass flow rate, decrease with Re, as typically occurs in rib-roughened channels, and range from 1.6 to 2.25 for the 1RW case and from 1.85 to 2.55 for the 2RW case.
(xiv) Rohit Kumar Choudhary	Single discrete arc rib 	3000-15000	0.0225-0.0315	0.6	α/90= 0.33	(1)Considerable enhancement is achieved in heat transfer coefficient by providing arc shaped roughness element. It is also seen that Nusselt no. increases and is maximum corresponding to relative roughness (e/d) of 0.0315. (2)The maximum enhancement in friction factor is found to be 1.6 times over the smooth plate at relative roughness height (e/d) 0.0315 and Re=15000.
(xv)D. Gupta and S.C. Solanki	Circular wire	3000-18000	0.023	10	40-90	Maximum heat transfer at α=60 and max.f at α=70
(xvi)A. Saidi& R.jia	>>II<<	15000-32000	0.062	---	45	<<ribs performed superior to >> and ll rib.
(xvii)Varun, R.P.saini, S.K.Singal	A review on roughness geometry used in solar air heaters.	--	--	--	--	--
(xviii)BrijBhushan, Ranjit Singh.	A review on methodology of artificial roughness used in duct of solar air heaters.	--	--	--	--	CONCLUSION :- In the present paper an attempt has been made to report heat transfer and friction characteristics of artificially roughened duct of solar air heaters. Methodology of artificial roughness and experimental studies carried out by various investigators have been discussed and reported in detail. It is

						observed that artificial roughness is a good technique to improve thermal performance of solar air heaters. Heat transfer coefficient and friction factor correlations reported in literature are presented in tabular form. Information provided in the present paper may be useful to the beginners in this area of research
(xix)S. K.Saini	Single arced shaped	2000-127000	--	--	30˚	Nusselt no.3.80 times and friction factor 1.75 times have been observed more than the smooth duct.

3 Solar Air Heaters

Energy in one-of-a-kind paperwork has performed a vital function in worldwide for monetary development and industrialization. On the grounds that it's far age of energy crises and traditional energy assets are limited, so extra interest is paid to enhance and make use of the non-conventional energy sources. Sun is closing supply of energy. The energy gains through sun in shape of daylight which has infrared assets is to be had unfastened, pollutants free. So, solar energy sticks out a brightest long variety useful resource for assembly continuously growing demand of present and destiny era. The simplest and greenest way to utilize solar energy is to convert it into thermal power, for heating utility by using the use of sun collector. To be had sun air heater, due to its inherent simplicity are reasonably-priced and maximum widely used for many applications at low and slight variety of temperature. when air drift over absorber plate, it creates laminar in addition to turbulent layer over the floor, inside turbulent layer close to plate floor, because of presence of laminar sub-layer is fashioned which decrease warmness switch price. To conquer this problem and to beautify warmness transfer coefficient, artificial roughened absorber plate is satisfactory suitable.

The fundamental game plan of sun air heater is display in determine (an) in which the air is transferring through the entry gave between the warmed divider and safety. Amid circulation the air ingests warmness from the absorber plate via convection system.

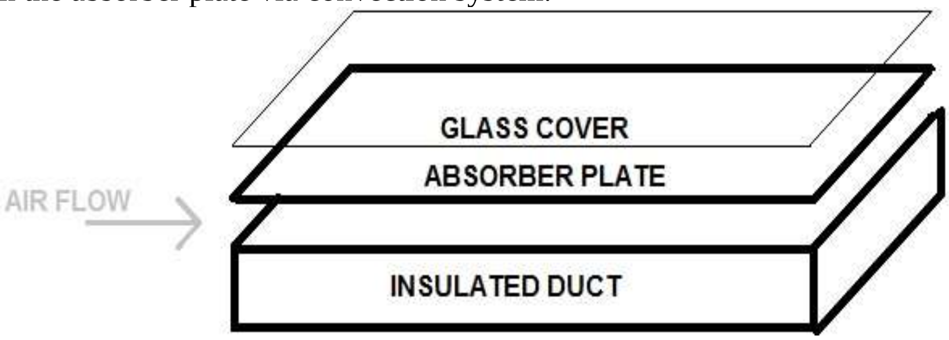


Fig. 10: Solar Air Heaters

Heat execution of a regular solar air heater has been seen to be bad due to the low estimation of convective heat transfer coefficient among the absorber plate and the running liquid however for turbulent circulation. The nice and cozy resistance for the convective warmness transfer is predominantly created through the gooey sub-layer created at the warmth exchanging floor. The utilization of synthetic harshness, notwithstanding enhancing heat transfer coefficient substantially, brings about higher frictional misfortunes prompting the over the top impact prerequisite for circulate of the working liquid (air) through the conduit. It is alongside these strains critical to decorate the geometrical parameters of the counterfeit unpleasantness in order to accomplish the maximum excessive manageable pick up in warmth transfer with least punishment as a way as extended frictional misfortunes. Some specific game plans of wind circulation which are not commonly applied are indicated underneath in determine (b) and figure (c).

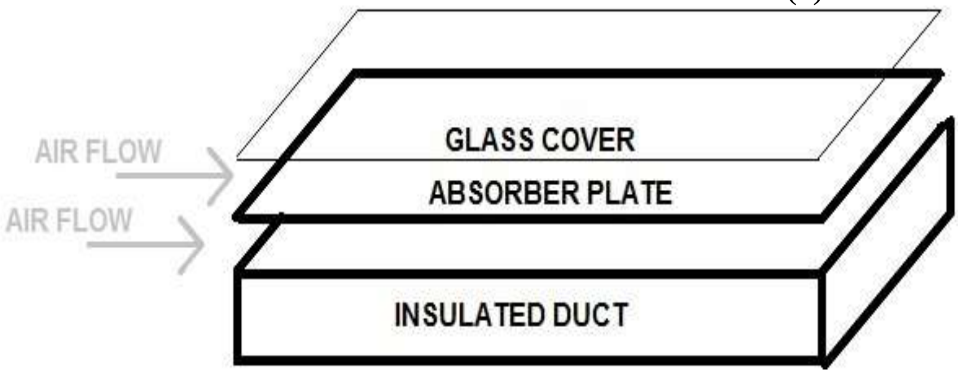


Fig. 11: Solar Air Heaters with dual air flow

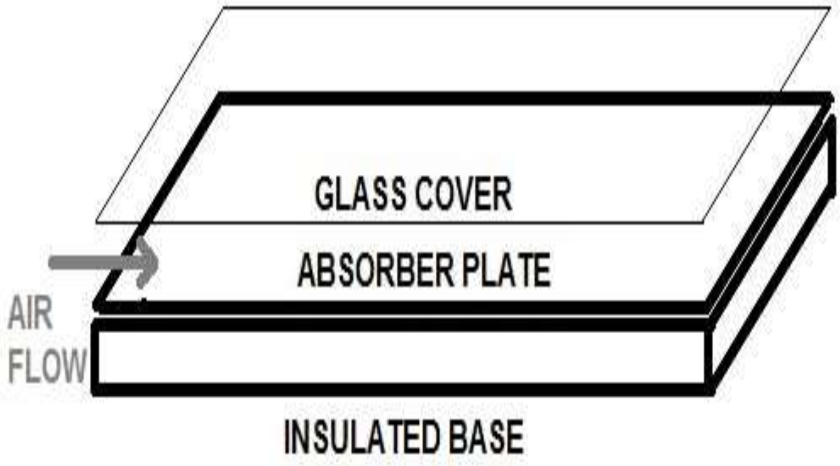


Fig. 12: Solar Air Heaters with single air flow

3.1 Parameters Effect on Thermal Performance of Solar Air Heater

3.1.1 Number of straightforward glass spread

The sincere cover over the absorber of the collector has the ability of allowing the sun based radiation to go through it and pass about as a murky window ornament to the radiation discharged with the aid of the hot guard, but using big number of truthful spread diminishes the charge of strength ingestion by diminishing the transmission of solar radiations. It is found that, using an honest spreads get the effective transmission of sun radiations.

3.1.2 Materials utilized for heated wall

Maintaining in mind the cease goal to change over the sunlight primarily based radiations falling at the warmed divider into heated divider is protected with dark hued paint and essentially metal absorber plate is utilized in light of better heat conductivity of metal than something other substances.

3.1.3 Particular Surface

Absorber plate surfaces which display characteristics of a excessive estimation of absorptive for coming near solar based radiations and coffee estimation of emissivity for energetic re-radiation are known as specific floor. Such floor appearances are appealing since they improve the internet power amassed.

3.1.4 Mass Stream Rate
Measure of energy switch is predicated on upon the mass circulate price, power switch from the absorber plate increments with better estimation of mass stream charge and abatements the temperature of absorber plate, which diminishes the misfortunes and outcomes in better heat productivity.

