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# Mass flow rate effect on the solar air heater characteristics in Baghdad

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**Abstract**

Computational analysis has matured into a reliable resource for foreseeing the outcome of heat absorption and honing their performance. This represents one of the most time-consuming and mind-numbing tasks to solve the computer simulations that reflect the solar air heating systems and process. Traditional solar air heaters with a single glass cover are mathematically modeled. A collector with a $2m^2$ aperture area has been modeled for Chennai. Once at solar insolation of 734 $W/m^2$, the mean temperature of such outlet atmosphere is 328.352K , meaning that now the ambient temperature increases by 8 C while passing through into the concentrator at a rate of flow of 440 kg/h. The immediate effectiveness of the concentrator is determined to be 51.8%, as well as the pressure loss is calculated to be 36.982 Pa. The findings are in close agreement with those from similar experiments. Heat transport equations for traditional solar air heaters may also be solved using the Finite Difference Method. The corresponding equations have also been supplied.

***Keywords:*** *solar air heater, design considerations, modeling, useful energy, Baghdad.*

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## 1. Introduction

In today's world, a country's wealth may be gauged by looking at its energy consumption, which in turn can be related to the GDP of that country. As a result, there is a continually growing need for various forms of energy. Generally speaking, there are two categories of energy sources: renewable (sun, air, and wind) and non-renewable (coal, oil, natural gas) (coal, petroleum). Nonrenewable energy sources boost industrial development, but they have finite supplies. Climate change and the anticipated rise in oil costs in place ofit run out of remnant fuels consume led many to conclude that a shift to a new energetic paradigm of non-conventional energy use is inevitable for our society. Over the last decade, there has been a concerted movement from academia and industry to hasten the transition to clean, renewable energy. The vast majority of this kind of energy comes from the sun. Solar energy's primary benefit over conventional energy sources is that it does not contribute to pollution when generated or distributed. Most of the world's energy needs have been met by burning fossil fuels for the better part of a century since doing so is both more economical and more practical than switching to renewable energy sources. Photovoltaics, which directly convert sunlight into electricity, have been the focus of much solar energy research in recent years. Beyond this, solar thermal energy may be used for a wide variety of tasks, including heating, drying, and distilling water. Radiation from the sun has a maximum strength of around 1 kWh/m2 when it reaches Earth's surface. Location, cloudiness, daily sunshine hours, and other factors all affect how much radiation is really useful. The ratio between direct and diffuse solar radiation depends on the density of the atmosphere. Though both direct and diffuse forms of radiation have their uses, only the former can be focused. One such equipment is the solar collector, which may be used for a wide variety of tasks including space and industrial heating, as well as the drying of agricultural, textile, and marine items. Several variations of solar thermal collectors have been developed and field-tested. Figures 1 and 2 provide an analytically useful exploded and graphical depiction of a conventional Flat Plate Solar Collector.

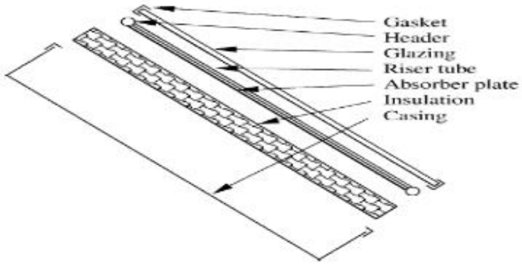


Fig.1 typical solar air heater component

In recent years, computer modeling has shown to be a useful tool for gaining understanding of physical industrial processes, enhancing the efficiency of systems, and optimizing operations. In order to accurately calculate the Thermal performance, Heat transfer gain, Concentrator Utilization, Receiver heat removal criterion, and Pressure loss variable for Flat Plate solar air heaters, it is necessary to first review and comprehend the proposed design of FPSAH. In addition, it is necessary to examine the impact of a temperature increase parameter just on functional effectiveness of other critical factors.

