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DESIGNING OF SOLAR WATER BATH HEATER FOR GAS PRESSURE REDUCING STATION IN OF 150,000 Nm^3/h CAPACITY IN ASSALUYEH REGION IN IRAN

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ABSTRACT

This paper proposes the design of a solar water bath heater for Central Power Plant in Assaluyeh region in south of Iran with the latitude of 27 °N. This heater uses flat plate solar collectors in an open circuit system. Solar intensity, absorbed radiation and ambient temperature are the regional parameters which are known to the designer. The temperature of the bath of water which is the outlet collector temperature (70 °C) belongs to the known parameters in the mentioned station. Flow rate, heat loss factor, the inlet temperature of the collector and the area which is the most important factor to evaluate the economical issues of the system are calculated with modeling the water bath with a shell and tube heat exchanger. The solar water bath heater is then simulated with TRNSYS software. The obtained results are in good agreement with analytical solution based on Duffie and Beckman method.

Key words: Gas pressure reducing station, solar energy, Water bath heater, flat plate solar collector

INTRODUCTION

In many power plants, the pressure of the gas delivered to the plant is not suitable for turbines and boilers. Therefore, the gas pressure must be reduced to the range, consumable for plant equipments, such as boilers and turbines. Gas Pressure Reducing Station (GPRS) is then required to maintain the gas pressure. In gas pressure reducing stations, the pressure of natural gas is reduced and consequently the temperature of gas is decreased. Before reducing the gas pressure it is obligatory to provide the heat needed to keep the temperature of the gas on 25 degree of Centigrade [1].

The temperature of the delivered gas to the plant is 25 °C and the pressure is 90 bar in Central Power Plant in Assaluyeh region; the south part of Iran. The pressure of gas reduced to 25 bar and the temperature must be maintained at 25 °C at the exit point of station to achieve the optimal performance of plant equipments and to prevent the hazards of dew condensation in natural gas. To reach the objective of the temperature and to retrieve the heat loss during regulation process of pressure, water bath heater (wbh) is used. The common design of the heaters has two gas burners to heat up the water bath to 70 °C in this special case [2,3].However, solar water bath heaters are an open solar heater systems with flat plate collectors and a shell and tube heat exchange to transfer the gained heat to gas passing through the cold side.

DESIGN VARIABLES

Design variables considered in this study can be divided into two groups: metrological related, and heater system-related. Each group of variables discussed elaborately and the effects produced are mentioned.

Metrological related variables

The metrology related variables include Incident solar radiation and ambient temperature. The south part of Iran especially the Assalyueh region in Bushehr Province has the latitude of 27 °N and receives strong solar radiation in a day light time. And the ambient temperature measured, never approaches zero even in winter [2].

Incident Solar Radiation

Solar incident radiation is the key factor for evaluating a region for installation of a solar heating system. The incident absorbed solar radiation which is mainly a function of solar incident radiation, the properties of covers and the angle of incident, affect the overall performance of collector and all the parameters of flat plate solar collectors [1]. The graph below depicts the pattern of variation of solar incident radiation in the first week of January. The Maximum amount f gain is 3148 kJ/h and the mean solar incident radiation for the hours of day light which counts as 70 hours are 1588 kJ/h.

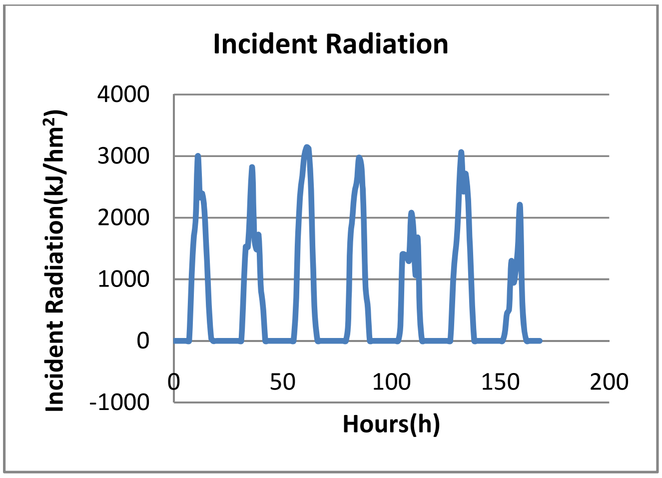

Figure 1. Solar Incident radiation variation in the first week of January

Ambient Temperature

The ambient temperature varies in the region in winter as depicts below. The considerable point is that the lowest temperature is 7 degree of Centigrade, there would then always above the freezing point of water in this region. This results in a situation that there would be no damage for collectors due to the freezing of recycling water. Such high ambient temperature in winter alarms for a very high summer ambient temperature. The measured temperature in summer days reaches almost 50 °C. therefore the design of expose equipments would be influenced by high surface temperature [4].

