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TECHNICAL NOTE

The Possibility of using Flat Plate Solar Collector Based on the Best Calculated Tilt Angle in the City of Rasht as a Case Study

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A B S T R A C T

The possibility of using flat plate collector in northern parts of Iran specially city of Rasht has been investigated in this paper. Due to the high humidity in the northern parts of this country, diffuse radiation plays a more important role than direct radiation. This fact can change the results of delivered solar energy and the best tilt angle of the collector compared to the sunny central cities. Therefore, maximum solar energy based on the best tilt angle is calculated first. Relative to the horizontal collector, changing the tilt angle, the daily, monthly, seasonally and yearly delivered solar energy increases16.58%, 15.84%, 15.31% and 10.79%, respectively. Then, the steady state two dimensional equation of conduction for the collector plate has been solved to obtain the length of the collector required for heating the water to a desired temperature20 meters of a typical collector (10 numbers) increases the water temperature to 66 and 85°C in the months December and September, respectively. Mean efficiency of the collectors decreases with increasing the temperature of inlet water. That is, the efficiency of the first and tenth collectors is approximately 60% and less than 10% respectively.

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NOMENCLATURE

b	Bond width (m)	$\overline{K}_{tm}$	Monthly average clearness index
c_p	Specific heat at constant pressure (J/kgK)	L	Length (m)
C_{sf}	Constant value in Nu of two phase flow	$\dot{m}$	Fluid mass flow rate (kg/s)
D	Tube outer diameter (m)	M	Glass number
D_i	Tube inner diameter (m)	n	Number of day beginning from January 1st
G	Solar energy (W/m^2)	Nu	Nusselt number
Gr	Grash of number	Pr	Prandtle number
Gz	Graetz number	Re	Reynolds number
h	Time (hour)	S	Absorbed solar energy (J/m^2)
h_{fg}	Evaporation enthalpy (J/kg)	T	Plate temperature (K)
h_s	convection heat transfer coefficient at the plate top and bottom (W/m^{2}K)	U	Heat loss coefficient (W/m^{2}K)
h_w	convection heat transfer coefficient due to wind (W/m^{2}K)	U_l	Overall heat loss coefficient (W/m^{2}K)
k	Thermal conductivity (W/mK)	V	Wind velocity (m/s)
K_{th}	Hourly clearness index	W	Width (m)
x	Axis along width of collector (m), quality	$bulk$	Bulk
X	Thickness (m)	B	Bond
y	Axis along flow (m)	cas	Case of collector

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Greek Symbols		d	Diffuse radiation
a	Absorptance	$edges$	Edges of collector
a_s	Altitude angle	f	Fluid
b	Tilt angle	g	Reflected from ground
d	Thickness (m)	h	Horizontal plain
Δx	Thickness of the bond (m)	ins	Insulation
e	Emissivity	m	Mean
m	Dynamic viscosity (kg/ms)	p	Plate
q	Incident angle	s	Reflected from sky
q_z	Zenith angle	sat	Saturation
r_g	Ground Reflectance	t	Related to tilted surface, total radiation
s	Stefan–Boltzmann constant (W/m^{2}K^4)	top	Top part of collector
t	Transmittance	$tube$	Tube
w_s	Sunrise or sunset hour angle	vap	Vapor
Subscripts		$wall$	Wall
b	Beam radiation, Bond	∞	Ambient
$Bottom$	Bottom of collector		

1. INTRODUCTION

High potential of Iran in receiving solar energy makes this country to benefit from this clean, low cost and renewable type of energy. While the central parts of Iran have the possibility of using solar energy to produce power in power plants, solar radiation in other regions is also good.

The amount of solar radiation depends on not only the geographical position and time of the day, but also on the climatic of the place. Humidity, smoke or dust can absorb or diffuse solar radiation and decrease the total amount of solar energy. Using the meteorological parameters, Angstrom [1] proposed an empirical relation for estimation of the global solar radiation and monthly clearness index. Bagheri Tolabi, et al.[2] calculated the experimental coefficients of Angstrom model for six different climate regions of Iran by Bees Algorithm. Some researchers have used SPSS and discovered clearness index of some cities in Iran. The city of Rasht as one of the northern cities of Iran near the Caspian Sea has humid and moderate climate conditions. Several numbers of relatively cloudy days and high amount of humidity cause the total solar radiation of this city to be consisted of more diffuse radiation than beam radiation. For this reason, the concentrating solar collectors which are designed to collect beam radiation are not proper to be used in these regions. While flat plate collectors with extensive flat absorber plate can receive diffuse radiation better. In addition, these collectors are manufactured more, so, cheaper and more available.