To transform the sun's rays into usable heat, the basic premise behind any solar-thermal collecting device is to point it towards a dark surface. The energy is partially dissipated into the surrounding fluid, usually water or air. The flat-plate collector seems to be the device used to collect irradiation when no refractive concentration is used. In the other sense, a flat-plate absorber is a kind of solar energy collecting device employed when the area of apprehension and absorption are equal. For its low cost, lack of working parts, and low maintenance needs, the flat plate collector has quickly become the most popular and widely used solar collector. It's versatile enough to serve a wide range of purposes that need for heat energy at temperatures between 40 and 100 degrees Celsius. In order to get temperatures exceeding 100 °C, it is frequently essential to concentrate the radiation. For this purpose, collector concentration is used. These devices, known as flat-plate collectors, are quite widespread and may be found in both liquid-based and air-based configurations. These collectors work well in applications that need heat in the winter and have a moderate temperature requirement (between 30 and 70 degrees Celsius). Air-based collectors are used for a wide range of applications, including space heating, ventilation, and crop drying. Using a flat absorber plate, this collector effectively converts solar energy into thermal energy. To To gather sunlight, a flat plate collector uses an absorbing surface—typically a metal plate that has been coated black—that has a high absorptivity. The absorber plate transfers its energy to a carrier fluid that flows through the collector, where it is used. To reduce heat loss, the back is often insulated. The front side is shielded from the absorber plate's infrared rays while still letting in the sun's visible light. There is no need to move or adjust a flat plate collector since it is always facing the sun. For optimal collection, the collector should be pointed due south in the northern hemisphere or due north in the southern hemisphere. Fig 4 Flat plate collector diagram. The plate is sandwiched between a clear glazing and an insulating layer to reduce heat loss. Maximum sunlight is allowed to reach the absorber by selecting glass with these properties. Solar energy has great promise in the areas of providing hot air for the drying of agricultural, textile, and marine goods, as well as heating buildings to keep occupants comfortable year-round, but particularly during the colder months. Several considerations are needed by both the designer and the future user of these systems. The key groups are I thermal performance, (ii) cost, (iii) lifetime/durability, (iv) maintenance, and (v) simplicity of installation. The idea of thermal efficiency allows for a comparison of the collectors' thermal performance. Predicting the thermal performance of the whole solar system, of which the solar air collector is a component, is thought to rely heavily on the collector's thermal efficiency. The testing methodologies for solar air heaters have been laid out in detail by Chandra and Sodha (1991). According to Ekechukwu and Norton (1999), solar air heating systems may be broken down into two main categories: bare plate and cover plate solar energy collectors. According to this categorization, the authors have summarized many solar air heating system configurations. There are easy-to-use gadgets available that harness the power of the sun to warm air. There are several uses for these heaters, all of which need temperatures below 60 °C. Due to air's low density as a working fluid and poor thermal capacity, solar air heaters need more air volume to be handled than liquids. Due to the low Prandtl number of air, solar air heaters are not very efficient. Ucar and Inall, 2006; Ozturk and Demirel, 2008; low absorber to air heat transfer coefficient. Moreover, water is preferable to air for heat storage. Theoretical models are being used to counteract some of these drawbacks. On the other side, solar air heaters' main benefits lie in their relatively inexpensive construction costs, light weight, and lack of risk of freezing, boiling, or pressure. The references include Selcuk (1977), Qenawy (2007), and Mohamad (2007). The significance of key design parameters is established, and their selection is confirmed by experimental findings. According to Karsl (2007) and Chow (2010). A number of improvements are proposed and implemented to boost the absorber plate's heat transfer coefficient with the air. Among these adjustments is the installation of a finned absorber. Hollow spheres Swartman and Ogunade

(1966), a solid matrix Sharma et al. (1991), a corrugated absorber Choudhury et al. (1988), and Garg et al. (1991). Even while these upgrades improve the solar collector's thermal efficiency, the increased pressure drop is a concern when dealing with large airflow rates. It has been observed that the thermal efficiency of a counter-flow solar air heater with a porous matrix is more than 75%, which is much better than the efficiency of the conventional solar air heaters, based on an analysis by Mohamad (1997). Several researchers have tried to improve the efficiency of solar air heaters by experimenting with different collecting materials, collector shapes, and solar air heater configurations. Deniz et al. (2010) conducted an experimental study on three distinct solar flat plate heating systems, two that had fins (Type II and Type III) and another without (Type I), with the only heaters with such a fin being the only glass cover while the other couple having double glasses covers. Solar air heaters' both energy and exergy production rates were measured over time for different air flow rates (25, 50, and 100 m3/m2 h), tilt angle (-15° to +30°), and operating temperatures. They discovered that the Type II heaters with two glass covers and fins were the most efficient, with a greater difference in air temperature between the input and output. They also discovered that the amount of transparent sheets was less of a factor than the amount of time air was allowed to circulate within the heater. Using lower air flow rates is preferable when temperature variations are more crucial in a given application.