3.1.5 Climatic Temperature
It is miles determined that the productiveness of daylight based totally air heater moreover prompted by using the surrounding temperature. Given that a strength loss from the collectors is the capability of barometrical temperature for this reason the executions of solar based totally air machine lessens with decline in encompassing temperature.

3.1.6 Spacing
Heat losses likewise fluctuate with keeping apart between spreads and that among the absorber plate and first cover. The dividing at which least misfortune takes place shifts with temperature furthermore with tilt. Considering the fact that collectors are intended to work at various regions with changing tilt and underneath differing management conditions, a really perfect advantage of separating is hard to suggest.

3.1.7 Collectors Tilt
By and big level plate government are applied as a part of an altered role and don't song the solar. Therefore, the lean side at which they're altered is important. Ideal tilt relies on upon the manner of the utility. The everyday exercise is to prescribed an estimation of (ϕ +10̊) or (ϕ + 15̊) for winter programs and (ϕ - 10̊) or (ϕ - 15̊) for summer applications.

3.1.8 Channel Liquid Temperature
The effect of Inlet liquid temperature on execution mentioned by Sukhatme with moving channel temperature from 40˚C to 90̊ C. Increment in gulf liquid temperature consequences diminish in performance since better delta temperature makes the absorber plate temperature better which activates better warm.

3.2 Performance Improvement of Solar Air Heater
Productivity of sun air heater is mainly being predicated on the buildup of daylight based radiations by using sun collectors and the execution of sun government is based on upon the misfortunes of sun based totally radiations from the absorber plate. alongside these strains to enhance the productivity of sun based totally air heater we want to decrease the misfortunes by means of utilizing some systems, some of them are: -

To minimize the heat losses:
- By utilizing various glasses covers.
- By specific covering on absorber plate.
- Use of two passes system s.
- By utilizing Honey brush structure.

To improve the power of solar radiations:
- By utilizing multi reflectors.
- By expanding the region of accumulation of sunlight based radiations

To expand the heat transfer coefficient-
- By utilizing fake unpleasantness on retaining plate
- By utilizing augmented balances.
- By utilizing stuffed bed solar heater

3.3 Impact of Artificial Roughness on Heat Transfer Coefficient and Friction Factor of Solar Air Heater
To increase the proficiency of sun air heater, it is miles appealing to build the convective warmness transfer. The fine method is to provide the manufactured harshness on the surface of engrossing plate which makes the movement of air turbulent on the warmth transfer surface. For the most part which

will make turbulence unreasonable pressure is obliged considering fan or blower is utilized because of this. Turbulence should be made near to the warmth switch floor i.e. in laminar sub-layer location, where the warmth alternate happens whilst it offers a high resistance for the stream of heat. Consequently, heat switch coefficient increment with the aid of softening the layer up this vicinity or making turbulence. Usage of synthetic roughness on the floor of engrossing plate of solar air heater is the best method to build the heat transfer coefficient. Roughness kind that's applied for that reason can be de-scribed via the size less geometric parameters known as relative roughness height (e/D) it's miles the proportion of roughness peak to the pressure pushed distance across of the phase, relative roughness pitch (P/e) the proportion of separation of innovative roughness factor to the peak of roughness, the technique (α) factor of roughness rib w.r.t. the heading of move and the country of roughness aspect. Artificial roughness s can be made by following methods:

- By utilizing scores and edges.
- By sand impacting at first glance.
- By utilizing ribs of distinctive geometries.
- By altering wires.
- By utilizing three dimensional roughness geometries

The improvement of warmth switch coefficient of roughness surface as assessment with the clean surface has been accounted for in writing which is to be discovered 1. seventy-three to 2.19 times and is based at the size less geometric parameters,

3.4 Terminologies used for Roughness

- Relative roughness height (e/D)
- Relative roughness pitch (P/e)
- Angle of attack (α)
- Aspect ratio (W/H)

4 Problem Formulation

The primary target of my work is to increase the heat transfer coefficient of solar air heater with the aid of giving artificial roughness on the absorber plate. It is far an effective device to enhance convective heat transfer of air inside a channel. Via and massive copper wires of numerous measurements (i.e. roughness top) and diverse shape has been utilized to decorate the warmth transfer coefficient. Artificial roughness adjustments over the movement of air from laminar to turbulent, which might likewise increment in erosion losses with extra noteworthy change in proficiency concerning smoother maintaining plate. Because of erosion greater power is obliged to suck the air via the impelled blower applied as a part of trial. Subsequently we need to decrease frictional losses by means of making turbulence extraordinarily close to laminar sub layer place. My target here is to examine the impact of staggered piece in a broken arc roughness on absorber plate of sunlight based air heater and its parameter like heat transfer coefficient and rubbing variable and contrast it and smooth absorber plate.

In perspective of the over, the present work is proposed to incorporate the accompanying targets:

- Test examination of impact of staggered piece in a broken arc on heat transfer coefficient and erosion figure stream.
- Test Setup of the proposed system staggered piece in a broken arc.
- Improvement of relations for heat transfer coefficient and erosion figure terms of harshness geometry and working parameters.
- Examination of progress of warm execution of sun based air heater having Absorber plate roughened with staggered piece in a broken arc.

5 Experimental Investigation

To cognizance the execution of sun orientated air heater by way of using counterfeit unpleasantness of staggered piece in a broken arc, facts in regards to heat change coefficient, rubbing issue, and warmth effectiveness is gotten with the aid of using exploratory installation. Through using exploratory facts, we have a look at the execution solar based totally air heater making use of smooth plate. For the most component we strive to build the warm temperature exchange coefficient and thermo-water powered execution of sun oriented air heater with increment in heat productivity.

5.1 Measurements used for Experimental Set Up

The go sectional angle of stream phase is indicated underneath with the measurements which can be applied to make the circulation vicinity of sun air heater with unsightly plate. The circulate phase includes the phase location from in which the air enters with environmental temperature, test location where the trial test plays at the unpleasant plate (twofold discrete curve molded unpleasantness) and manner out section to take the yield temperature. The pipe is fabricated from timber forums of size 25 mm thickness having dimension of inner go phase is 2042 mm X 2 hundred mm X 20 mm as indicated in discern. The duration of take a look at phase is taken as 1500 mm and passage and manner out area or mixing phase is taken 192mm and 350 mm separately. As some distance as same size of air entry (Dh).

a. Test section= 33.75 Dh
b. Section section=7.2 Dh
c. Way out segment or blending section=12 Dh

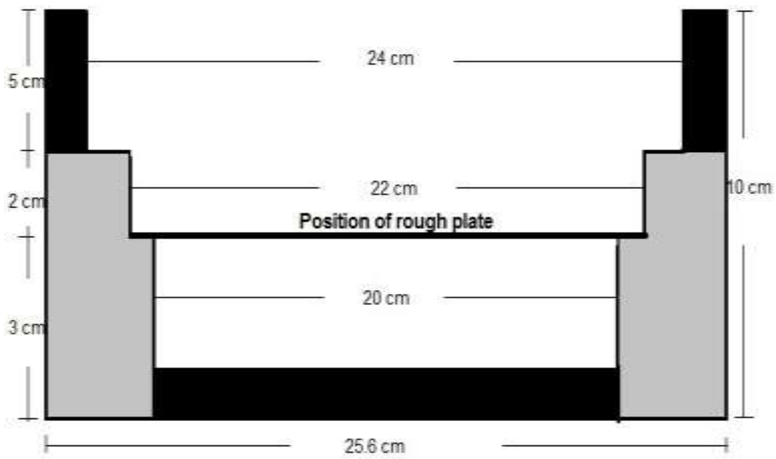


Fig. 13: Cross sectional perspective of Flow segment

Section segment is given to change over the stream of air into completely created stream for the testing area and to take bay temperature of air. In blending segment three astounds are given at equivalent separation i.e. at the separation of 116 mm with the end goal of legitimate blending of hot air turning out from the conduit of solar air heater to get the uniform outlet temperature i.e. mass mean temperature. The position of unpleasant plate on the pipe is demonstrated in figure. The schematic chart of test setup is demonstrated as follows, which contains the instruments utilization to take the suitable information for coveted computation. The subtle element working of test set up and its outcomes has been examined beneath. The test results help us to create the suitable connections.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