Flat plate collector consists of a flat absorber plate with high absorptance, usually a glass cover with high transmittance (in order to decrease the convection and radiation heat transfer coefficient) and back and edge insulation (in order to decrease thermal conductivity and heat loss). In order to receive the maximum amount of solar radiation, the collector has to be approximately perpendicular to the ray of sight of sun. Together with the tilt angle of the collector, researcher studied the optimum amount of azimuth angle of the flat plate collector for some cities of Iran with sunny and dry climate conditions. They found that the collector has to be placed exactly facing south in order to receive maximum power. The tilt angle of the collector can be changed daily, monthly or seasonally. In one research, the best tilt angle for receiving the maximum yearly solar energy has been reached to be equal the latitude of the location with angle variations of 10-15˚ more or less [3]. In one other research, this value has been estimated (latitude+15)±15 [4].

Determination of the received solar energy is the first step to determine the amount of temperature increase of the fluid that flows inside the tubes of the collector. Flat plate solar collector can be used to supply hot water, heating or cooling buildings and dryers. Gude, et al.[5] studied the possibility of using flat plate collector to desalinate water for the whole day use. They predicted the volume of the storage tank and collector area for supplying 100 liter water per day. Usually, in order to find out flowing fluid temperature of the collector, analysis of collector efficiency factor with consideration of absorber as a one dimensional fin is carried out [6]. Kazeminejad[7] solved two-dimensional conduction equation of absorber plate and showed that the two-dimensional discretization of the plate yields more accurate results for low mass flow rate of the fluid.

The studies show that the received solar radiation and the possibility of using this energy in the cities with high amount of humidity like Rasht have not been investigated yet. The solar radiation in the regions with high amount of humidity consists of diffuse radiation more than beam radiation. Therefore, the amount of total received energy and the best tilt angle of the collector can be affected and changed in comparison with the sunny regions where have been the subjects of the most studies. Therefore, the present research, based on the maximum daily received solar power, investigates the best tilt angle of the flat plate collector daily, monthly and seasonally and compares the results with the angles predicted in references [3, 4]. Then, the value of this maximum solar energy is used as the source in the two-dimensional conduction equation of the absorber plate and the variation of temperature in a typical collector is investigated. Variation of temperature with collector length is calculated for the December (coldest month of winter and autumn) and September (the coldest month in spring and summer). So, the possibility of using solar collector in these regions and the collector length for the desired fluid temperature can be investigated.

2. MATHEMATICAL MODEL

2. 1. Solar Radiation Incident on a Tilted Surface

The amount of monthly average solar radiation incident on a horizontal plain is usually determined by different data of weather stations. This value can be measured directly or be modeled and derived from meteorological data such as cloud cover. In both conditions, a value called monthly average clearness index is calculated that can determine the amount of beam and diffuse solar radiation through different methods. Due to lack of access to the daily amount of solar radiation, this paper uses Watanabe method [8] to model the solar power on the plain. This method which is created for Japanese climate conditions has been in good agreement with the data measured for different cities of Iran and has been proved to be reliable for Iran climate conditions.

The amount of beam and diffuse radiation by Watanabe method is as follows:

$$K_{TC} = 0.4268 + 0.193 \sin a_s \tag{1}$$

$$K_{DS} = K_{th} - (1.107 + 0.03569 \sin a_s + 1.681 \sin^2 a_s)(1 - K_{th})^2 \quad if\ K_{th} \geq K_{TC} \tag{2}$$

$$K_{DS} = (3.996 - 3.862 \sin a_s + 1.54 \sin^2 a_s) K_{th}^{\ 2} \quad if\ K_{th} < K_{TC} \tag{3}$$

$$G_{bh} = 1367\left(1 + 0.033\cos\left(\frac{360n}{365}\right)\right) K_{DS} \times \frac{1 - K_{th}}{1 - K_{DS}} \sin a_s \tag{4}$$

$$G_{dh} = 1367\left(1 + 0.033\cos\left(\frac{360n}{365}\right)\right) \times \frac{K_{th} - K_{DS}}{1 - K_{DS}} \sin a_s \tag{5}$$