## 2. Problem Formulation

Many researchers have carried out experimental studies of solar air heaters using a variety of systems including operating circumstances, as shown by a study of the relevant literature. Without using the same values for factors like surrounding temperature, intake air temperature, airflow rate of mass flow per unit of collectors breadth, gap between both the absorber as well as cover panels, radiation from the sun intensity, etc., it is impossible to compare the performance of various heaters. This necessitates their simulation so that their performance may be compared under the same conditions. In recent years, simulation software has emerged as a useful tool for enhancing system performance and fine-tuning processes. The purpose of this study is to examine the design process for FPSAHs and to provide a mathematical model for thermal analysis of FPSAHs. The literature research informs the selection of a standard solar air heater with a basic geometry. The traditional flat plate passive solar heater (FPSAH) was already simulated mathematically. Applying the underlying conservation rules yields a theoretical formulation for creating an FPSAH. Heat is evenly distributed between the glass caps, the air flow, and the thermally insulated in an FPSAH. The partial differential equation equations as well as operating conditions are obtained from the thermal environment for the air flow. In order to model a particular solar air heater, the mathematical expressions describing it are solved using the method of finite differences (FDM). To have a better understanding, researchers have experimented with varying the air mass flow rate, intake air temperature, collector duct depth, and solar radiation intensity. Simply said, simulation is a way to estimate how a new or current system will perform without actually doing any tests. The creation of a dynamic mathematical model of the issue is an integral part of system simulation. A numerical solution is found for the mathematical model. The energy consumption and production of FPSAH have been analyzed. Heat and fluid flow are assumed to be one-dimensional and stable throughout the study. The answer to the issue is found by a numerical method.

The standard FPSAH assessment utilizes the following presumptions:

1. An airflow was uniform and unidirectional.
2. Air's thermophysical characteristics don't change much with temperature. No matter where in the channel you are, the speed of the air is the same everywhere.
3. Because of the thinness of the coverings, there is hardly any discernible temperature loss.
4. Radiant heat lost via the collector's walls is negligible and may be ignored.
5. All elements and their protective glass shells maintain a consistent temperature throughout.

## 3. Mathematical modeling

A solar air heater design process is outlined below for your perusal. Use of Mani, 1981 for solar data necessary for simulation software. Collector efficiency is calculated using formulae derived from the research presented in SukhatmeS.P.andNayak J K, 2011.

## 4. Solar Collectors Design Process

The steps for running the simulation are detailed below. Day-of-the-week calculator on April 21, 2022
FPSAH's energy efficiency has been analyzed. One-dimensionality and steady-state conditions for the heat and fluid flow are assumed for the study. To get the answer to the issue, we resort to a numerical method. In the current investigation, a mathematical model is initially developed by applying the underlying conservation rules.

Balanced heating is achieved between the glasses covers, air flows, and thermally insulated of any particular air heater. Its governing equations formulas and boundary conditions are obtained from the heat balance for the air flow. The non-linear nature of the issue, brought about by the radiation heat exchange factors, makes finding an accurate solution tedious. For this reason, a numerical method that provides a solution with acceptable precision is required. Differential equations have been solved using finite difference method (FDM). First, the physical domain must be converted into a computational grid in order for the FDM method to be used. The second step is to convert the differential equations into difference equations. These are the simultaneous non linear algebraic equations, combined with the equations derived from a heat balance of the coverings and absorber. The next step is to use the gauss elimination technique to find numerical solutions to those. Nodal temperatures for the coverings, air streams, and absorber are the result of this calculation. After doing extensive research on the effects of varying the air volume flow rate, the input air temperature, the level of the collector duct, as well as the quantity of solar radiation, a complete picture of the system's performance has been pieced together. The following is the energy balance for the conventional FPSAH and the suggested model using the Finite Difference Method during the steady state.

