solar Air Heaters

This chapter deals with the description and analysis of various types of solar air heaters. The principal applications in which solar air of solar air used are drying for agricultural and industrial purposes, heaters are used are drying for agricultural and industrial purposes, heaters are heating. Indeed, they are the logical choice for these and space heating. Indeed, they are the logical choice for these applications, compared to liquid flat-plate collectors, because they applications the need to transfer heat from one fluid to another.

5.1 INTRODUCTION

A conventional solar air heater generally consists of an absorber plate with a parallel plate below forming a passage of high aspect ratio through which the air to be heated flows. As in the case of the liquid flat-plate collector, a transparent cover system is provided above the absorber plate, while a sheet metal container filled with insulation is provided on the bottom and sides. The arrangement is sketched in Fig. 5.1 (a). Two other arrangements, which are not so common, are also shown in Fig. 5.1. In the arrangement shown in Fig. 5.1 (b), the air to be heated flows between the cover and the absorber plate itself instead of through a separate passage, while in Fig. 5.1 (c), the air flows between the cover and the absorber plate, as well as through the passage below the absorber plate.

Like a liquid flat-plate collector, a solar air heater is simple in design

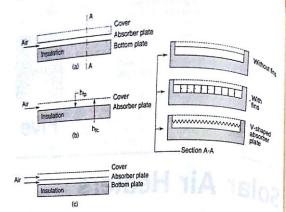


Fig. 5.1 Various Types of Solar Air Heaters

freeze, the solar air heater has the advantage of not requiring any freeze, the solar air neaver has all calculations of the horal leakage special attention at temperatures below 0°C. Corrosion and leakage problems are also less severe. However, the value of the heat transfer coefficient between the absorber plate and the air is low and this results in a lower efficiency. For this reason, the surfaces are some times roughened or longitudinal fins are provided in the air-flow passage. Another variation is to use a V-shaped or corrugated absorber plate [see Sec. A-A, Fig. 5.1 (a)].

A further disadvantage associated with the use of a solar air heater is that large volumes of fluid have to be handled. As a result, the electrical power required to blow the air through a system can be significant if the pressure drop is not kept within prescribed limits.

The face areas of solar air heaters range from 1 to 2 m². Materials of construction and sizes are similar to those used with liquid flat-plate collectors (see Sec. 4.1). Thus, the absorber plate is a metal sheet about 1 mm in thickness, usually made of GI or steel. Glass of thickness 4 to 5 mm is the most commonly used cover material. However, plastics are being used in increasing numbers. Mineral wool or glass wool of thickness 5 to 8 cm is used for the bottom and side insulation. The whole assembly is contained in a sheet metal box and inclined at a

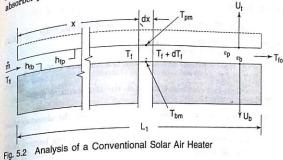
neame argue. Compared to liquid flat-plate collectors, the pace of commercialisa tion for the production of solar air heaters has been slow all over the world. This is true in India as well, where they have been used primarily in systems for forced convection drying of various kinds of gricultural products. Only about 100 such systems have been installed

The reason to slow pace is the fact that drying of far. The products is a seasonal activity, requiring energy for only a figure months. As a result, the drying systems remain idle for a larger months and the economics in terms of the great state when year The reason for the slow pace is the fact that drying of fur. That drying of fur. As a result, the drying systems remain idle for a large few the year and the economics in terms of the payback nerial few the year sessential to pursue other applications. agriculture. As a result, the drying systems remain idle for a large few the year and the economics in terms of the payback period is few the seems essential to pursue other applications like droing is part of seems essential to pursue heating in the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications like droing is part of the seems essential to pursue other applications and the seems essential to pursue other applications are seen at the seems essential to pursue other applications are seen at the seems essential to pursue other applications are seen at the seems essential to pursue other applications are seen at the seems essential to pursue other applications are seen at the seems essential to pursue other applications are seen at the seems essential to pursue other applications are seen at the seems essential to pursue other applications are seen at the seems essential to pursue other applications are seen at the seems essential to pursue other applications are seen at the seems essential to pursue other applications are see after multiple economics in terms of the payback period is part of the seems essential to pursue other applications like drying for part of the seems essential to pursue other applications like drying for port of purposes and space heating in the northern parts of the poor. It is purposes and space heating in the northern parts of the poor. It is purposes and space heating in the northern parts of the industry if the market for solar air heaters is to increase. poor. I purposes and space neating in the northern industrial purposes are solar air heaters is to increase.