Where, a_s is the altitude angle and K_{th}, hourly clearness index, can be calculated through Equation (6)[4].

$$K_{th} = [a + b\cos p/12(h - 12)]\overline{K}_{th} \tag{6}$$

$$a = 0.409 + 0.5016 \sin(w_s - 60) \tag{7}$$

$$b = 0.6609 - 0.4767 \sin(w_s - 60) \tag{8}$$

In these relations, h and ω_s are time in hour and sunset or sunrise hour angle, respectively.

While reaching the amount of beam and diffused solar radiation on the horizon, the amount of total radiation on a south facing plain with β tilt angle is calculated through isotropic model [9]:

$$G_{tt} = G_{bh}\frac{\cos q}{\cos q_z} + G_{dh}\left(\frac{1 + \cos b}{2}\right) + r_g (G_{bh} + G_{dh}) \times \left(\frac{1 - \cos b}{2}\right) \tag{9}$$

Integrating the total radiation on the tilted surface of the plain from sunrise to sunset, the daily solar power is reached. In this way, the best tilt angle which gives maximum amount of daily solar power can be obtained.

2. 2. Flat Plate Collector

In order to model the governing equations, a parallel flat plate collector with sheet and tube configuration shown in Figure 1 is considered.

The heat balance on a differential volume of the absorber plate yields the following two-dimensional, steady state conduction equation.

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{S - U_l(T - T_\infty)}{k_p d_p} = 0 \tag{10}$$

Boundaries of the absorber plate are described with the following equations:

$$T = T_B \qquad x = W,\ 0 \leq y \leq L \tag{11}$$

$$\frac{\partial T}{\partial y} + \frac{h_s(T - T_\infty)}{k_p} = 0 \qquad 0 \leq x \leq W,\ y = L \tag{12}$$

$$\frac{\partial T}{\partial x} = 0 \qquad x = 0,\ 0 \leq y \leq L \tag{13}$$

$$\frac{\partial T}{\partial y} - \frac{h_s(T - T_\infty)}{k_p} = 0 \qquad 0 \leq x \leq W,\ y = 0 \tag{14}$$

In Figure 1, the axis x is considered perpendicular to the flow along the sheet and begins from its center, and y is the axis along the fluid flow. Therefore, according to Equation (11), the temperature of the absorber plate ($T(x,y)$) near the tube is assumed constant, and equals to T_B. In the middle of the plate, the axisymmetric condition has been established (Equation (13)).T_{inf}, k_p and h_s represent ambient temperature, plate thermal conductivity and heat transfer coefficient regarding insulation and casing of the beginning and end part of the collector. In order to reach accurate calculation of temperature even in conditions with low mass flow rate of fluid flowing inside the collector tube, it is better to consider the plate conduction equation as two dimensional [7].In Equation (10), S is the absorbed energy of the south facing absorber plate tilted with angle β. By using glass transmittance and absorber absorptance, S is calculated through isotropic model:

$$S = G_{bh}\frac{\cos\theta}{\cos\theta_z}(\tau\alpha)_b + G_{dh}\left(\frac{1+\cos\beta}{2}\right)(\tau\alpha)_s + \rho_g(G_{bh}+G_{dh})\left(\frac{1-\cos\beta}{2}\right)(\tau\alpha)_g \tag{15}$$

The first term of the right hand side of Equation (15) determines the beam radiation transmitted from the glass cover (with transmittance $\tau(\theta)$) and absorbed by the absorber (with absorptance $\alpha(\theta)$). The second and third terms determine the absorbed diffuse radiation reflected from sky and ground, respectively. $(\tau\alpha)_b$ is assumed independent of temperature and changes with the incident angle of solar radiation. This value for diffuse radiation is calculated based on the constant incident angle by Brandemuehl and Beckman relation [9].In Equation (10), U_l is the total heat transfer loss coefficient of the collector; sum of the heat loss coefficients of its top, bottom and edges.