The simulation procedure is given below. Determining number of the day for

21st April 2022

n=31+21=52

Hour angle at 11.00 pm

ω = ((12-time)*15□)= 15□

Declination angle for the day of the year, n = 111, for 21st April

$$\delta = (23.45 \cdot \text{deg}) \cdot \sin\left[\frac{3}{3}(284 + n) \cdot d\right]$$

δ = 115.8 deg

Cos of incident angle for β = 30□and $\phi_1$ =19.12□

$$\cos\theta = \sin(\delta)\sin(\Phi_l - \beta) + \cos(\delta)\cdot\cos(\Phi_l - \beta)$$
$$\cos\theta = 0.924$$

Angle of reflection

$$\varphi_r = \sin^{-1}\left(\frac{s \quad \theta}{1.5}\right)$$
$$\varphi_r = 14.77°$$

Transmissivity of beam radiation for the values of $\tau_r$ = 0.922, $\tau_{ar}$ = 0.969

$$\tau = \tau_r \cdot \tau_a$$
$$\tau = 0.894$$

Transmissivity absorptivity product for $\alpha_p = 0.9$

$$\tau\alpha_b = \tau \cdot \frac{\alpha_p}{1-(1-\alpha_p).0.1}$$
$$\tau\alpha_b = 0.82$$

Transmissivity of diffused radiation for the values of $\tau_d = 0.738, \tau_a =$ 0.964

$\tau_d \quad = \tau_d \cdot \tau_a \quad = 0.71$

Transmissivity and absorptivity product of diffused radiation

$$\tau\alpha_d = \tau_{\text{diff}} \cdot \frac{\alpha_p}{1-(1-\alpha_p).0.1} = 0.65$$

Cos of zenith angle

$$\cos\Theta = \sin\Phi_l \cdot \sin\delta + \cos\Phi_l \cdot \text{ccs}\,\delta \cdot \cos\omega = 0.96$$

Tilt factor for beam radiation

$$r_1 = \frac{c \quad \theta}{c \quad \Theta} = 0.963$$

Tilt factor for diffuse radiation

$$r_2 = \frac{1+c \quad \beta}{2} = 0.933$$

Tilt factor for reflected radiation

$$r_3 = \rho_r \cdot \frac{1-c \quad \beta}{2} = 0.013$$

Flux falling on tilted surface for the values of

$$I_b = 591 W/m^2, I_d = 254 W/m^2$$

$$I_t = [I_b \cdot r_1 + I_d \cdot r_2 + (I_b + I_d) \cdot r_3] = 817.34 \ W/m^2$$

Assuming efficiency of solar collector as 66%.

$$\eta_c = \frac{q_u}{I_t}$$

$$q_u = 539.44 W/m^2$$

Mass flow rate of the air is calculated by assuming a difference of 30 °C in inlet and outlet air temperature of the collector.

$$q_u = m$$

Mass flow rate of the air m = 17.89 g/s or 64.4 kg/h.Mass flow rate of the air can be controlled by adjusting fan speed or using dampers or flow controllers. Energy Balance analysis have been done for FPSAH. The analysis is based on the assumption that heat and the fluid flow are one dimensional and in steady state.A numerical approach is applied to obtain the solution of the given problem. In the present study first, a mathematical model is obtained by the application of the governing conservation laws.The heat balance is accomplished across each component of a given air heater, i.e., the glass covers, the air streams and the absorber plate.
The heat balance for the air stream yields the governing differential equations and the associated boundary conditions. It is because of the radiation heat exchange terms that render the problem non-linear hence making the exact solution cumbersome. So, a numerical approach which would give a solution with a fairly good accuracy is needed.

The mathematical expressions have been solved with the help of finite difference method (FDM). The initial phase of the FDM approach is to map the real-world physical environment onto a computer grid. Step two involves changing existing differential equations as difference equations. These represent the simultaneously nonlinear quadratic equations, together with the thermal equations for the covering with absorber. The next stage is to use the gauss - Jordan technique to find numerical solutions to those. Nodal temperature changes for the coverings, air streams, as well as absorber are the result. Performance characteristics were established after extensive research into varying controlling factors including flow rate, input air temperature, width of such collector ducts, and concentration from solar irradiance. The following is the basal metabolism for something like the traditional FPSAH as well as the suggested model using Finite Difference Technique during steady state operation:

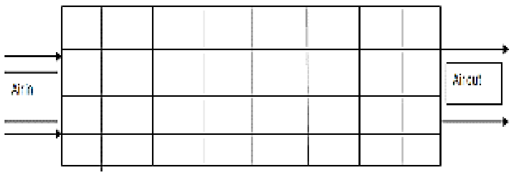

Fig. 4 computational domain for FPSAH

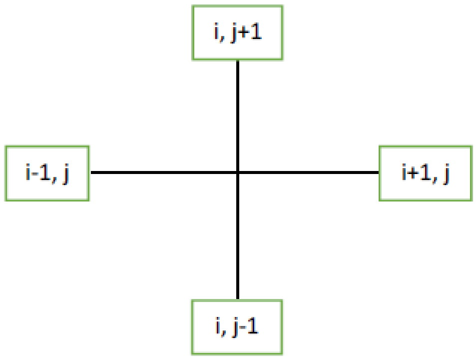


Fig. 4.2 simple nodal diagram

1. For i[th] node 1.

For Absorber plate:

Governing Differential Equation is

$$I\,\tau_b d_b = U_l(T_{pm} - T_a) + h_{fp}(T_{pm} - T_f) + h_r(T_{pm} - T_{bm})$$

The Finite Difference equation is (FDE)

$$I\,\tau_b \alpha_b = U_1(T_{pm}[i] - T_a) + h_{fp}(T_{pm}[i] - T_f[i]) + h_r (T_{pm}[i] - T_{bm}[i])$$

By solving this differential equation, it can be reaching the following

$$T_{pm}[i] = \frac{I\tau_b\alpha_b + U_1T_a + h_{fp}T_f[i] + h_rT_{bm}[i]}{U_1 + h_{fp} + h_r}$$

2. Computational domain of air flow

The differential equation that governed the air flow can be expressed as

$$m_c \frac{dT_p}{dx} = hfp(T_{pm} - T_f) + h_{fb}(T_{bm} - T_f)$$

On solving we get Tf [i+1] =

The central difference formulation had been used to solve this partial differential equation,

$$\frac{T_f[i+1] - T_f[i-1]}{2\Delta x} = h_{fp}(T_{pm}[i] - T_f[i-1]) + h_{fb}(T_{bm}[i] - T_f[i+1])$$

## 5. Results and discussion

MathCAD software was developed to mimic the behavior of a real FPSAH. In addition, finite difference methods have been used to solve differential equations derived from heat exchange across all components (glass cover, air stream and absorber plate). Standard Solar Radiation Data for Chennai is used to model FPSAH. Assuming 7.5 hours of sunlight per day, the average solar irradiance in Chennai is 5.5 kW/m2, or 734 W/m2. Radiation from the sun intensity is also computed for a variety of incoming angles. The collector used in the simulation includes a single transparent cover, a selectively painted aluminum panel absorber, and fiber glass insulation housed in a metal frame. For a certain mass flow rate of air throughout the day, an outlet temperature was calculated. There were a number of losses estimated. The collector's potential heat gain was calculated. A final determination of the collector's thermal efficiency was made. One crucial factor in determining a collector's efficiency is the mass flow rate of the air passing through it. The generated model was also used to determine the outlet temperature of the air from the collector at different flow rates. The generated model was used to forecast the impact of varying volume flow rate, radiation from the sun brightness, and absorber material overall collector performance, as well as this prediction was then contrasted with experimental data gathered from the literature.

Thermal performance as a function of mass flow rate (shown in Fig.5.1) demonstrates the influence of varying parameters on thermal performance. For minimal mass flow rates (0.01 kg/s), efficiency improves dramatically, before leveling off at higher rates. Specifically, the efficiency of the solar is defined as the percentage of the useable gain to an overall solar energy falling on it, and so this ratio is directly related to the mass flow rate.

Figure 5.2 shows how t/Io varies as mass flow rate as a result of the effect of altering parameters. After a mass flow rate of 0.1 kg/s, the ratio of time to IO slows dramatically at first but subsequently stabilizes at a nearly constant value. This might be due to the fact that firstly the system's thermal performance is transformed from solar heat.