PERFORMANCE ANALYSIS OF A PERFORMIONAL AIR HEATER

consider the performance analysis of the conventional air We now consider the Fig. 5.1 (a). The heater has an absorber plate of length heater shown in Fig. 5.1 (a). The air flows in a parallel plate passage but the heater has an absorber plate of length heater width L_2 . The air flows in a parallel plate passage but the heater has an absorber plate of length heater width L_2 . The same shown in Fig. 1 are shown in Fig. 1 are shown in Fig. 2 are shown in Fig. 3.1 (a). We shown in Fig. 0.1 (a). The neater has an absorber plate of length heater shown in Fig. 0.1 (a). The air flows in a parallel plate passage below the L_1 and width L_2 . The air flows in Fig. 5.2.

L1 absorber plate. Details are shown in Fig. 5.2.



The analysis is due to Whillier* and proceeds along lines identical to those adopted for the liquid flat-plate collector (Chapter 4) for the calculation of $(\tau\alpha)_b$, $(\tau\alpha)_d$, U_t and U_b . Considering a slice of width L_2 and thickness dx at a distance x from the inlet, we write down energy balances for the absorber plate, the plate below it, and the air flowing in between. We assume that (i) the bulk mean temperature of the air changes from T_f to (T_f+dT_f) as it flows through the distance $d\mathbf{x}$, (ii) the air mass flow rate is \dot{m} , (iii) the mean temperatures of the absorber plate and the plate below are $T_{\it pm}$ and $T_{\it bm}$ respectively and their

Conventional Air Heater with Continuous Longitudinal

The addition of continuous longitudinal fins to the bottom side of the absorber plate improves the heat transfer. This is desirable because it increases the efficiency. We now analyse such a heater in which fins of height L_f and thickness δ_f are spaced at a distance W centre-to-centre apart (Fig. 5.3). The distance between the absorber plate and the bottom plate is L. Consequently the clearance between the fins and the bottom plate is $(L-L_f)$. Considering a slice of width W and thickness dx at a distance x from the inlet, we again write down energy balances for the absorber plate, the bottom plate, and the air flowing in between. The assumptions made earlier in Sec. 5.2 are again made. We get

$$S W dx = U_{t}W dx (T_{pm} - T_{a}) + h_{fp}W dx (T_{pm} - T_{f}) + 2L_{f} dx \phi_{f} h_{ff} (T_{pm} - T_{f}) + h_{r}W dx (T_{pm} - T_{bm}) h_{r}W dx (T_{pm} - T_{bm}) = h_{fb}W dx (T_{bm} - T_{f}) + U_{b}W dx (T_{bm} - T_{a})$$
(5.35)

^{*}A. Whillier, "Black-painted Solar Air Heaters of Conventional Design", Solar Energy

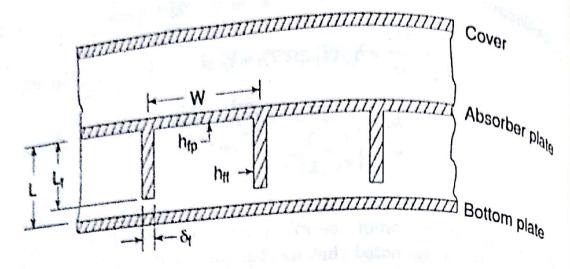


Fig. 5.3 Conventional Air Heater with Fins

$$\frac{W}{L_2} \dot{m} C_p dT_f = h_{fp} W dx (T_{pm} - T_f) + 2L_f dx \phi_f h_{ff} (T_{pm} - T_f) + h_{fb} W dx (T_{bm} - T_f)$$

$$+ h_{fb} W dx (T_{bm} - T_f) \qquad (5.36)$$

It will be seen that additional terms are introduced in Eqs (5.34) and (5.36) to take account of heat transfer from the fin surfaces.