$$U_l = U_{top} + U_{Bottom} + U_{edges} \tag{16}$$

$$U_{top} = \left[\frac{M}{\left(\frac{C}{T_{pm}}\right)\left(\frac{T_{pm}-T_\infty}{M+f}\right)^{0.33}} + \frac{1}{h_w}\right]^{-1} + \left[\frac{\sigma\left(T_{pm}^2+T_\infty^2\right)\left(T_{pm}+T_\infty\right)}{\frac{1}{\varepsilon_p + 0.05M(1-\varepsilon_p)} + \frac{2M+f-1}{\varepsilon_g - 1} - M}\right] \tag{17}$$

$$f = \left(1 - 0.04h_w + 0.0005h_w^2\right)\left(1+0.091M\right) \tag{17a}$$

$$h_w = 5.7 + 3.8V_\infty \tag{17b}$$

$$C = 365.9\left(1 - 0.00883\,\beta + 0.0001298\,\beta^2\right) \tag{17c}$$

$$U_{Bottom} = U_{edges} = h_s = \frac{1}{\left(\frac{X_{ins}}{k_{ins}}\right) + \left(\frac{X_{cas}}{k_{cas}}\right)} \tag{18}$$

The first boundary condition (Equation (11)) relates to the part of the absorber plate near tube and flowing fluid. It is assumed that $T_B(y)$ is constant in the distance between $(W-D)/2 \le x \le (W+D)/2$ and is derived by the following equation.

$$\pi\frac{D^2-D_i^2}{4}k_p\frac{d^2T_B}{dy^2} + D\left(S - U_l(T_B - T_\infty)\right) - U_{B-f}\left(T_B - T_f\right) - 2d_p k_p\left.\frac{\partial T}{\partial x}\right|_{x=B} = 0 \tag{19}$$

Equation (19) can be solved with boundaries like relations (12) and (14). $U_{B\text{-}f}$ is the reverse thermal resistance of the outlet area of tube and the fluid and can be reached by the following equation.

$$U_{B-f} = \frac{1}{\frac{\ln(D/D_i)}{2\pi k_{tube}} + \frac{1}{h_f\pi D_i} + \frac{\Delta x_b}{bk_b}} \tag{20}$$

Heat balance on a differential volume of flowing fluid yields the equation of its temperature or quality. Regarding the single or two phase flow of the fluid, Equation (21) or (22) is solved.

$$\dot{m}c_{p,phase}\frac{dT_f}{dy} - U_{B-f,phase}\left(T_B - T_f\right) = SD - \frac{\pi D}{2}U_l\left(T_B - T_\infty\right) \tag{21}$$

$$\begin{cases} T_f = T_{sat} \\ \dot{m}h_{fg}\dfrac{dx_{vap}}{dy} - U_{B-f}\left(T_B - T_f\right) = SD - \dfrac{\pi D}{2}U_l\left(T_B - T_\infty\right) \end{cases} \tag{22}$$

Inlet temperature of fluid or quality is used as the boundary condition of Equation (21) or (22).The most probable mode of heating water in solar collector tubes is mixed convection (free and forced) [7]. Film heat transfer coefficient of the single phase flow is provided by Brown and Gauvin[10] correlation for laminar and Metais [10] for non-laminar flow.

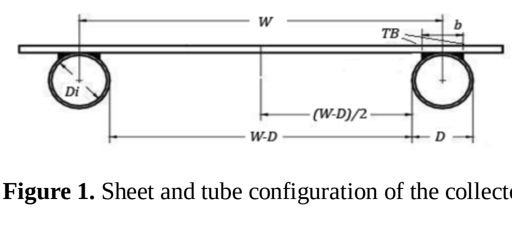

Figure 1. Sheet and tube configuration of the collector

$$Nu = 1.75\left(\frac{m_{bulk}}{m_{wall}}\right)^{0.14}[Gz + 0.012\left(GzGr^{1/3}\right)^{4/3}]^{1/3} \qquad (23)$$

$$Nu = 4.69\,\mathrm{Re}^{0.27}\,\mathrm{Pr}^{0.21}\,Gr^{0.07}\left(\frac{D_i}{L}\right)^{0.36} \qquad (24)$$

For the two phase flow, relations 25 and 26 can be used for low and high temperature difference of fluid and wall [11].