Figure 2 cites the ambient temperature variation in the first week of January; which is regarded the coldest period of time in the mentioned geographical area [4].

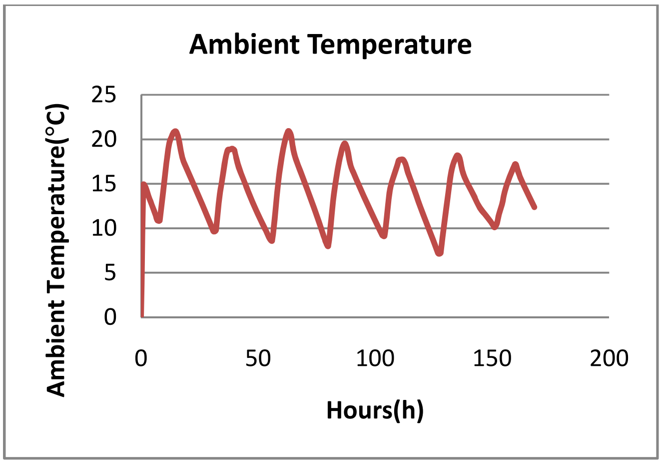

Figure 2. Ambient temperature variation in the first week of January

Heater system-related variable

Known and unknown parameters related to the condition of the water bath heater belong to the heater related variables. The temperature of the bath of water which is the outlet collector temperature (70°C) belongs to the known parameters in the mentioned station. Hot side condition of the Shell and tube heat exchanger, flow rate, inlet temperature of the collector and the area which is the most important factor to evaluate the economical issues of the system are calculated with modeling of the total system and the unknowns. To start the analytical modeling the flow rate of collector was estimated by the experience and the correction of the parameters occurred during the steps of the process.

MODELING SOLAR WATER BATH HEATER

SWHB open circuit system consists of solar flat collectors, shell and tube heat exchanger and a single speed pump. The schematic of the heater station is shown in figure 3. The SWHB in comparison with the conventional heater has the collector as the burner and water bath is modeled with a shell and tube heat exchanger. A number of simplifying assumptions

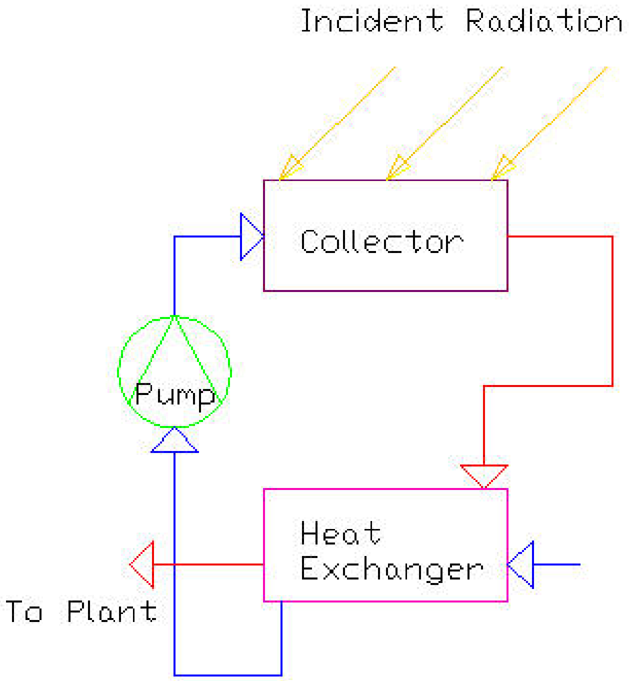

Figure 3. Schematic of Solar Water bath heater

can be made to lay the foundation without obscuring the basic physical situation [5]. These assumptions are as follows:

1-Performance is steady state

2-Construction is of sheet and parallel tube

3-The headers cover a small area of the collector and can be neglected

4- Properties are independent of temperature

5- The sky is clear

6- Dust and dirt on the collector are negligible

7-Shading of the collector absorber plate is negligible

8- The sky model is isotropic diffuse model

9-Axial heat conduction along the tube of heat exchanger is negligible

10-The outer surface of the heat exchanger is perfectly insulated

11- The elevation of site is the sea level

Heat Exchanger

Water bath simplified to a shell and tube heat exchanger the heat flow of collector hot water which passes through the shell to the gas flows in the tubes. Considering the table 1 and table 2 for the hot side and cold side condition, the effectiveness-NTU method is selected to estimate the unknown parameters of the heat exchanger [6,7].

Table 1. Heat Exchanger cold side condition

Cold Side Condition		
Tin	50	C
Tout	25	C
Flow rate	1.14E+05	kg/h
cp	2.7	kJ/kgC

Table 2. Heat Exchanger hot side condition

Hot side Condition		
Tin	70	C
Tout	-	C
Flow rate	-	kg/h
cp	4.19	kJ/kgC

To determine the effectiveness of the heat exchanger the maximum possible and actual heat transfer is are required and calculated as follows:

$$\dot{Q}_{max} = C_{min}\left(T_{h,in} - T_{c,in}\right) \qquad (1)$$

$$\dot{Q} = C_c\left(T_{c,out} - T_{c,in}\right) = C_h\left(T_{h,in} - T_{h,out}\right) \qquad (2)$$

From the cold side condition the actual heat transfer rate is estimated by eq(1) and the amount is 2136 kW. In order to calculate the Maximum heat transfer rate, mass flow rate of the solar collector which is the same as the mass flow rate of hot side of the exchanger and it depends on the area of the collectors which can be estimated by the actual heat transfer rate that it is almost about 4000 square meter and the mass flow rate is by experience in an conventional collector varies from 0.001 to 0.02 kg/s.m2. Thus it is assumed that $\dot{m} = 0.0075 * 4000 = 30\ \mathrm{kg/s}$ and then the C of hot side and cold side condition can be determined and the minimum of C is respectively determined.

$C_c = 85.43$

$C_h = 118.5$

Cmin is therefore the heat capacity rate of cold side, and $\dot{Q}_{\max}$ = 3845 kW in consequent the effectiveness and the heat capacity rate determines as follows:

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}} = 0.56 \qquad (3)$$

$$c = \frac{C_{min}}{C_{max}} = 0.72 \qquad (4)$$

NTU of the heat exchanger obtained from the eq(5) [6,7]:

$$\varepsilon = 2\left\{1 + c + \sqrt{1+c^2}\ \frac{1+exp\left[-NTU\sqrt{1+c^2}\right]}{1-exp\left[-NTU\sqrt{1+c^2}\right]}\right\}^{-1} \qquad (5)$$

Thus NTU equals 1.3 and from eq(6) the outlet temperature of the hot side is acquired and it equals 55 °C.

$$ln\,\frac{T_{h,out}-T_{c,out}}{T_{h,in}-T_{c,in}} = -\frac{UA_s}{C_c}\left(1+\frac{C_c}{C_h}\right) \qquad (6)$$

The obtained parameters are the critical factors for the collector input data.

Flat Plate Collector

The prediction of collector performance requires the solar energy absorbed by the collector absorber plate .the solar incident on a tilted collector can be found by the eq (7):

$$I_T = I_b R_b + I_d\left(\frac{1+cos\beta}{2}\right) + \rho_g\left(\frac{1-cos\beta}{2}\right) \qquad (7)$$

Using the isotropic diffuse model an hourly basis, the, eq(7), can be modified to give the absorbed radiation S by multiplying each term by the appropriate transmittance-absorptance product[5]:

$$S = I_b R_b(\tau\alpha)_b + I_d(\tau\alpha)_d\left(\frac{1+cos\beta}{2}\right) + \rho_g I(\tau\alpha)_g\left(\frac{1-cos\beta}{2}\right) \qquad (8)$$