Changes in air supply temperature (ta.o) as a result of the mass flow rate are shown in Fig 5.3. This is the result of adjusting the various parameters. At low mass flows, the air outlet air temperature ta.o is quite high. However, as the mass flow rate exceeds 0.1 kg/s, the exit temperature stabilizes at a somewhat constant value. That also illustrating the amount of usable heat gain increases with increasing mass flow rate. As more heat is dissipated into the surrounding air, the temperature within the collector drops. As the temperature of the collector drops, the amount of energy lost decreases. The result is a rise in thermal efficiency.

Measurements of airflow, air temperature at the intake and output, and collector temperature lift are compared with experimental data. There is a good agreement between the findings predicted by the model and the simulation software and the data obtained in experiments. This model has the potential to be useful for assessing standard FPSAH. Baghdad (Latitude: 33° 19' 30.00" N and Longitude: 44° 25' 19.20" E) was used as the site to test the simulation. In the simulation, it was shown that an insolation of 734 W/m2 combined with a mass flow rate of 440 kg/h (0.122 kg/s) yielded an efficiency of roughly 51.8%. This finding agrees closely with previous findings in the literature for the identical collection design.

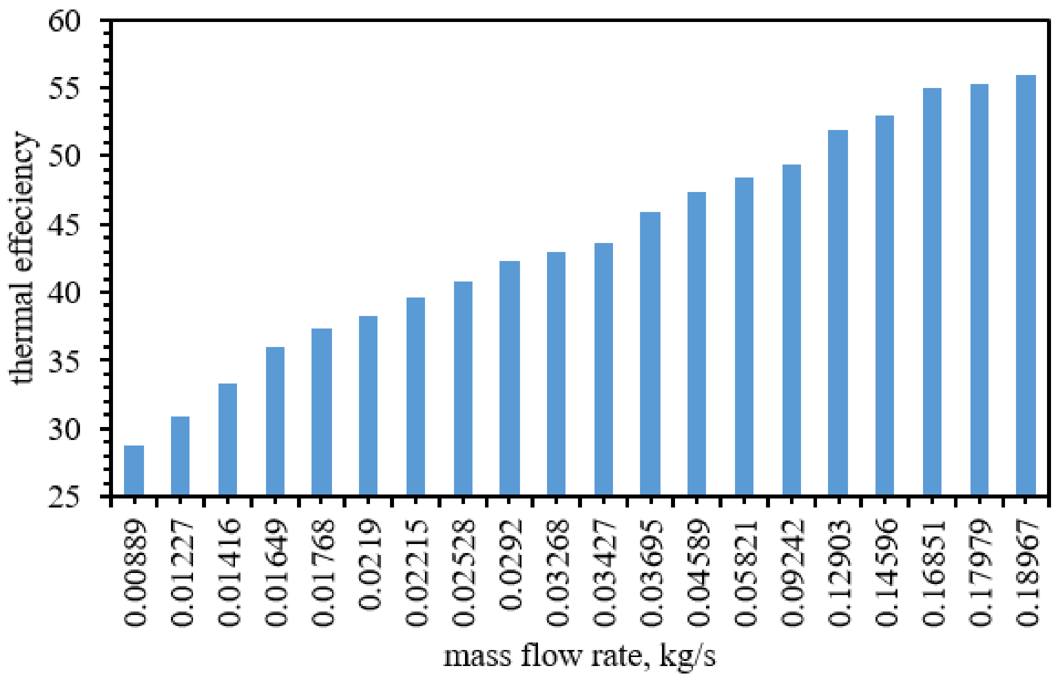

Fig. 5.1 effect of mass flow rate on the thermal efficiency

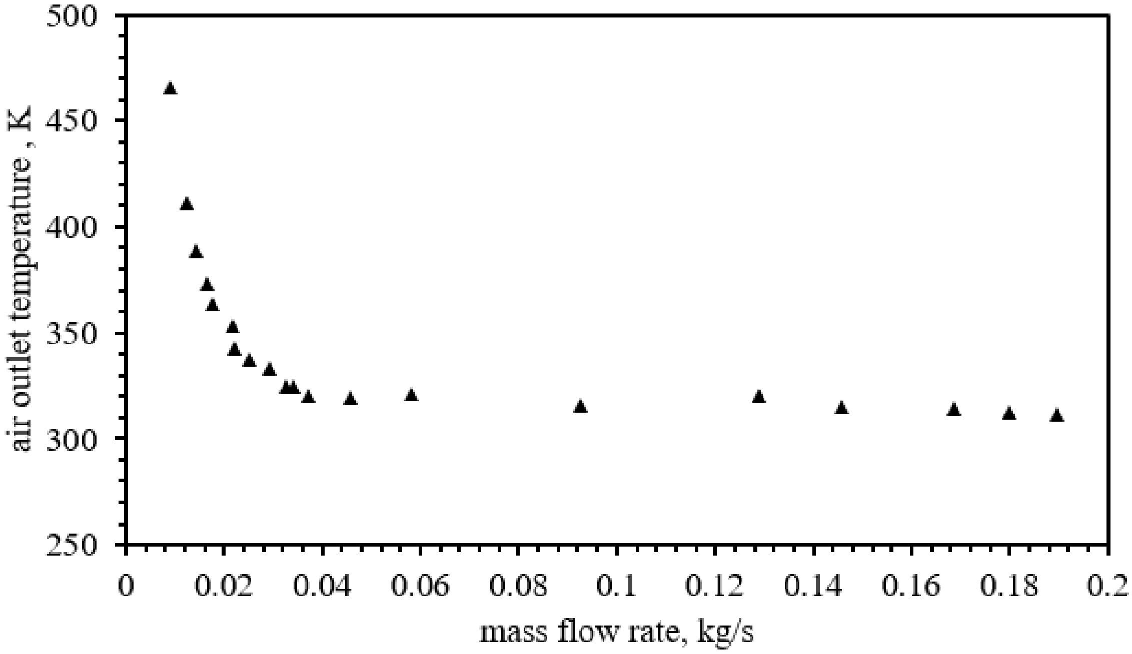


Fig. 5.2 variation of outlet temperature of air with mass flow rate

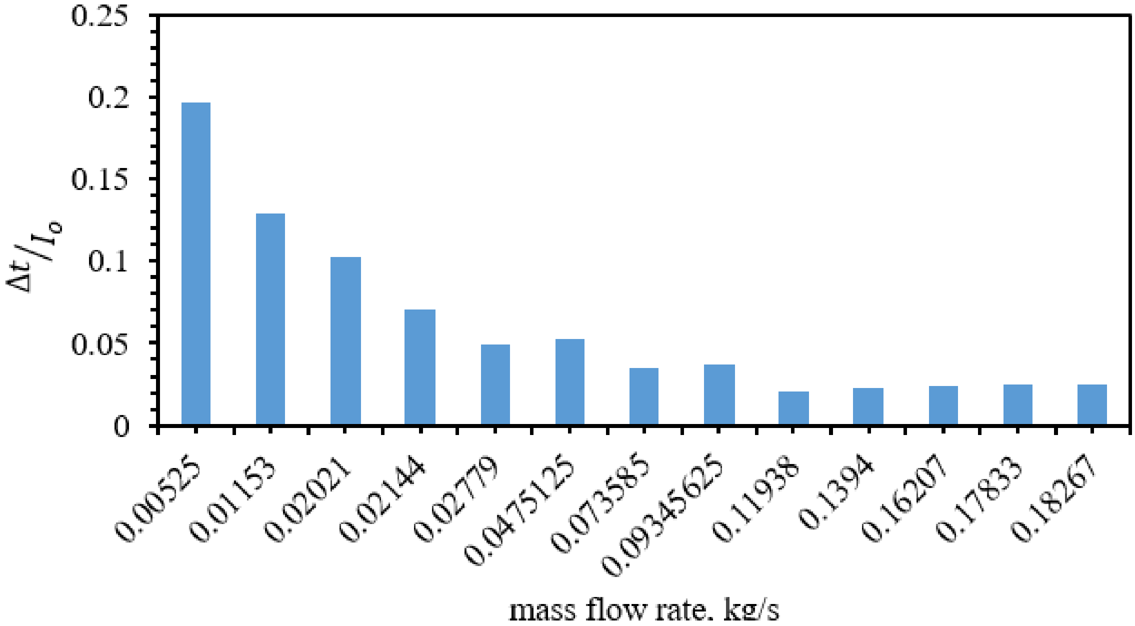


Fig. 5.3 effect of mass flow rate on the useful energy

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