In these equations,

 $\phi_f = \text{fin effectiveness,*}$

 h_{ff} = convective heat transfer coefficient between the h_{ff} surface and the air stream,

 h_r = equivalent radiative heat transfer coefficient;

As in Sec. 5.2, we delete the bottom loss term from Eq. (5.35) and club it with the top loss term in Eq. (5.34). Eqs (5.34) to (5.36) then simplify to

$$S = U_{I}(T_{pm} - T_{a}) + h_{fp} \left(1 + \frac{2L_{f} \phi_{f} h_{ff}}{W h_{fp}} \right) (T_{pm} - T_{f}) + h_{r} (T_{pm} - T_{bm})$$
(5.37)

$$h_r(T_{pm} - T_{bm}) = h_{fb} (T_{bm} - T_f)$$
 (5.38)

$$\frac{\dot{m}C_{p}}{L_{2}}\frac{dT_{f}}{dx} = h_{fp}\left(1 + \frac{2L_{f}\,\phi_{f}\,h_{ff}}{Wh_{fp}}\right)(T_{pm} - T_{f}) + h_{fb}\,(T_{bm} - T_{f}) \quad (5.39)$$

Equations (5.37) to (5.39) become the same as Eqs (5.5) to (5.7) if

$$h_{fp} \left(1 + rac{2 L_f \, \phi_f \, h_{ff}}{W \, h_{fp}} \right)$$
 is replaced by h_{fp} . Thus, the solutions given in

186 Solar Energy $f = 0.06006 \times 3635^{-0.2352} = 0.008734$ $Pressure drop = \frac{4 \times 0.008734 \times 1.060 \times 2 \times 3.900^{2}}{2 \times 0.01768}$ Therefore

= 31.85 N/m²

Comparing these results with those of Example 5.1, we see that the comparing these results with those of Example 5.1, we see that Comparing these results with those of Example 5.1, we see that Comparing these results with the comparing the comp efficiency of the air heater has been cent in absolute terms. Hope cent to 49.8 per cent, a gain of 7.3 per cent in absolute terms. Hope cent to 49.8 per cent, a gain of 7.3 per cent in absolute terms. Hope cent to 49.8 per cent, a gain of 7.3 per cent in absolute terms. efficiency efficiency again of the pressure drop has also increased by a factor of $\frac{1}{2} \frac{1}{h_0}$, the pressure drop has also increased by a factor of $\frac{1}{2} \frac{1}{h_0}$. 15.78 N/m² to 31.85 N/m².

e press. 78 Nm² to 31.85 Nm². 78 Nm² to 31.85 Nm² en finned solar air heaters are some experimental studies a substantial improvement in efficiency. Some experimental studies on improvement in efficiency able. These also indicate a substantial improvement in efficiency able. These also indicate a substantial improvement in efficiency able. These also indicate a substantial improvement in efficiency able. able. These also indicate a subsection of the efficiency of the section of the efficiency of the section of the efficiency of the section of the efficiency However, as seen in Example of the However, as seen in Example of the increase the number of fins because the numb extra pressure drop. Thus, the number of fins because of the increase it does not pay to increase the number of fins because of the increase pressure drop.

Two-pass Solar Air Heater

Two-pass Solar and Deonarine† have suggested the use of a two-pass Sateunanathan and Deonarine† have suggested the use of a two-pass Sateunanathan and Deonarmer in reduce the losses from the top. The solar air heater in order to reduce the losses from the top. The solar air heater in order to reduce the top. They constructed a unit in which the air was first passed between the constructed a unit in which the air was first passed between the constructed a unit in which the air was first passed between the constructed a unit in which the air was first passed between the constructed a unit in which the air was first passed between the constructed a unit in which the air was first passed between the constructed a unit in which the air was first passed between the constructed a unit in which the air was first passed between the constructed a unit in which the air was first passed between the constructed a unit in which the air was first passed between the convergence of the constructed a unit in which the air was first passed between the constructed a unit in which the air was first passed between the convergence of the constructed a unit in which the and then under the absorber plate of a two-glass cover heater and then under the absorber plate of a two-glass cover heater and then under the absorber plate. of a two-glass cover heart as an open system with inlet air at (Fig. 5.4 (a)). When operated as an open system with inlet air at (Fig. 5.4 (a)). When operated as found that the outer glass cover temperature, it was found that it operated neares the ambient temperature, it was lowered by 2 to 5°C and that it operated nearer the ambient ture was lowered by 2 to 5°C and that it operated nearer the ambient ture was lowered by 2 to 5 date the losses were reduced and the efficiency of temperature. As a result, the losses were reduced and the efficiency of temperature. As a result, the collector was measured to be 10 to 15 per cent higher than of ${}_{\hat{a}}$ conventional heater.