$$\begin{cases} Nu = 0.56(Gr\,\mathrm{Pr})^{1/4} & if\ 10^4 < Gr\,\mathrm{Pr} < 10^8 \\ Nu = 0.13(Gr\,\mathrm{Pr})^{1/3} & if\ Gr\,\mathrm{Pr} > 10^8 \end{cases} \qquad (25)$$

$$Nu = 1/C_{sf}\,\mathrm{Re}^{0.667}\,\mathrm{Pr}^{-0.7} \qquad (26)$$

2. 3. Solving Algorithm In order to reach the temperature of absorber plate, finite-difference approximation of Equation (10) together with plate boundary conditions (Equations (11)-(14)) are solved. Because of the nonlinear radiative term in Equation (17), an iterative procedure is used. In addition, first boundary condition (Equation (11)) is not known and has to be corrected iteratively with fluid temperature. Figure 2 shows the solution algorithm.

3. RESULTS AND DISCUSSION

In this section, first, maximum received solar energy based on the best tilt angle is calculated for the city of Rasht (latitude 37.2° N). Then, variation of temperature of the fluid with collector length during the months December (coldest month of winter and autumn) and September (coldest month of Rasht in spring and summer) is discussed. According to the calculated length for the desired temperature, the question of using flat plate collector for a special application can be answered easily.

3. 1. Best Tilt Angle of the Collector In order to reach solar radiation on the horizon, the values of monthly clearness index has been used. These values together with the monthly average daily received energy in Rasht have been demonstrated in Table 1.

According to Table 1, minimum and maximum amount of received energy in Rasht relates to the months of December and June, respectively. By using the values of monthly clearness index shown in Table 1, the hourly values can be calculated by Equation (6). In this way, the maximum amount of received solar energy based on the best tilt angle is calculated for every day of the stated months.