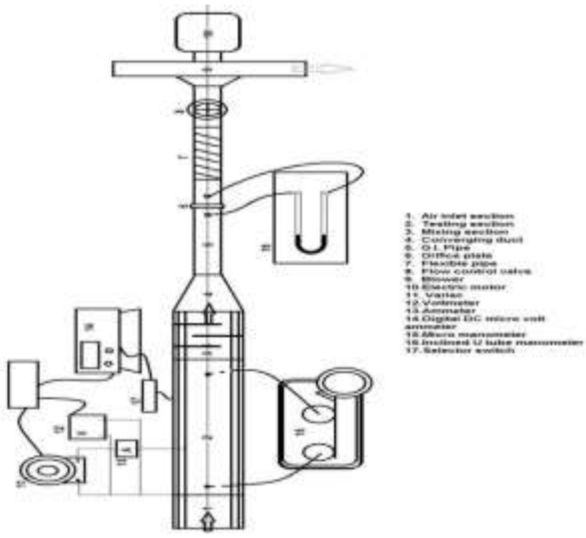


Fig. 14: Schematic diagram of experimental set up showing Top view

We have efficiently talked about the measurements of streaming channel and the location of harsh plate in the pipe. The preserving plate is made by using GI sheet (electrifies iron sheet) having measurements of 1500 mm X 216 mm X 0.5mm and the harshness is given by using utilizing copper wire of unpleasantness stature zero.8mm, 1.3mm and 1.5mm. The higher aspect of preserving plate is protected with darkish paint to build its heated grossing limit. Each side of the engrossing plate, i.e. data air phase and yield place of the conduit is secured with clean confronted 8 mm thick plywood. The outside floor of whole setup is secured through using 25mm thick polystyrene froth having warm conductivity of zero.037 W/m-okay for safety cause. Measurement of GI channel is recommended via Ehlinger, gave on the premise of funnel distance throughout (d1) the duration of GI funnel is taken as 10 seasons of funnel breadth on the upstream side and 5 seasons of funnel width at the downstream side of the hollow plate in gift trial setup we applied 1000mm (13times of d1) channel duration on its upstream side and 700mm (9times of d1) on its downstream side.

Orifice meter is related to slanted u-tube manometer to gauge the mass movement price of air. The circulation of air is managed via utilising manage valve gave the channel. According to the thought of preobrazhensky the width of hollow plate is supposed for the circulation estimation within the channel is taken as 53mm, the opening plate is orchestrated inside the center of the spines to regulate it concentric to the funnel as indicated in fig. of exploratory setup. The T- type thermocouple wires i.e. balanced copper-constantan is utilized to quantify the temperature distinction of air and warmed plate as e m f. Created by means of see lower back impact, the facts in regards to e m f is received by using digital DC smaller scale volt ammeter which display the yield of thermocouple wires in ˚ C. The thermocouple wires are located at equidistance at the warmed divider as validated in fig. Weight drop created over the trying out section amid research become measured by utilizing my smaller scale manometer as indicated in fig. of test setup.

Fig. 15: Data taker

5.2 Instruments used for Data Collection

5.2.1 Heater

Considering that our trial setup is of indoor kind on this way retaining in thoughts the give up purpose to supply the fake sun based radiations at the engrossing plate an electric heater of length 1650mm X 216mm become created through organizing heating wires in association and parallel circles on five mm asbestos sheet. A mica sheet of 1mm thickness is given within the middle of the engrossing plate and heater which is going about as an encasing. Heat flux can be shifted from 0 to a 1000 W/m2 by means of utilizing variac. The pinnacle part of the entire channel is secured with 12mm thick plywood to shield the complete get together.

5.2.2 Miniaturized Scale Manometer

To quantify the load, drop over the check vicinity manometer is utilized with minimum take a look at of 0.0025 mm. Small scale manometers have a roundabout dial having fifty-two divisions and a straightly transferring save. Water is stuffed inside the deliver; a slanted straightforward tube is mounted at the point of interest of device which show the burden drop inside the channel.

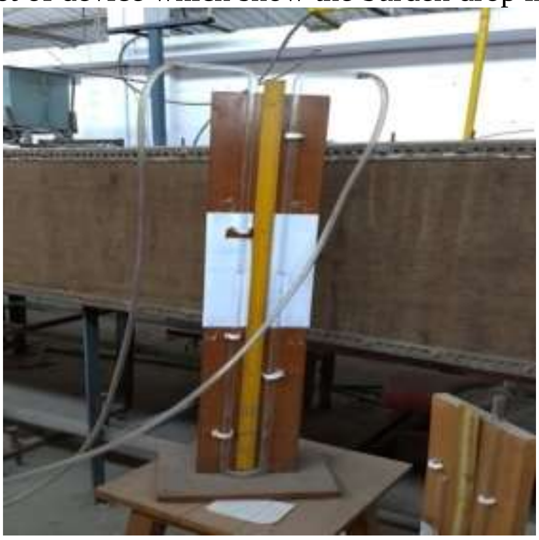


Fig. 16: Micro manometer

5.3 Experimental Procedure

The segments and gadgets are joined accurately with the exploratory installation for becoming operation, next to checking all the institutions blower is then exchanged on. All of the joints of GI funnel are made watertight to take out the slips. Earlier than changing the flow of air thru manipulate valve we have to make the micrometer and U-tube manometer leveled. The circulate control valve is then open to regulate foreordained charge of circulate of air for the testing phase. Test is brought about collect the facts in regards to warmth switch coefficient and frictional flow underneath Quasi-relentless nation situation. Every adjustment in price of move of air the gadget need to attain a long lasting country before the facts turned into recorded. at the point while the running conditions changes then the system takes around 40-forty-five minutes to obtain the Quasi-enduring kingdom. To gather the precise end, result the temperature of streaming air via the channel became saved up extra noteworthy than 10̊ C considering that the temperature estimation affects the precision of heat switch coefficient matter. The temperature difference between the warmed plate and mass air temperature has been stored greater than 20˚C.

The scope of delta air coursing thru the channel is stored up between 30˚C to fortẙ C amid the trying out through community barometrical circumstance. the opening temperature scope of trying out location lies among 50˚C to 80̊ C. The temperature with reference to plate at extraordinary streaming scope of air have taken simply to gather the unfaltering nation circumstance which is concept to be come to while the plate temperature and air outlet temperature did no longer digress extra than a 15 min. of time period. in the wake of coming to the Quasi-enduring nation situation the channel, outlet air temperature and plate temperature by using thermocouple wires, voltage and present day of heater get together through utilizing voltmeter and ammeter, weight drop over the pipe and weight drop over the hole plate through utilising U tube manometer were recorded. For every fake unpleasantness stature six numerous fee of wind cutting-edge as for the Reynolds quantity have been led. The scope of Reynolds range is taken inside the center of 4000 to14000. The parameters measured amid the investigations had been Inlet air temperature, outlet air temperature and plate temperature by using utilizing advanced millimeter and thermocouple wires, stress drop over the pipe with the aid of utilising miniaturized scale manometer and weight drop over the hollow plate with the aid of utilizing slanted U-tube manometer.

Fig. 17: Geometrical construction of staggered piece in a broken arc rib plate.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