Subsequently Wijeysundera et al.‡ have studied the two-pass concept in greater detail both analytically and experimentally. Two two-pass flow arrangements were considered. One arrangement was the same as the one studied by Satcunanathan and Deonarine (Fig. 5.4 (a)), while in the other, the inlet air flowed first above the absorber plate and then under it (Fig. 5.4 (b)). For open systems, with inlet air at ambient temperature, both the two-pass arrangements gave an efficiency of about 10-15 per cent more than the conventional single pass arrange

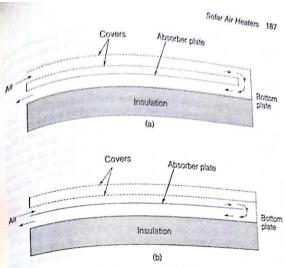


Fig. 5.4 Two-pass Solar Air Heater

ment over a wide range of operating conditions. However, for closed air ment over a systems, the two-pass arrangements yielded a better recirculating system to a certain value of the difference between the air performance only a performance between the air inlet temperature to the collector and the ambient temperature. With inlet temperature. With the arrangement shown in Fig. 5.4 (a), the two-pass design was found the arrangement that the single pass design up to an inlet air temperature to be petter. An arrangement shown in Fig. 5.4 (b). the two-pass design was better up to an inlet air temperature difference

5.3.2 Some Novel Designs

A number of novel designs have also been suggested from time to time by many investigators. Some of these will now be briefly described. They are (i) the overlapped glass plate air heater, (ii) the matrix air heater, (iii) the honeycomb porous-bed air heater, (iv) the all-plastic air heater, and (v) the jet plate air heater. In the first four designs, the air flows through the absorbing surface. For this reason, they are referred to as collectors with porous absorbers. Such collectors generally yield higher efficiencies than conventional designs. In addition, because of larger flow areas, they have smaller pressure drops. In spite of these advantages, they have not been used extensively. A possible deterrent could be the fact that the air flows directly under the cover.

^{*}T.M. Kuzay, M.A.S. Malik and K.W. Boer, "Solar Collectors of Solar One", Proc. Workshop Solar Collectors Heating Cooling Buildings, 99 (1974).

†S. Satunanathan and S. Deonarine, "A Two-pass Solar Air Heater", Solar Energy.

^{15, 41 (1973).}

⁴N.E. Wijeysundera, L.L. Ah and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana" C. J. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana C. J. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana C. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana C. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana C. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana C. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana C. Ah. and L. Ah. and L.E. Tjioe, "Thermal Performance Study of Two-pustable Air Ucatana C. Ah. and L. Ah. Solar Air Heaters", Solar Energy, 28, 363 (1982)

Honeycomb Porous-bed Air Heater

Honeycomb Porous-Deu

The honeycomb porous-bed air heater was suggested by Lalude The honeycomb porous-bed air heater was suggested by Lalude The honeycomb porous-bed air heater was suggested by Lalude Theory.* It is a variation on the matrix air heater, a honeyout the present The honeycomb porous-bed an include the honeycomb porous-bed and honeycomb porous-bed an include the honeycomb porous-bed and honeycomb porous-bed an include the honeycomb po The honeycome.* It is a variation of the Buchberg.* It is a variation of the Buchberg.* It is a variation of the Buchberg.* Because of the presence of the presence of the presence of the presence of the being placed over the matrix (Fig. 5.7). Because of the presence of being placed over the matrix (116. being placed ove honeycomb, the top losses are the honeycomb yielded very high with test module having a rectangular honeycomb yielded very high with test module having a rectangular honeycomb yielded very high with test module having a rectangular honeycomb yielded very high with the honeycomb. test module having a rectangular tion efficiencies, between 10 and 5. Figure 10 and 5. Fi of $(\overline{T_f} - T_a)/I_T$ equal to 18 and 50 selectively reflecting, the ratio of the depth of the honeycomb to the selectively reflecting was 7.1, while that of the two sides are selectively reflecting, the rand selectively reflecting the rectangle was 7.1, while that of the two sides of the rectangle was 7.1, while that of the two sides of the rectangle was 7.1, while that of the two sides of the rectangle was 7.1, while that of the rectangle was 7.1, while the rectangle was 7.1,