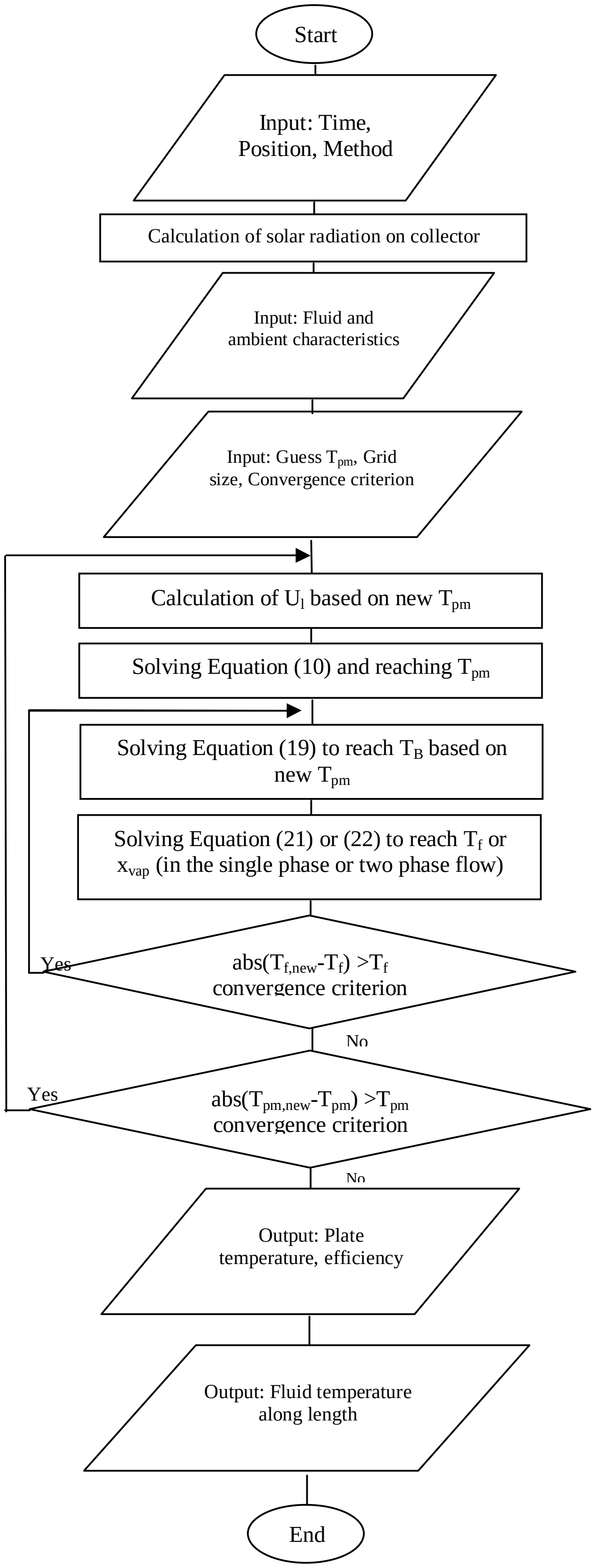

Figure 2. Solution algorithm

TABLE 1. Monthly clearness index and daily received energy for Rasht

Month	Clearness index	Monthly average daily received energy (MJ/m^2)
January	0.38	6.455
February	0.37	8.096
March	0.37	10.611
April	0.39	13.786
May	0.41	16.345
Jun	0.42	17.491
July	0.42	17.079
August	0.42	15.508
September	0.39	12.046
October	0.40	9.538
November	0.38	6.858
December	0.38	5.883

TABLE 2. Best seasonally and whole year tilt angle for Rasht

Season	Best tilt angle
Winter	38.32
Spring	8.56
Summer	9.0
Fall	47.46
Whole year	25.84

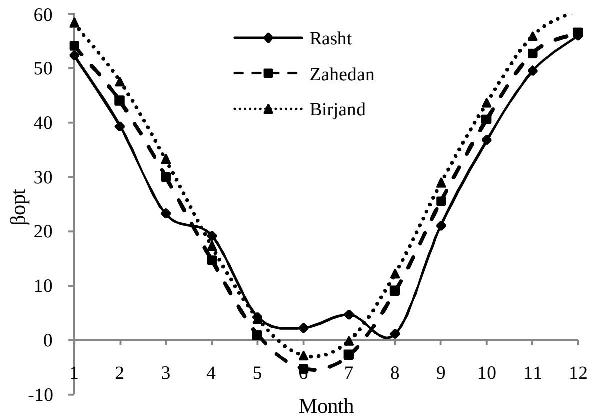

Figure 3. Best tilt angles for each month in Rasht and comparison of the values with Zahedan and Birjand

The mean values of best daily angles in each month for the collector in Rasht are shown in Figure 3.In addition, the best tilt angles calculated for the cities of Zahedan (29.28˚ N) and Birjand (32.52 ˚ N) has been demonstrated too.

The clearness index for Zahedan and Birjand differs by the mean amount of 3.22%. So, what differs in their tilt angles in Figure 3 relates to their geographical position. Birjand (North of Zahedan) has bigger tilt angles. While Rasht (North of Birjand) reaches the maximum energy in smaller tilt angles of its absorber in most months in comparison with Birjand. Therefore, it seems that the type of climate condition (moderate or sunny and dry) or clearness index can affect the best slope of the collector.

In spite of Rasht, the trend of variation of the best slope of collector for Zahedan and Birjand is smooth. In the present paper, the collector is considered south facing. So, all the tilt angles are positive. This fact can be the reason of the change in the trend of tilt angle of collector in Rasht for June and July. Figure 3 shows a little bigger tilt angle of collector in Rasht for April and May in comparison with two other cities.

Table 2 demonstrates the best seasonally and whole year tilt angles. These values are obtained by averaging the values in months.

According to Table 2, the best calculated slope of collector in Rasht suitable for the whole year is 28.84˚. References [3] and [4] predict this value between 22.2˚ and 52.5˚ and 37.2˚ and 67.2˚, respectively. It seems that these references predict these slope angles for the cities with relatively high clearness index which are not proper for the city of Rasht. According to Table 2, the proper tilt angles of seasons are greatly different.

Table 3 shows the yearly received energy for the collector with tilt angle changing daily, monthly, seasonally and with the constant value of 25.84˚ for the whole year. It also demonstrates the percentage of increasing this value in comparison with the horizontal plain. (The yearly received energy for the horizontal collector is calculated 4.256×1e+3 MJ/m^2.) As Table 3 shows, changing the tilt angle of the collector daily results the maximum received energy. Monthly and seasonally changing and constant value of 25.84˚ of the collector slope causes the received energy to decrease 0.8%, 1.3% and 5.79% respectively in comparison with daily tilt angle.