5.4 EXPERIMENTAL SETUP

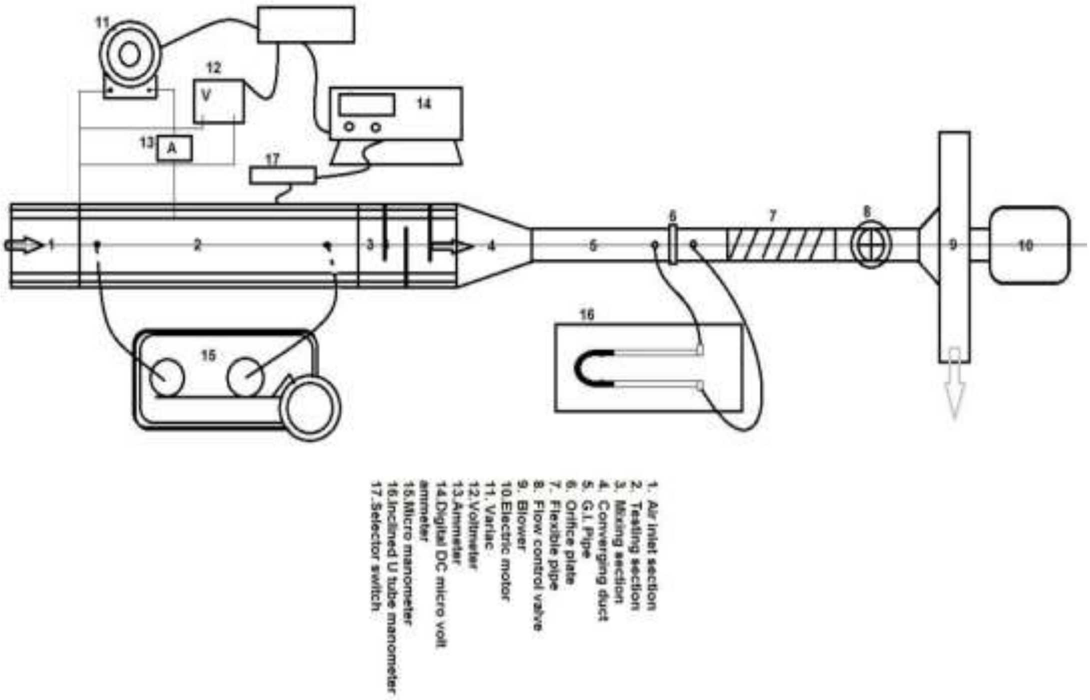


Fig. 18: VARIAC

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

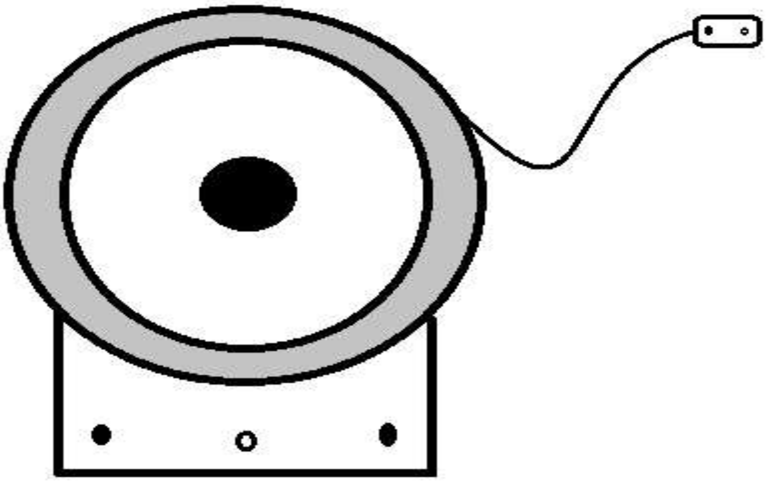


Fig. 19: DIGITAL DC MICRO VOLT AMMETER

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

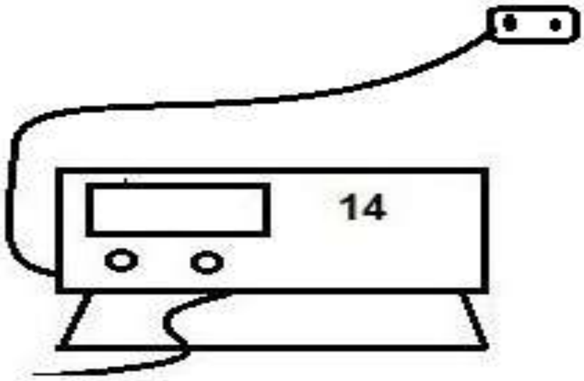


Fig. 20: Setup of Experimentation

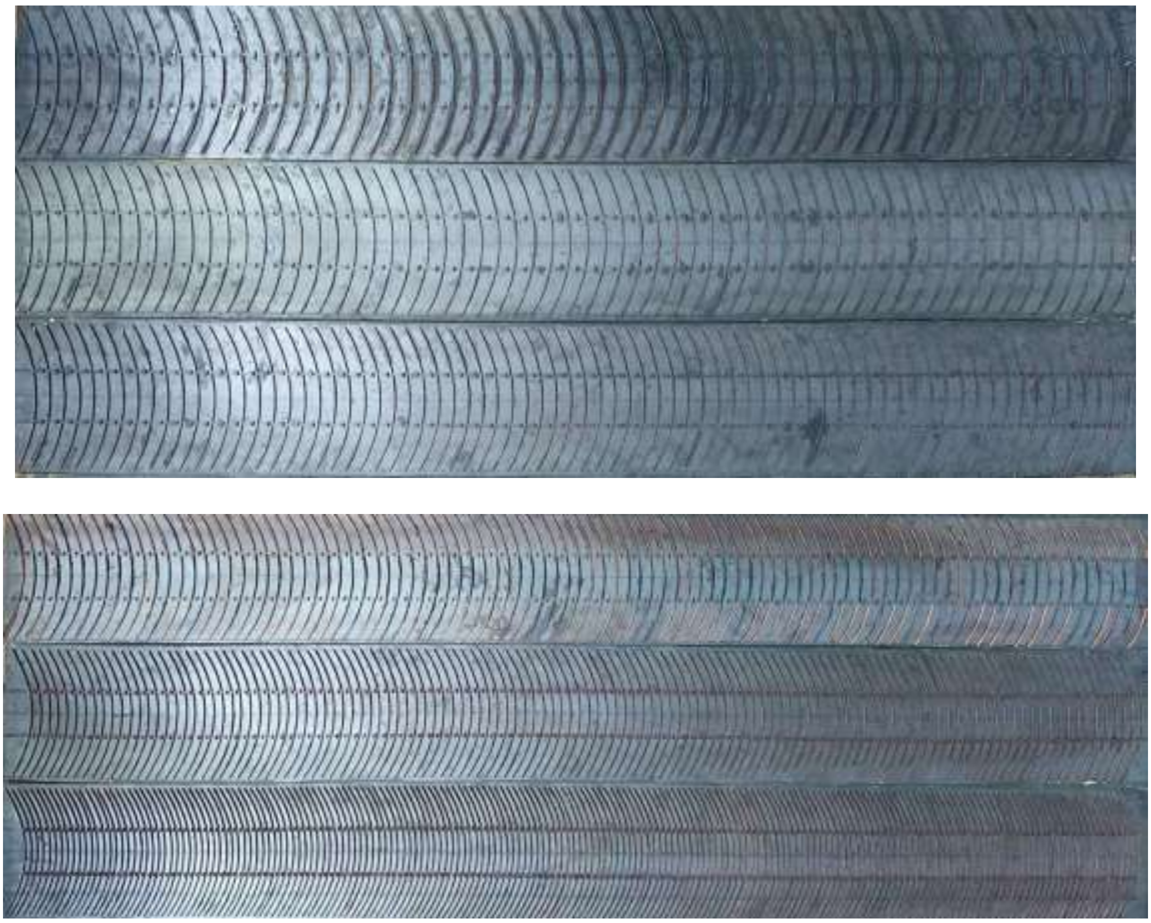


Fig. 21: GEOMETERY OF ARTIFICIAL ROUGHNESS

6 Experimental Data

As we have examined that the information is gathered tentatively by utilizing distinctive segments and instruments for diverse harshness stature of engrossing plate. The stream of air changes by utilizing control valve and the information of roughened plate is contrasted and the smooth plate. The information acquired through test has been utilized to focus the Nusselt number, contact variable, heat transfer coefficient and heat proficiency.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

6.1 Experimental Conditions

6.2 Table 2: Parametric Range

PARAMETERS	VALUE
Roughness height (e)	2 mm
Reynolds number (Re)	4000-14000
Relative roughness height (e/Dh)	2/44.44
Hydraulic diameter(Dh)	0.04444
Angle of Attack (α)	60°
Staggering pitch ratio (P'/P)	0.65
Staggering width ratio (w/e)	2
Relative roughness pitch (P/e)	4 ,6 ,8 ,10, 12,14
Relative angle of attack (α/90)	0.666
Material of absorbing plate	HR sheet
Aspect ratio of Duct (W/H)	8
Testing length	1500 mm
Heat flux (l)	950 watt/m^2

6.3 Data Reduction

6.3.1 Mean bulk air temperature (T_{fav})

Simple arithmetic mean of measured inlet and exit value of air under testing section

T_{fav} = (Ti + To) /2

Where,

Ti = Inlet temperature of air in ˚C

To = outlet temperature of air in ˚C

6.3.2 Mean plate temperature (T_{pav})

Thermocouple wires are arranged at equidistance on the entire length of plate therefore it is the average reading of seven points located at the distance of 187mm on the plate.

T_{pav} = (Tp1 + Tp2 +Tp3 +Tp4+ Tp5 +Tp6) / 6

Where,

Tp1-6= temperature of plate at different locations of plate.