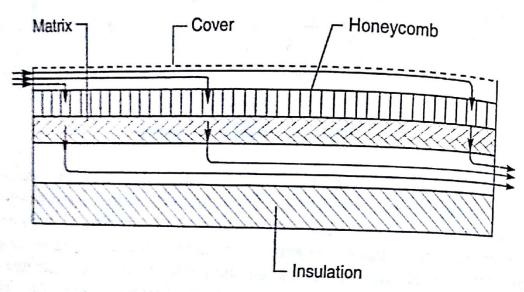


Fig. 5.7 Honeycomb Porous-bed Air Heater

All-plactic Air Una

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significant improvement in the useful heat gain and the collection between the specific case of a spacing of 10 cm between the specific case of 10 cm between the 10 cm between the specific case of 10 cm between the significant improvement in the description of 10 cm between efficiency. For the specific case of a spacing of 10 cm between efficiency. For the specific case of a spacing of 10 cm between efficiency plate and the bottom plate and a flow length of 26.5 per cents of significant improvements are specific case of a spacing of 10 cm between the efficiency. For the specific case of a spacing of longth of the efficiency. For the specific and the bottom plate and a flow length of 2 th, the absorber plate and the bottom plate and to be 26.5 per cent for a mass that increase in efficiency was calculated to be 26.5 per cent for a mass that increase in efficiency was calculated to be 26.5 per cent for a mass that the contract of the provided that the contract of the contract o absorber phase an efficiency was calculated to be bettern for a $\ln_{10} \eta_{0}$ increase in efficiency was calculated to be bettern for a $\ln_{10} \eta_{0}$ increase in efficiency was calculated per unit area of 50 kg/h-m². However, the authors $\ln_{10} \eta_{0}$ increase in efficiency was calculated with additional pressure drop associated with the $\ln_{10} \eta_{0}$ increase the jet plate. This is also likely to be significant. calculated the additional partial tion of the jet plate. This is also likely to be significant,

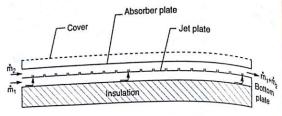


Fig. 5.9 Jet Plate Solar Air Heater

5.4 TESTING PROCEDURES

The standard procedures suggested for testing solar air heaters are The standard procedures suggested in Sec. 4.12 for testing liquid similar in most respects to those described in Sec. 4.12 for testing liquid similar in most respects to those diagram showing the essential features flat plate collectors. Aschematic diagram showing the essential features of the test set-up is shown in Fig. 5.10. It is a closed loop consisting of the solar air heater to be tested, a blower and an apparatus for reconditioning the air which ensures that the air enters the air heater at the desired temperature T_{fi} . Provision is made for measuring the same quantities specified earlier. Some precautions are, however, necessary. Since the fluid is air, it has to be ensured that it is well mixed at the exit from the air heater before its temperature is measured. The mixing is achieved with the help of vanes. As an additional precaution, the temperature both at the inlet and exit of the air heater is measured at a number of locations across the duct cross section.

Measurements are made under the conditions specified earlier and the results are also presented in the same manner. A typical set of results given by Gupta and Garg* is shown in Fig. 5.11. It will be noted that the European practice of plotting the parameter $(\overline{T}_f - T_a) I_T$ on the



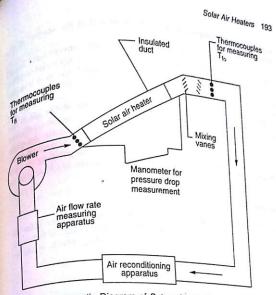
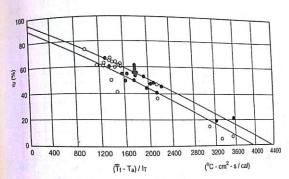


Fig. 5.10 Schematic Diagram of Set-up for Testing Solar Air Heaters



Typical Performance Curves for Two Solar Air Heaters Using

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x-axis has been followed. It will also be seen that the scatter of the again large.

r-axis has been read at a sagain large.

data is again large.

It has been mentioned in Sec. 4.12 that for conventional liquid.

It has been mentioned in the value of m do not appreciably liquid.

flat-plate collectors, changes of high values of the liquid side heat translatery formance because of high values of the refore, generally a street of the same translatery formance because of the same translatery formance because of high values of the liquid side heat translatery formance because of high values of the liquid side heat translatery formance because of high values of the liquid side heat translatery formance because of high values of the liquid side heat translatery for the liquid side heat transla data is again large. It has been in the values of the liquid side heat b_1^{li} b_1^{li} b_2^{li} the performance because of high values of the liquid side heat b_2^{li} b_2^{li} the performance because of such collectors. In the case of b_2^{li} b_2^{li the performance of such collectors. In the case of $\frac{a_1}{b_1}$ degraded the coefficient h_i . A single test curve is, therefore, generally adequals degraded to coefficient h_i . A single test curve is, therefore, in the case of $\frac{a_1}{b_1}$ degraded the predicting the behaviour of such evalues of m appreciably affect $\frac{b_1}{b_1}$ heaters, however, changes in the value of the air side heat transfer coefficient to obtain the coefficient of predicting however, changes in the heat ransfer coefficient of the air side heat transfer coefficient performance because the value of the air side heat transfer coefficient performance because the value of the air side heat transfer to obtain comments in platively low. For this reason, in order to obtain comments it becomes necessary to comments. heaters, more because the value of the performance because the value of the value of the performance because the value of the v performance of mass flow rates with each flow rate yielding its (h_{fp}) is related as solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater, it becomes necessary to conduct team information on a solar air heater than the solar heater than Example 5.3.