It can be concluded that when a few collectors are used, monthly or seasonally changing in tilt angle does not change the received energy very much. But, when the number of the collectors increases, it is better to change the slope of the collectors monthly. In both conditions, installation of the collector with the constant angle wastes much of energy and is not preferable.

3. 2. Calculation for Collector

3. 2. 1. Verification

In order to verify the results of the written code, plate mean temperature and efficiency of the collector is calculated for the work of Kazeminejad [7]. The comparison of the results in two different inlet temperatures of fluid is shown in Table 4.

TABLE 3. Yearly received energy for the collector with tilt angle changing and comparison with the horizontal collector

Slope changing	Yearly energy (GJ/m^2)	Increment relative to horizon (%)
Daily	4.962	16.58
Monthly	4.930	15.84
Seasonally	4.908	15.31
Whole year	4.715	10.79

TABLE 4. Comparison of the results of the present work and the work of Kazeminejad [7]

	Inlet water temperature (K)	Plate mean temperature (K)	Eff. (%)
Present work	313.15	333.2	55.5
Kazeminejad	313.15	334.6	53.4
Present work	323.15	341.3	50.3
Kazeminejad	323.15	342.9	48

TABLE 5. Properties of a typical collector

Collector property	Value
Length	2 m
Glass normal transmittance	0.82
Absorber normal absorptance	0.96
Absorber material	Copper
Absorber thickness	0.5 mm
Width of absorber fin	143 mm
Tube diameter (outer/inner)	10/9.1 mm
Insulation thickness	50 mm
Insulation conductivity	0.04 $Wm^{-1}K^{-1}$
Glass number	1
Glass thickness	4 mm

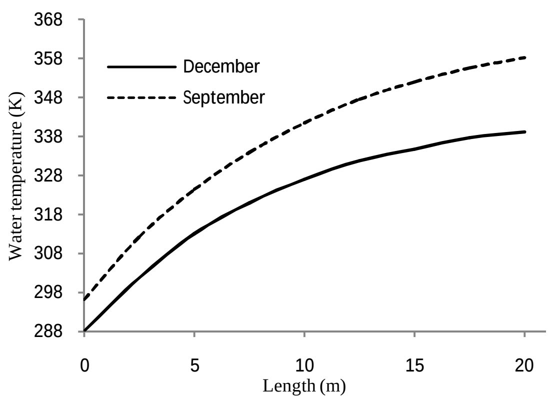

Figure 4. Water temperature with collector length in December and September for Rasht

According to Table 4, the results of the two works are in good agreement. The little difference between them can be related to this fact that all the detailed information of the collector of the work of Kazeminejad [7] is not identified.

The length of each grid along the axes x and y are obtained 2.5 and 25 mm. The criterion of numerical convergence for plate mean temperature and fluid temperature are considered 1e-4 and 1e-10, respectively.

3. 2. 2. Collector Length for the Desired Temperature In order to determine the length of the collector for different applications, the properties of a typical collector manufactured in Iran have been used. These characteristics are shown in Table 5.

Most of solar systems work as helping or with energy storage systems. So, when the solar power is low, the energy of the storage system is used and when the proper amount of solar power is provided, the helping system is off.

In the present paper, the time between 10 A.M. to 15 P.M. is the time when helping system is considered off. Therefore, the calculations are carried out for 10 A.M. According to the minimum amount of received solar energy in December for Rasht, the first day of this month with the tilt angle of 56.04˚ (best monthly slope angle) have been considered. In addition, the month of September as the coldest month in spring and summer is studied too. By solving the typical collector in Rasht, the variation of water temperature is determined with the collector length. This value can be used as a point for deciding of using the collector for the specified application in Rasht; a city with moderate climate condition.

Figure 4 illustrates the water temperature with collector length in December and September for Rasht. Water mass flow rate in the header tube is considered 0.09 kgs^{-1}. In both months, the water inlet temperature is considered equal to the ambient temperature of 15˚C and 23˚C, respectively.

According to Figure 4, if the collector is considered to work the whole year (length design based on December), the maximum water temperature of 66˚C is reached in 20 meters of the collector. If the collector is considered to work in 6 months of spring and summer, 20 meters of collector heats water to 85˚C.