6.3.3 Pressure Drop across the Orifice Plate (ΔPo)

$$\Delta Po = \Delta h \times 9.81 \times \rho m \times 1/5$$

Where,

Δh = Difference of water level in U-tube manometer

ρ_m = Density of water i.e. 1000

6.3.4 Mass flow rate measurement (m)

$$m = Cd \times Ao \times [2\rho(\Delta Po)/1-\beta^4]^{0.5}$$

where, $\beta = d_2/d_1$

C_d= Coefficient of discharge of orifice i.e. 0.61

A_o= Area of orifice plate, m^2

P = Density of air in kg/m^3

6.3.5 Velocity of air

$$V= m/ \rho WH$$

Where,

H= Height of the duct in m

W= Width of the duct, m

6.3.6 Reynolds Number

$$R_e= VD_h/v$$

Where,
ν = Kinematics viscosity of air at t_{fav} in m^2/sec
D_h= Hydraulic diameter
=4WH/2(W+H)

6.3.7 Heat Transfer Rate

$$Qa= mc_p(t_o-t_i)$$

6.3.8 Heat Transfer Coefficient

$$h= Qa/A_p(t_{pav}-t_{fav})$$

6.3.9 Nusselt Number

$$Nu= hD_h/k$$

Where,
k= thermal conductivity
D_h= hydraulic diameter

6.3.10 Thermal Efficiency

$$\eta= Q_a/Apl$$

Where,
l= Heat Flux i.e. 1000W/m^2

6.3.11 Friction Factor

$$f= 2(\Delta Pd\ )D_h/4\rho L_f V^2$$

Where,
ΔPd = Pressure drop in N/m^2

6.4 Observation Tables

Table 3: Experimental observation of smooth plate

Pressure difference, mm							
mm	1.8	2.6	4.2	6.3	8.7	11.9	15.9
Manometer reading, mm							
Mm	15mm	26mm	57mm	100mm	155mm	230mm	326mm
Inlet temperature, ℃							
T1, ℃	30.72	32.06	33.58	35.12	36.11	37.51	37.81
Outlet temperature, ℃							
T2, ℃	43.62	46.07	46.25	46.15	45.45	45.45	45.19
T3, ℃	42.71	45.06	45.25	45.10	44.92	44.78	44.33
T4, ℃	42.06	44.16	44.71	44.74	44.54	44.26	44.12
T5, ℃	42.23	44.42	44.95	45.04	44.70	44.47	44.48
T6, ℃	43.03	45.24	45.98	46. 01	45.34	45.35	45.34
Plate temperature, C							
T7, ℃	72.23	76.97	74.35	71.81	69.29	67.83	66.56
T8, ℃	85.12	86.85	82.27	78.37	74.75	72.59	70.76
T9, ℃	86.81	88.51	83.18	78.79	74.66	72.08	69.84
T10, ℃	90.13	92.16	86.53	82.04	77.66	74.89	72.48
T11, ℃	94.22	96.70	90.61	85.34	80.41	77.38	75.03
T12, , ℃	93.03	95.99	90.04	85.13	80.74	78.12	76.00

Table 4: Experimental observation of an artificial roughness geometry, P/e =4 or $P = 8$

	Pressure difference, mm						
Mm	2.9	5.2	9.8	17.1	26.7	39.3	55.5

Manometer reading, mm							
Mm	15mm	26mm	57mm	100mm	155mm	230mm	326mm
	Inlet temperature, ℃						
T1,℃	38.92	38.45	37.46	35.77	34.29	33.05	32.17
Outlet temperature, ℃							
T2,℃	56.54	56.27	53.28	49.39	45.82	42.63	40.37
T3, ℃	59.08	58.63	55.28	51.16	47.35	44.06	41.65
T4, ℃	58.57	58.17	54.85	50.86	46.99	43.64	41.27
T5, ℃	57.03	56.83	53.77	49.91	46.13	42.86	40.42
T6, ℃	55.34	55.15	52.29	48.48	44.91	41.85	39.71
Plate temperature, ℃							
T7, ℃	79.73	74.20	68.48	63.83	59.52	55.81	53.48
T8, ℃	86.36	82.04	75.85	70.57	65.61	61.29	58.46
T9, ℃	86.69	82.42	75.37	69.16	63.63	59.02	55.85
T10, ℃	89.29	85.04	77.53	70.80	64.75	59.66	56.19
T11, ℃	91.28	87.10	79.51	72.52	66.14	60.80	57.16
T12, ℃	91.18	87.85	80.67	73.74	67.32	61.88	58.17

Table 5: Experimental observation of an artificial roughness geometry, P/e = 6 or $P = 12$

pressure difference, mm							
Mm	4.5	7.7	14.8	25.7	38.7	54.4	75.2
manometer reading, mm							
Mm	15mm	26mm	57mm	100mm	155mm	230mm	326mm
Inlet temperature, ℃							
T1, ℃	39.14	38.80	37.86	36.49	34.92	33.82	32.82
Outlet temperature, ℃							
T2, ℃	56.32	56.46	53.45	49.80	46.36	43.43	41.06
T3, ℃	60.18	59.74	56.20	52.09	48.40	45.15	42.56
T4, ℃	59.76	59.27	55.64	51.63	48.01	44.81	42.21
T5, ℃	57.60	55.26	53.91	45.95	46.46	43.44	40.96
T6, ℃	54.84	55.20	52.49	49.00	45.66	42.75	40.32
Plate temperature, ℃							
T7, ℃	75.16	71.55	66.52	62.48	59.20	55.79	53.15
T8, ℃	83.31	79.93	74.25	69.76	66.00	61.97	58.88
T9, ℃	83.01	79.05	72.24	66.62	62.14	57.84	54.55
T10, ℃	86.61	82.36	74.62	68.40	63.63	59.23	55.81

T11, ℃	88.83	84.74	77.16	71.01	66.30	61.83	58.38
T12, ℃	87.43	83.79	76.57	70.68	66.00	61.49	57.94

Table 6: Experimental observation of an artificial roughness geometry, P/e = 8 or $P = 16$

Pressure difference, mm							
mm	4.0	6.3	12.4	20.1	30.1	42.4	57.4
Manometer reading, mm							
Mm	15mm	26mm	57mm	100mm	155mm	230mm	326mm
Inlet temperature, ℃							
T1, ℃	30.26	31.92	33.45	34.96	36.13	37.33	38.58
Outlet temperature, ℃							
T2, ℃	46.45	47.78	46.76	45.82	44.92	44.61	45.12
T3, ℃	49.61	50.86	49.38	48.03	46.89	46.36	46.76
T4, ℃	49.05	50.26	48.84	47.59	46.53	46.07	46.51
T5, ℃	47.39	48.57	47.26	46.13	45.23	44.91	45.35
T6, ℃	44.74	46.47	45.83	45.05	44.37	44.17	44.66
Plate temperature, ℃							
T7, ℃	65.04	64.22	61.15	59.24	57.91	57.13	58.29
T8, ℃	71.14	69.59	65.25	62.54	60.44	59.13	60.14
T9, ℃	71.01	69.18	64.15	60.97	58.59	57.27	50.02
T10, ℃	73.82	71.99	66.52	62.97	60.47	59.02	59.68
T11, ℃	76.88	75.01	69.35	65.61	62.86	61.14	61.78
T12, ℃	78.06	76.79	71.74	68.20	65.42	63.57	64.26

Table 7: Experimental observation of an artificial roughness geometry, P/e = 10 or $P = 20$

Pressure difference, mm							
mm	4.0	6.8	13.8	23.1	35.4	50.1	68.1
Manometer reading, mm							
Mm	15mm	26mm	57mm	100mm	155mm	230mm	326mm
Inlet temperature, ℃							
T1, ℃	39.99	39.96	39.80	38.83	37.95	36.94	35.20
Outlet temperature, ℃							
T2, ℃	57.85	58.27	55.47	52.07	49.01	46.23	43.49
T3, ℃	61.44	61.40	58.31	54.43	51.05	48.07	44.90
T4, ℃	60.84	60.85	57.71	53.89	50.47	47.60	44.49
T5, ℃	58.57	58.66	55.66	52.05	48.79	46.06	43.09
T6, ℃	56.20	56.89	54.27	51.04	47.96	45.31	42.50
Plate temperature, ℃							
T7, ℃	78.45	74.25	69.23	64.97	61.84	58.82	55.26
T8, ℃	84.36	79.66	73.93	68.97	65.10	61.78	57.89
T9, ℃	85.79	81.03	74.70	69.14	64.86	61.34	57.22
T10, ℃	89.10	84.25	77.55	71.55	67.07	63.40	59.11
T11, ℃	90.76	86.13	79.25	73.08	68.29	64.42	59.99
T12, ℃	94.27	90.57	84.11	77.83	73.02	68.81	63.72

Table 8: Experimental observation of an artificial roughness geometry, P/e = 12 or $P = 24$

Pressure difference, mm							
mm	3.9	6.0	12.0	19.9	29.6	42.5	57.8
Manometer reading, mm							
Mm	15mm	26mm	57mm	100mm	155mm	230mm	326mm
Inlet temperature, ℃							
T1, ℃	36.40	37.27	38.24	38.86	39.45	39.80	40.25
Outlet temperature, ℃							
T2, ℃	52.84	54.42	52.82	51.03	49.59	47.90	46.83
T3, ℃	56.32	57.83	55.91	53.64	51.91	49.88	48.64
T4, ℃	55.77	57.31	55.41	53.20	51.50	49.56	48.33
T5, ℃	53.63	55.15	53.34	51.34	49.84	48.01	46.92
T6, ℃	51.68	53.59	52.07	50.37	49.10	47.43	46.42
Plate temperature, ℃							
T7, ℃	72.42	72.02	68.43	65.99	64.45	62.12	60.62
T8, ℃	79.73	78.86	73.89	70.32	67.71	64.82	63.00
T9, ℃	82.05	81.02	75.43	71.37	68.52	65.42	63.53
T10, ℃	84.90	83.78	77.30	72.70	69.60	66.28	64.19
T11, ℃	85.94	85.15	78.72	73.90	70.56	67.02	64.88
T12, ℃	88.76	86.60	82.52	77.77	74.27	70.66	68.39