The transmittance- absorptance product for the sky and ground diffuse radiation depends on the effective and equivalent angle of incident which are presented by eq(9) and eq(10) [5]:

$$\theta_{e,g}=90-0.788\beta+0.002693\beta^2 \qquad (9)$$

$$\theta_{e,d}=59.7-0.1388\beta+0.001497\beta^2 \qquad (10)$$

The most important factor to evaluate the economical issues of the system is the area of the collector which is obtained by the eq(11):

$$Q_u = A_c F_R[S - U(T_i - T_a)] \qquad (11)$$

Q_u, S, F_R, and the term of loss $U(T_i\text{-}T_a)$ are known, and the area of the collector is then obtained [5].

The flow rate or natural gas in the cold side has no variation during the day, thus the area of the collector due the variation of incident solar energy and the ambient temperature is varied during the day.

Pump

To select a pump two parameters are required; the design volumetric flow rate and the differential pressure of the pump. The hydraulic power of the pump is the calculated by eq(12):

$$W_{hydraulic} = \frac{V_d * dP}{36} \qquad (12)$$

The flow rate and the pressure required for the system are constant; therefore a single speed pump would suffice the requirements of the system.

The differential pressure of the pump was estimated by the header elevation and the pressure drop of the network of 1700 connected collectors. The network was modeled in pipe net and the total differential pressure is estimated 2 bar. Regarding the design mass flow rate of 30 kg/s and the differential pressure of 2 bar, a single speed pump of 8 kW would support the total system.

TRNSYS SIMULATION

A computer model of the heater was developed in TRNSYS. A special care was taken for the materials. The collector and the heat exchanger were modeled in details to fit the performance of actual heater system. For validation, the TRNSYS model was run using measured weather data for the first week of January, and a one hour time step with the concept of constant area. And simulations results were compared with data resulted from the Duffie-Beckman [5] method in previous chapter in terms of temperatures and area of the collector.

SYSTEM CONFIGURATION

In the document of site civil general arrangement; which is indicated in figure 4; an area of 20*20 is considered for conventional heater. SWBH requires an area of 4500 square meter for the collectors [8] and the area of conventional heater can be used for installation of heat exchanger.

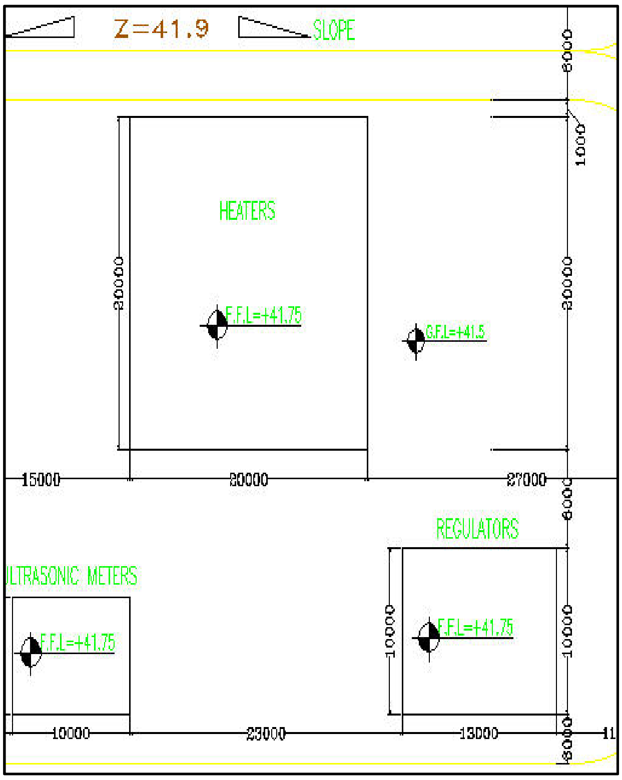

Figure 4. Civil general arrangement of GPRS

In Assaluyeh Central Power plant an extension area of 5000 square meter; Figure 5; has been provided for the gas pressure reducing station which can be used as the collector site. The network of piping will be then designed due to south [8].