Example 5.3

The efficiency curves shown in Fig. 5.12 are obtained for a solar air The efficiency curves shown in the state over a range of flow rates heater $(L_1 = 1.2 \text{ m}, L_2 = 0.9 \text{ m})$ which is tested over a range of flow rates varying from 25 to 200 kg/h. Find the efficiency which would be

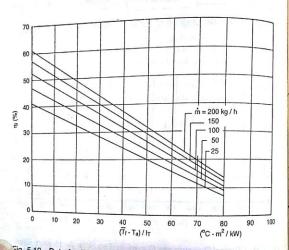


Fig. 5.12 Data for Example 5.2 (η_i is Based on Absorber Plate Area)

obtained and the corresponding mass flow rate if the air heater is used the following conditions:

obtained and following conditions:

obtained and the corresponding mass flow rate if the air heater is used the following conditions: obtained and the corresponding conditions:

obtained and the following conditions:

obtained the following conditions:

= 75°C

Air outlet temperature Ambient temperature Ambient incident on collector face

= 27°C $= 950 \text{ W/m}^2$

Solutions, the x-axis parameter for the given conditions, the x-axis parameter $(\overline{T}_f - T_a)/I_T = \left(\frac{55 + 75}{2} - 27\right) / 0.950$

A trial and error procedure will be necessary in order to find the A trial values of η_i and m.

required values of n_i and m.

quireu vance m = 25 kg/h.

From r_{15} .

Therefore, useful heat gain rate $q_u = 0.242 \times 950 \times 1.2 \times 0.9$

 248.3×3600 $\dot{m} = \frac{q_u}{C_p(T_{fo} - T_{fi})} = \frac{248.3 \times 3600}{1.007 \times (75 - 55) \times 1000} = 44.4 \text{ kg/h}$

(ii) Since the value of \dot{m} calculated from the useful heat gain rate (ii) Since the value of the assumed value, we assume $\dot{m} = 50$ kg/h. This yields does not match the assumed value, we assume $\dot{m} = 50$ kg/h. This yields

 $\eta_i = 28.0 \text{ per cent}$

 $q_u = 287.3 \text{ W}$

 $\dot{m} = 51.4 \text{ kg/h}$

and

(iii) Assume $\dot{m} = 51.4$ kg/h.

This yields

 $\eta_i = 28.09 \text{ per cent}$

 $q_u = 288.3 \text{ W}$

 $\dot{m} = 51.5 \text{ kg/h}$

We accept these values as the solution to the problem.

PROBLEMS

1. The following data is given for a conventional solar air heater with one glass

Length of absorber plate

= 1.90 m

Width of absorber plate

bottom plate

= 0.80 m

Spacing between absorber plate and

= 2 cm



Six

concentrating

In Chapters 4 and 5, we have considered flat-plate collectors for heating liquids and gases to temperatures up to and around 100°C. We now take up the description and analysis of some types of concentrating collectors. These are needed when higher temperatures are required. Typical thermal applications requiring the use of concentrators are medium or high temperature energy conversion cycles and numerous systems for supplying industrial process heat at intermediate temperatures from 100 to 400°C or at high temperatures above 400°C.

Brief descriptions of a few concentrating collectors have been given in Sec. 2.1. We begin this chapter by mentioning briefly the characteristics associated with concentrating collectors (Sec. 6.1). After this, various terms are defined and typical collector geometries described. Flat-plate collectors with reflectors are considered in Sec. 6.2, and the cylindrical parabolic collector in Sec. 6.3. The tracking modes adopted with it are listed and compared, and a performance analysis of the collector is given. The compound parabolic collector is analysed in Sec. 6.4. The chapter concludes with descriptions of the paraboloidal dish collector in Sec. 6.5 and the central receiver collector in Sec. 6.6.