Table 9: Experimental observation of an artificial roughness geometry, P/e = 14 or $P = 28$

Pressure difference, mm							
+mm	3.3	6.7	12.6	21.5	31.9	45.3	62.5
Manometer reading, mm							
Mm	15mm	26mm	57mm	100mm	155mm	230mm	326mm
Inlet temperature,℃							
T1, ℃	28.83	30.38	31.71	33.87	35.19	36.28	37.38
Outlet temperature, ℃							
T2,℃	44.32	45.83	44.85	44.34	44.10	44.04	44.25
T3,℃	47.89	49.33	48.04	47.01	46.46	46.13	46.14
T4,℃	47.29	48.77	47.40	46.44	45.88	45.60	45.68
T5,℃	45.36	46.77	45.61	44.84	44.45	44.27	44.43

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

T6, ℃	42.87	44.47	43.75	43.42	43.30	43.29	43.61
Plate temperature, ℃							
T7, ℃	64.14	63.37	60.29	58.87	58.02	57.86	58.09
T8, ℃	70.55	69.70	65.88	63.83	62.56	62.08	61.94
T9, ℃	70.26	69.32	64.98	62.45	60.85	60.11	59.75
T10, ℃	73.19	72.29	67.53	64.54	62.64	61.68	61.21
T11, ℃	74.97	74.08	69.10	65.86	63.72	62.64	62.12
T12, ℃	74.25	73.71	68.89	65.58	63.38	62.26	61.69

7 Experimental Results and Discussion

7.1 Experimental Results

The accompanying results have been acquired amid the exploratory testing which is given underneath in arranged form. The estimation of grating element and nusselt number acquired from the tests where com-pared with the qualities got from connection of the Dittus-Boelter mathematical statement for the nusselt number and adjusted Blasius comparison for the erosion variable. Altered Blasius comparison $fs = 0.085(Re)^{-0.25}$

The estimation of rubbing variable indicated above gives us an examination between the exploratory and anticipated estimation of grinding element. Dittus-Boelter mathematical statement for nusselt number

$Nus = 0.024\ Re^{0.8}\ Pr^{0.4}$

The above estimation of nusselt number gives the trial and anticipated estimation of nusselt number.

EXPERIMENTAL DATAS AND CHARTS

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

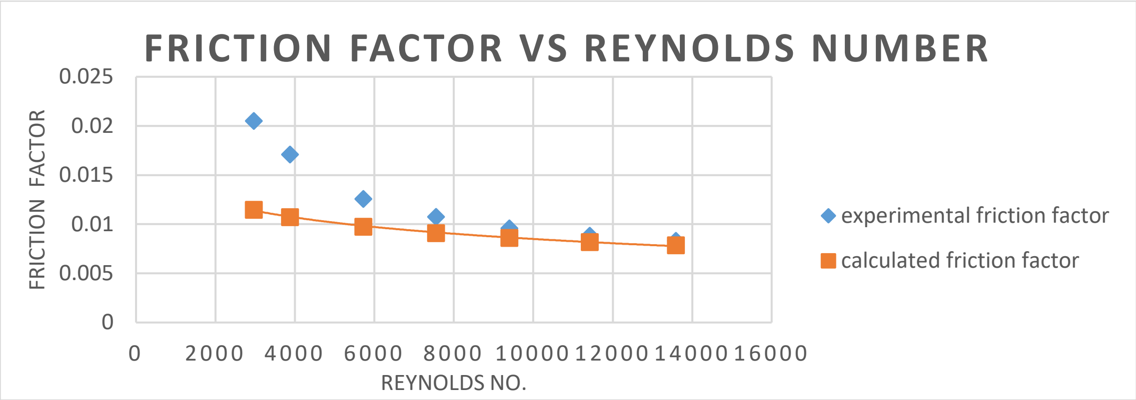


Fig. 22: Comparison of experimental and formulated value of Friction Factor Vs Reynolds no. for smooth plate

Table 10: Observation table for the validation of Friction factor.

S.no.	Reynolds no. (Re)	Smooth experimental data(f)	calculated data(fs)	percent deviation
1	2968.38	0.020507	0.011489	0.4397
2	3880.19	0.017089	0.010744	0.3712
3	5722.96	0.012592	0.009750	0.2256
4	7557.54	0.010766	0.009095	0.1552
5	9398.46	0.009592	0.008613	0.1020
6	11420.06	0.008842	0.008203	0.0722
7	13592.59	0.008335	0.007853	0.0578

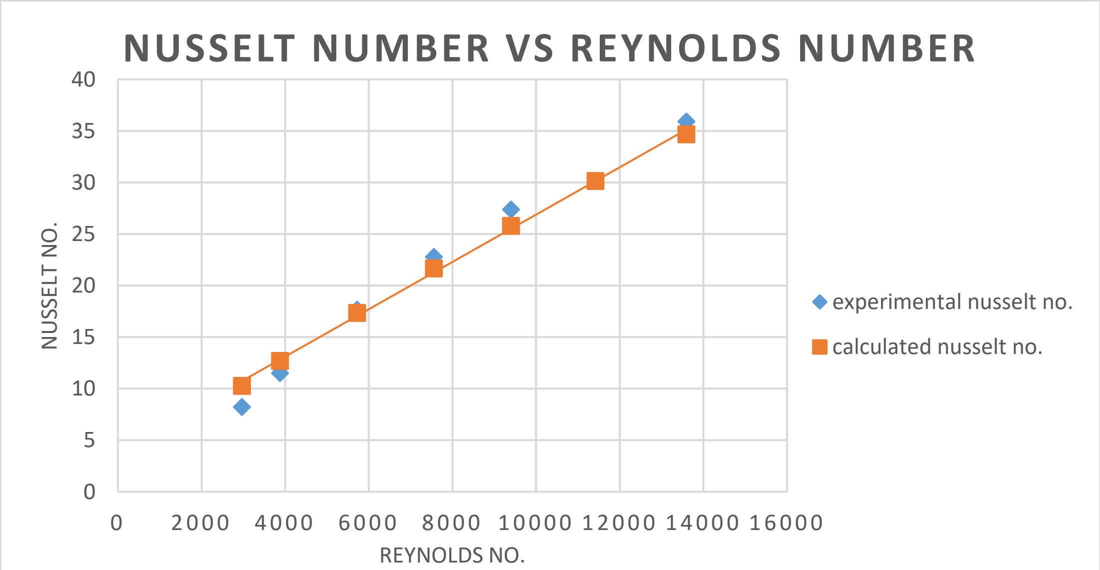


Fig. 23: Comparison of experimental and calculated value of nusselt no.Vs Reynolds no for smooth plate

Table 11: Observation table for the validation of nusselt number

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

S.no.	Reynolds no. (Re)	Smooth experimental data(Nu)	calculated data(Nus)	percent deviation
1	2968.38	8.2531	10.2727	-0.2447
2	3880.19	11.5376	12.7241	-0.1028
3	5722.96	17.6706	17.3609	0.0175
4	7557.54	22.7956	21.6845	0.0457
5	9398.46	27.3999	25.8139	0.0578
6	11420.06	30.1538	30.1656	-0.0039
7	13592.59	35.9079	34.6766	0.0342

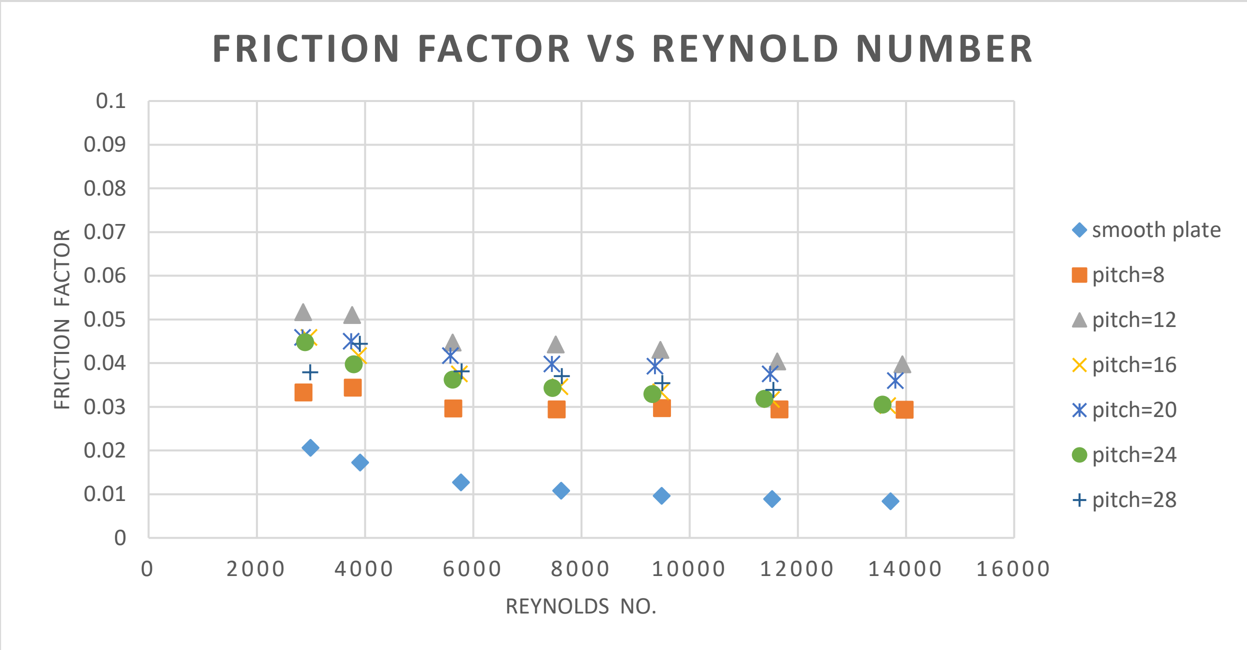


Fig. 24: Variation of friction factor vs Reynolds no. for plate having different p/e ratio.