Figure 4 shows fluid temperature for 20 meters of the collector (10 series). The 11^{th} collector efficiency decreases to below 10% and is not considered. Table 6 shows the mean efficiency of collectors in December and September.

As illustrated in Table 6, all series collectors' efficiency in December is more than the month September. Higher plate temperature caused by higher solar power in September has decreased the efficiency. Higher temperature of inlet water which enters the next

TABLE 6. Mean efficiency of the collectors in the months of December and September for Rasht

Collector number	Efficiency in December (%)	Efficiency in September (%)
1	65.34	62.16
2	54.07	51.26
3	43.42	41.80
4	35.1	33.88
5	29.11	27.35
6	23.49	22.08
7	18.94	17.74
8	15.24	14.24
9	12.26	11.42
10	9.86	9.16

series collectors has decreased the efficiency from the value 0.6 to less than 0.1 in the collectors with number 1 to 10, respectively.

4. CONCLUSION

In order to investigate the possibility of using solar energy with solar collectors in Rasht, a city with moderate climate conditions, the best tilt angle of the absorber plate changing daily, monthly, seasonally and the constant angle for the whole year have been calculated. Determination of the best daily tilt angle is carried out based on reaching the maximum daily solar power. By averaging the best daily tilt angle, monthly, seasonally and yearly tilt angles have been obtained. The results have shown that the amount of beam or diffuse radiation and the best slope angle of the collector for the northern cities of Iran, where have moderate climate conditions, are different from sunny and dry cities. Received solar energy with tilt angle changing daily, monthly, seasonally and yearly has respectively increased 16.58%, 15.84%, 15.31% and 10.79% in comparison with the horizontal collector. Therefore, it is suggested to change the tilt angle seasonally for a few numbers of collectors. By increasing the numbers, monthly changing is offered. The maximum solar power based on the best monthly slope has been used as the source of the two-dimensional conduction equation of the absorber plate and fluid temperature in the 20 meter length of the collector in two months of December (the coldest month of Rasht) and September (the coldest month in spring and summer) has been reached. The considered flat plate collector increases the water temperature to 60˚C and 85˚C in December and September, respectively. By increasing the inlet temperature of water which enters the series collectors their efficiency decreases from 60% to lower than 10% in the first and 10th collectors.

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The Possibility of using Flat Plate Solar Collector Based on the Best Calculated Tilt Angle in the City of Rasht as a Case Study

TECHNICAL NOTE

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چکیده

این مقاله به بررسی امکان استفاده از کلکتور خورشیدی صفحه‌تخت در مناطق شمالی ایران به ویژه شهر رشت می‌پردازد. در مناطق شمالی کشور با توجه به میزان رطوبت بالا، تابش پخش سهم بیشتری را نسبت به تابش مستقیم داشته و این امر می‌تواند نتایج محاسبات مربوط به میزان دریافت انرژی خورشید و زاویه‌ی بهینه‌ی کلکتور را نسبت به شهرهای مرکزی با ساعات آفتابی بیشتر متفاوت کند. برای این منظور ابتدا بیشترین انرژی خورشیدی قابل دریافت بر اساس تغییر در زاویه‌ی شیب کلکتور محاسبه شده است. درصد افزایش انرژی با تغییر شیب روزانه، ماهانه، فصلی و سالانه نسبت به کلکتور افقی در این شهرستان به ترتیب 16/58، 15/84، 15/31 و 10/79 به دست آمده است. سپس، معادله‌ی هدایت دوبعدی صفحه‌ی جاذب به صورت پایا حل شده و طول مورد نیاز برای دست‌یابی به دمای دلخواه آب محاسبه شده است. طول 20 متر از یک نمونه کلکتور مطالعه شده (10 عدد کلکتور)، دمای آب را تا 66 و 85 درجه‌ی سانتی‌گراد در ماه دسامبر (آذر) و سپتامبر (شهریور) بالا می‌برد. بازده‌ی متوسط کلکتورها با افزایش دمای آب ورودی به آنها کاهش یافته به طوری که بازدهی کلکتور اول و دهم به ترتیب در حدود 60 و کمتر از 10 درصد است.

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