6.1 INTRODUCTION

6.1.1 General Characteristics 6.1.1 General Characteristics are a chieved by using a reflecting arrangement of lenses to a refracting arrangement of lenses to a rediation onto an absorb Concentration of solar radiation arrangement of lenses, harmangement of mirrors or a refracting arrangement of lenses, harmangement of solar radiation onto an absorber of solar radiation on the solar radiation of solar radiation of solar radiation of solar radiation on the solar radiation of solar radiation on the solar radiation of solar radiation of solar radiation on the solar radiation of solar radiation Concentration of a radiation onto an absorber of single arrangement of mirrors of a radiation onto an absorber of single applied system directs the solar radiation onto an absorber of single applied by a transparent cover. Because it is addition to the solar radiation and solar radiation and solar radiation and solar radiation onto an absorber of single solar radiation onto arrangement directs the solar to state optical system directs the solar to state optical system directs the solar to state optical system directs the solar to state optical system, certain losses (in addition to those which we state system, certain losses) the course the course optical system optical syst optical system, certain losses (in addition to those which area which is usually surrounteed in addition to those which we optical system, certain losses (in addition to those which we will be optical system, certain losses (in addition to those which we will be used in the control of the c the optical system, certain iosses through the cover) are introduced through the radiation is transmitted through the cover) are introduced while the radiation or absorption losses in the mirrors or leading reflection or absorption losses in the mirror or leading reflection or absorption losses in the mirror or leading reflection or absorption losses in the mirror or leading reflection or absorption losses in the mirror or leading reflection or absorption losses in the mirror or leading reflection or absorption losses in the mirror or leading reflection or absorption losses in the mirror o

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allector and the collection embedding of the attractive features of the lattractive features of the structure of design and ease of maintains of the structure It has been noted earlier licity of design and ease of maintenance flat-plate collector are simplicity of design and ease of maintenance flat-plate collector. flat-plate collector are simple of the same cannot be said of a concentrating collector. Because of the The same cannot be said of a concentrating collector usually has t_0 presence of an optical system, a concentrating collector usually has t_0 presence of an optical system, that the beam radiation is directed only follow or "track" the sun so that the beam radiation is directed only follows or "track" the sun so that the beam radiation is directed only follows. follow of track the sale and the method of tracking adopted and the precision with which it has to be done varies considerably. In collectors giving a low degree of concentration, it is often adequate to make one or two adjustments of the collector orientation every day. These can be made manually. On the other hand, with collectors giving a high degree of concentration, it is necessary to make continuous adjustments of the collector orientation. The need for some form of tracking introduces a certain amount of complexity in the design. Maintenance requirements are also increased. All these factors add to the cost. An added disadvantage is the fact that much of the diffuse radiation is lost because it does not get focussed.

In the last few years, significant advances have been made in the development of concentrating collectors and a number of types have been commercialised abroad. Almost all of them are line-focussing cylindrical parabolic collectors, and yield temperatures up to 400°C.

6.1.2 Definitions

In order to be consistent in the use of terms, we will use the phrase "concentrating collector" to denote the whole system. The term "concentrator" will be used only for the optical subsystem which directs the solar radiation onto the absorber, while the term "receiver" will

be used to denote the subsystem consisting of the absorber, and other accessories.

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61.3 Methods of Classification 6.1.3 Met. 6.1.3 collectors are of various types and can be classified in Concentrating collectors are of the reflecting type utilizing. Concentrating consecuted and the reflecting type and can be classified in many ways. They may be of the reflecting type utilizing mirrors or of many ways. They may be utilizing Fresnel lenses. The reflection many ways. They may be parabolic, spherical or flat. They may be parabolic, spherical or flat. They may be the refracting type decision is also possible from the point of the po used may be partially a large may be continuous or used may be continuous or used may be continuous or the segmented. Classification is also possible from the point of view of the segmented. Classic distribution of the image, the concentrator being either imaging or formation. Further, the imaging concentrator. formation of the finaging concentrator may focus on a line or

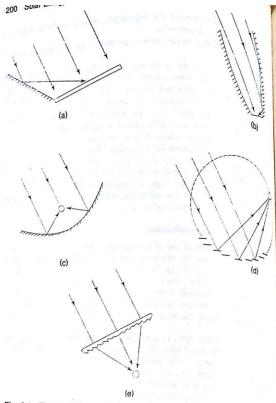
The concentration ratio is also used as a measure for classifying at a point. The concentrating collectors. Since this ratio approximately determines the operating temperature, this method of classification is equivalent to operating temperature range.