Table 12: Observation table of friction factor for plates having different pitch to roughness height ratio.

S.no.	Re	Friction factor of smooth	f of P/e=4	f of P/e=6	f of P/e=8	f of P/e=10	f of p/e=12	f of p/e=14
1	2968.38	0.020507	0.033039	0.051268	0.045572	0.045572	0.044432	0.037597
2	3880.19	0.017089	0.034179	0.050611	0.041409	0.044695	0.039437	0.044038
3	5722.96	0.012592	0.029382	0.044372	0.037177	0.041374	0.035978	0.037777
4	7557.54	0.010766	0.029223	0.04392	0.03435	0.039476	0.034008	0.036742
5	9398.46	0.009592	0.029438	0.042668	0.033186	0.03903	0.032635	0.035171

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 4, No. 5, April : 2024

6	11420.06	0.008842	0.029201	0.04042	0.031504	0.037225	0.031578	0.033659
7	13592.59	0.008335	0.029094	0.039421	0.03009	0.035699	0.030300	0.032763

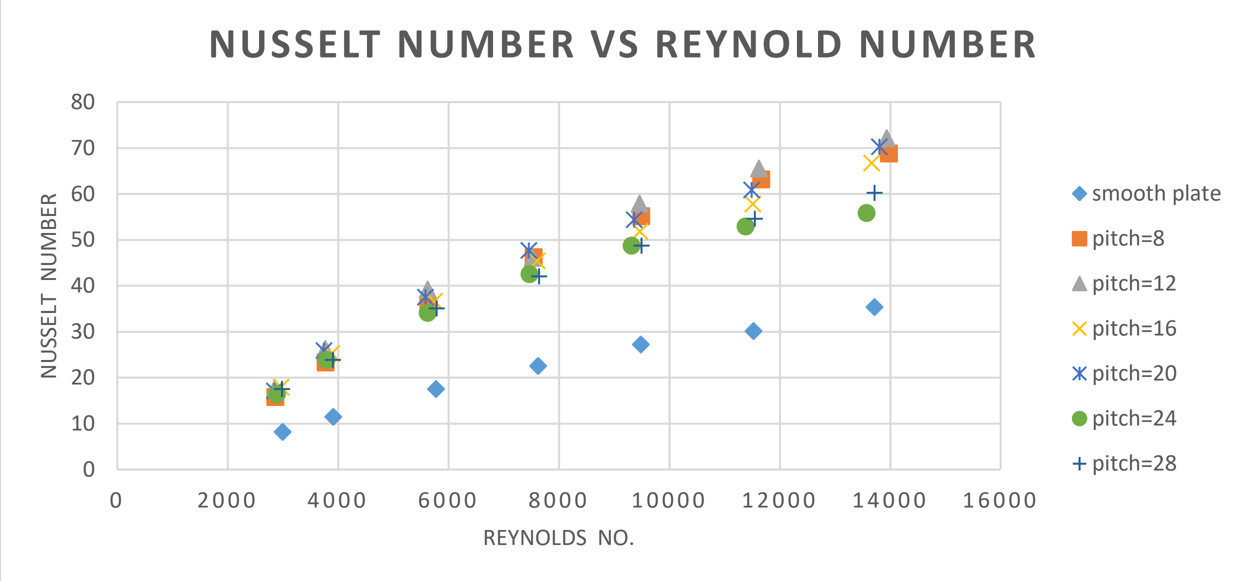


Fig. 25: Variation of Nusselt no. vs Reynolds no. for plates having different p/e ratio

Table 13: Observation table of Nusselt no. for the plates having different pitch to roughness height ratio.

S.no.	Re	Nu of smooth	Nu of p/e=4	Nu of P/e=6	Nu of P/e=8	Nu of P/e=10	Nu of p/e=12	Nu of p/e=14
1	2968.38	8.25	15.53	17.30	17.55	16.65	15.99	17.07
2	3880.19	11.53	22.95	25.60	24.74	25.29	23.26	23.88
3	5722.96	17.67	35.15	39.15	36.63	37.53	34.11	35.06
4	7557.54	22.80	45.64	46.10	45.41	47.69	42.51	42.02
5	9398.46	27.40	54.39	57.83	51.79	54.38	48.73	48.75
6	11420.06	30.15	62.21	65.53	57.81	60.87	52.88	54.56
7	13592.59	35.90	68.80	72.15	66.67	70.22	55.80	60.21

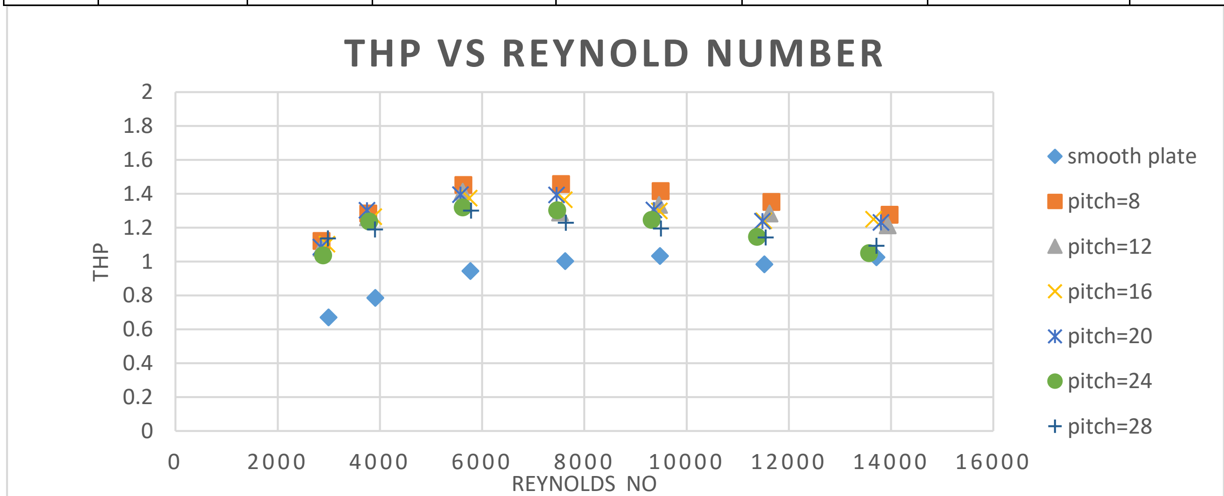


Fig. 26: Variation of Thermo-Hydraulic Performance with Reynolds no. for the plates having different values of p/e.

8 Conclusion

Table 14: Observation table of THP for the plates having different p/e ratio.

Re	THP of P/e=4	THP of P/e=6	THP of P/e=8	THP of P/e=10	THP of P/e=12	THP of P/e=14
2968.38	1.12056	1.08153	1.10180	1.08581	1.03569	1.13520
3880.19	1.28347	1.25964	1.26481	1.30248	1.23519	1.18913
5722.96	1.45029	1.41196	1.37308	1.39491	1.31835	1.29921
7557.54	1.45737	1.28803	1.36425	1.39336	1.30287	1.22929
9398.46	1.41472	1.33396	1.29759	1.30482	1.24585	1.19470
11420.06	1.35197	1.28318	1.23981	1.23794	1.14520	1.14149
13592.59	1.27598	1.21353	1.24840	1.23000	1.04896	1.09216

The experimental investigation has yielded valuable insights into the performance of solar air heaters equipped with staggered pieces in broken arc ribs, particularly in relation to heat transfer and friction characteristics. One notable finding is the correlation between convective heat transfer coefficient and Nusselt number with the increasing Reynolds number, a trend observed across various pitches (p/e = 4, 6, 8, 10, 12, 14). Additionally, the friction factor exhibits a similar trend of increasing with relative roughness pitch. Interestingly, the study highlights that the maximum enhancement in Nusselt number occurs at a pitch of 12 or p/e = 6. Looking ahead, there are promising avenues for future research. Further exploration of heat transfer enhancement can be conducted by varying pitches while employing staggered pieces in broken arc ribs. Moreover, the study underscores the potential for significantly improving the thermo-hydraulic performance of solar air heaters through the strategic use of this particular geometry of artificial roughness. These findings pave the way for advancements in solar energy utilization and contribute to the ongoing efforts in enhancing the efficiency of renewable energy systems.

References

1. Muneer, T.; Asif, M.; Munawwar, S. (2005). "Sustainable production of solar electricity with particular reference to the Indian economy". Renewable and Sustainable Energy Reviews. **9** (5):444. doi:10.1016/j.rser.2004.03.004. (publication archived in Science Direct, needs subscription or access via university)
2. "Solar". Ministry of New and Renewable Energy, Govt. of India. Retrieved 21 February 2014.
3. "Comprehensive technical data of PV modules". Retrieved 21 February 2015.
4. "Solar Energy to Power India of the Future". The World Bank. 2016-06-30. Retrieved 2017-04-"Region-wise monthly solar power generation, CEA". Retrieved 30 November 2016
5. Ekechukwu OV, Norton B. Review of solar-energy drying systems II: an overview of solar drying technology. Energy Convers Manag 1999; 40(6):615–55.
6. Tyagia VV, Panwarb NL, Rahima NA, Kotharic Richa. Review on solar air heating System with and without thermal energy storage system. Renew Sustain Energy Rev 2012; 16:2289–303.

7. Alkilani Mahmud M, Sopian K, Alghoul MA, Sohif M, Ruslan MH. Review of solar air collectors with thermal storage units. Renew Sustain Energy Rev 2011; 15:1476–90.
8. Chamolia, Sunil, Ranchan, Chauhan, Thakura NS, Sainib JS. A review of the performance of double pass solar air heater. Renew Sustain Energy Rev 2012; 16:481–9
9. Prasad BN, Saini JS. Effect of artificial roughness on heat transfer and friction factor in a solar air heater. Solar Energy 1988; 41:555–60.
10. Verma, SK, Prasad BN. Investigation for the optimal thermo-hydraulic performance of artificially roughened solar air heaters. Renew Energy 2000; 20:19–36.
11. Sahu MM, Bhagoria JL. Augmentation of heat transfer coefficient by using 90° broken transverse ribs on absorber plate of solar air heater. Renew Energy 2005; 30:2057–73.
12. Gupta D, Solanki SC, SainiJS. Thermo-hydraulic performance of solar air heaters with roughened absorber plates. SolEnergy1997; 61:33–42.
13. Aharwal KR, Gandhi BK, Saini JS. Experimental investigation on heat-transfer Enhancement due to a gap in an inclined continuous rib arrangement in a rectangular duct of solar air heater. Renew Energy 2008; 33:585–96.
14. Aharwal KR, Gandhi BK, Saini JS. Heat transfer and friction characteristics of solar Air heater ducts having integral inclined discrete ribs on absorber plate. Into J Heat Mass Transfer 2009; 52:5970–7.
15. Momin AME, SainiJS, SolankiSC. Heat transfer and friction in solar air heater duct with v-shaped rib roughness on absorber plate. Into J Heat Mass Transfer 2002; 45:3383–96.
16. Singh S, Chander S, Saini JS. Investigations on thermo-hydraulic performance due to flow-attack-angle in V-down rib with gap in a rectangular duct of solar air heater. Apply Energy 2012; 97:907–12
17. Karwa R, Bairwa RD, Jain BP, Karwa N. Experimental study of the effects of rib angle and discretization on heat transfer and friction in an asymmetrically heated rectangular duct. JEnhancHeatTransf2005; 12(2005):343–55.
18. Maithani R, Saini JS. Heat transfer and friction factor correlations for a solar air heater duct roughened artificially with multiple V-ribs. Sol Energy 2016; 84:898–911.
19. Hans VS, Saini RP, Saini JS. Heat transfer and friction factor correlations for a solar air heater duct roughened artificially with multiple V-ribs. Sol Energy 2010; 84:898–911.
20. Kumar A, Saini RP, Saini JS. Experimental investigation on heat transfer and fluid flow characteristics of air flow in a rectangular duct with Multi V-shaped rib with gap roughness on the heated plate. Sol Energy 2012; 86:1733–49.
21. Kumar A, Saini RP, Saini JS. Development of correlations for Nusselt number and friction factor for solar air heater with roughened duct having multi V-shaped with gap rib as artificial roughness. Renew Energy 2013; 58:151–63.
22. Lanjewar AM, Bhagoria JL, Sarviya RM. Performance analysis of W-shaped rib roughened solar air heater. J Renew Sustain Energy 2011; 3:43110.
23. Lanjewar A, Bhagoria JL, Sarviya RM. Heat transfer and friction in solar air heater duct with W-shaped rib roughness on absorber plate. Energy 2011; 36:4531–41.
24. Lanjewar A, Bhagoria JL, Sarviya RM. Experimental study of augmented heat transfer and friction in solar air heater with different orientations of W-Rib roughness. Exp Thermal and Fluid Science 2011; 35:986–95
25. Saini SK, Saini RP. Development of correlations for Nusselt number and friction factor for solar air heater with roughened duct having arc-shaped wire as artificial roughness. Sol Energy 2008; 82:1118–30.
26. Singh AP, Varun, Siddhartha. Heat transfer and friction factor correlations for multiple arc shape roughness elements on the absorber plate used in solar air heaters. Exp Thermal Fluid Science 2014; 54:117–26.

27. Singh AP, Varun, Siddhartha. Effect of artificial roughness on heat transfer and friction characteristics having multiple arc shaped roughness element on the absorber plate. Sol Energy 2014; 105:479–93.
28. V.S. Hans et al. heat transfer and friction factor correlation for a solar air heater duct roughened artificially with broken arc ribs. Experimental Thermal and Fluid Science 80 (2017) 77–89.
29. N.K. Pandey, V.K. Bajpai, Varun, Experimental investigation of heat transfer augmentation using multiple arcs with gap on absorber plate of solar air heater Solar Energy 134 (2016) 314–326.
30. Varun, Saini RP, Singal SK. Investigation of thermal performance of solar air heater having roughness elements as a combination of inclined and transverse ribs on the absorber plate. Renew Energy 2008; 33:1398–405.
31. Patil AK, Saini JS, Kumar K. Effect of gap position in broken v-rib roughness combined with staggered rib on thermo-hydraulic performance of solar air heater. Green Energy 2011; 1:329–38.
32. Patil AK, Saini JS, Kumar K. Heat transfer and friction characteristics of solar air heater duct roughened by broken V-shape ribs combined with staggered rib piece. J Renew Sustain Energy 2012; 4:13115.
33. Patil AK, Saini JS, Kumar K. Nusselt number and friction factor correlations for solar air heater duct with broken V-down ribs combined with staggered rib roughness. J Renew Sustain Energy 2012; 4:33122
34. Deo NS, Chander S, Saini JS. Performance analysis of solar air heater duct Roughened with multi gap, V-down ribs combined with staggered ribs. Renew Energy 2016; 91:484–500
35. Dongxu Jin, Jianguo Zuo, Shenglin Quan, Shiming Xu, Hao Gao. Thermo hydraulic performance of solar air heater with staggered multiple V-shaped ribs on the absorber plate, Energy (2017), doi: 10.1016/j.energy.2017.03.101
36. Layek A, Saini JS, Solanki SC. Heat transfer and friction characteristics for artificially roughened ducts with compound tabulators. Into J Heat Mass Transfer 2007; 50:4845–54.
37. Saini RP, Verma J. Heat transfer and friction factor correlations for a duct having Dimple-shape artificial roughness, for solar air heaters. Energy 2008; 33:1277–87.
38. Bhushan B, Singh R. Nusselt number and friction factor correlations for solar air heater duct having artificially roughened absorber plate. Sol Energy 2011; 85:1109–18.
39. Sethi M, Thakur NS, Varun. Heat transfer and friction characteristics of dimple shaped roughness element arranged in angular fashion (arc) on the absorber plate of solar air heater. J Renew Sustain Energy 2012; 4:23112.
40. Sethi M, Varun, Thakur NS. Correlations for solar air heater duct with dimpled shape roughness elements on absorber plate. Sol Energy 2012; 86:2852–61.
41. Arvind et al. Heat transfer and friction correlations for artificially roughened solar air heater duct with discrete W-shaped ribs Energy Conversion and Management 50 (2009) 2106–2117.