Assiming the best of the state of tracking adopted. Depending upon the acceptance angle, the tracking may be intermittent (one adjustment daily or every few days) or continuous. Further, the tracking may be required about one axis or

6.1.4 Types of Concentrating Collectors

Anumber of concentrating collector geometries are shown in Fig. 6.1.

antity defined here is more precisely referred to as the area or geometric



Types of Concentrating Collectors: (a) Flat-plate Collector with Plane Reflectors, (b) Compound Parabolic Collector, (c) Cylindical Parabolic Collector, (d) Collector with Fixed Circular Concentrator and Moving Receiver, (e) Fresnel Lens Concentrating

The first type shown in Fig. 6.1 (a) is a flat-plate collector with adjustable mirrors at the edges to reflect radiation onto the absorber plate. It is simple in design, has a concentration ratio a little above unity and is useful for giving temperatures about 20 or 30°C higher

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than those obtaine than in Sec. 6.2. those sec. 6.2.

It is discussed the rippound parabolic concentrating collector (CPC) is shown in a compound. The concentrator consists of curved segments which is a compound to parabolas. Like the first type, the concentration in the concentration of the conce her in ound parabola. Like the first type, this collector is shown in 6.1 (b). Parabolas. Like the first type, this collector is the first type, this collector is the first type oncentration ratio is moderate. first compound for two parabolas. Like the first type, this collector is also parts againg. The main advantage of the compound for the concentration ratio is moderate and generally also points in 10. rig. 6.1 (by parabolas. Like the first type, this collector is are also for two parabolas. Like the first type, this collector are an advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. a high acceptance angle and consequently requires only that it tracking. In addition its concentration ratio is equal to the parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound parabolic collector from 3 to 10. The main advantage of the compound pa from 3 to has a high acceptance angle and consequently requires only is that it tracking. In addition its concentration ratio is equal to the occasion of the concentration of the concentration occasion of the concentration of the concentrat is that it tracking. In determine the concentration ratio is equal to the occasional value possible for a given acceptance angle. The CPC is national in Sec. 6.4. maximum value possil considered in Sec. 6.4.

aximured in Sec. of collector [Fig. 6.1 (c)] is a cylindrical parabolic next type of collector [Fig. 6.1 (c)] is a cylindrical parabolic which the image is formed on the focal axis of the consult type of the image is formed on the focal axis of the parabolic collector immercial versions of this type are now available. collector in which collect commercial versions of this type are now available. For this many it is described and analysed in detail in Sec. 6.3 Many commercial and analysed in detail in Sec. 6.3.

goon, it is described parabolic collector in which the concentrator Unlike the cylindrical parabolic collector in which the concentrator Unlike the cyncur order to track the sun, the type shown in Fig. 6.1 (d) has a fixed concentrator and a moving receiver. The concentrator is an has a fixed concentrator is an has a fixed concentrator is an has a fixed along a marrow, flat mirror strips fixed along a long, has a fixed concentratory, flat mirror strips fixed along a cylindrical array. The mirror strips produce a narrow line image at cylindrical face. array of long, array of long, the mirror strips produce a narrow line image which follows surface. The mirror strips produce a narrow line image which follows surface. The man as the sun moves. This path is on the same circle on the mirror strips are fixed. Thus, the receiver have a circular paus acircular path in order to track the sum which the circular path in order to track the sum which the circular path in order to track the sun.

ong the circum's also achieved by using lenses. The most commonly Concentration Content and Cont used device is a thin sheet, flat on one side and with fine longitudinal the figure is a continuous of the side and with fine longitudinal grooves on the other. The angles of these grooves are such that radiation is brought to a line focus. The lens is usually made of extruded acrylic plastic sheets. Line focussing collectors like the ones shown in Figs 6.1 (c), (d), (e) usually have concentration ratios between 10 and 80 and yield temperatures between 150 and 400°C.

In order to achieve higher concentration ratios and temperatures, it becomes necessary to have point focussing rather than line focussing. The point focussing paraboloid dish collector has been mentioned earlier in Chapter 2 (Fig. 2.4). Such collectors can have concentration ratios ranging from 100 to a few thousand and have yielded temperatures up to 2000°C. However, from the point of view of the mechanical design, there are limitations to the size of the concentrator and hence, the amount of energy which can be collected by one dish. Commercial versions have been built with dish diameters up to 17 m. In order to collect larger amounts of energy at one point, the central receiver concept (see Fig. 2.16) has been adopted. In this case, beam radiation is reflected from a number of independently controlled mirrors called heliostats to a central receiver located at the top of a tower.