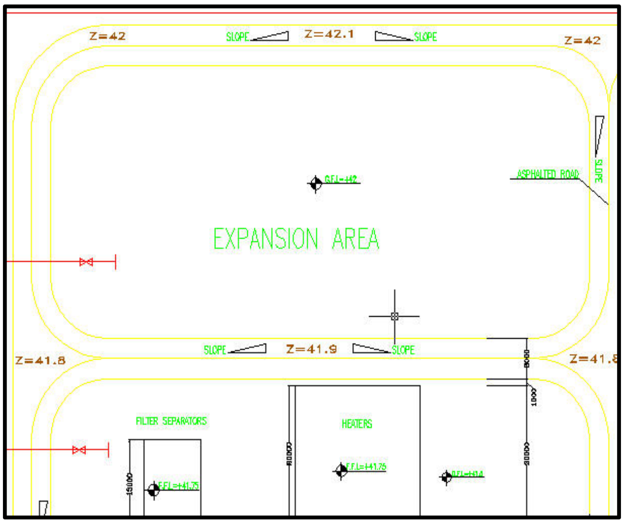

Figure 5. The extension area used for the collect installation

RESULTS

The output results are also divided into two groups of analytical and simulation output. Each group is treated separately and then the outcomes are also compared.

Analytical result

The results obtained by Duffie-Beckman method is emphasizes on the variation of area needed by the collector to gain the required power to heat up the gas, depending on the time of the day. The time of the day is representative of incident solar energy and the absorbed solar incident [5].

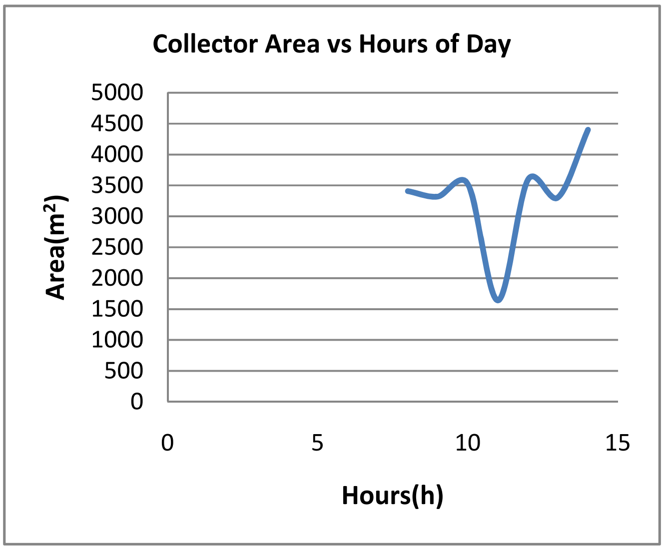

Figure 6. Total area of collector variation in the first week of January

Taking a look at the figure (7), it is obvious that in the first day of January, when the sun starts to down and the bright sunshine is decreased in the region; around the hour 14:30, the solar incident radiation decreased and the area required increases.

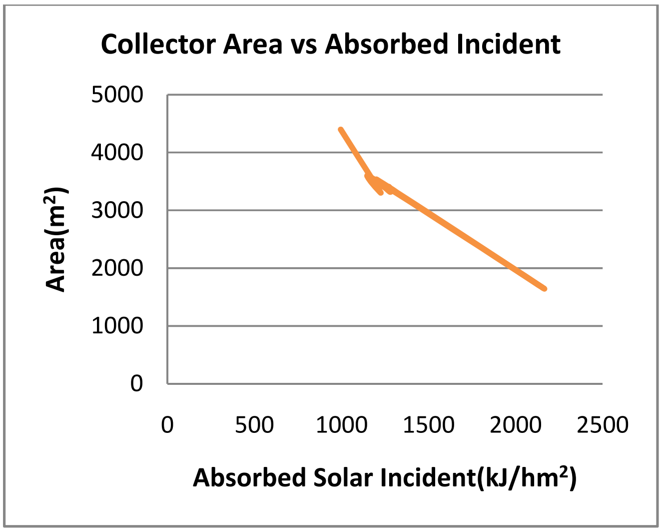

Figure 7. Total area of collector variation vs variation of absorbed solar incident

Simulation result

The results obtained by the TRNSYS simulation based on constant area of 3800 square meter, which leads to the variation of collector outlet temperature with the variation of absorbed incident.

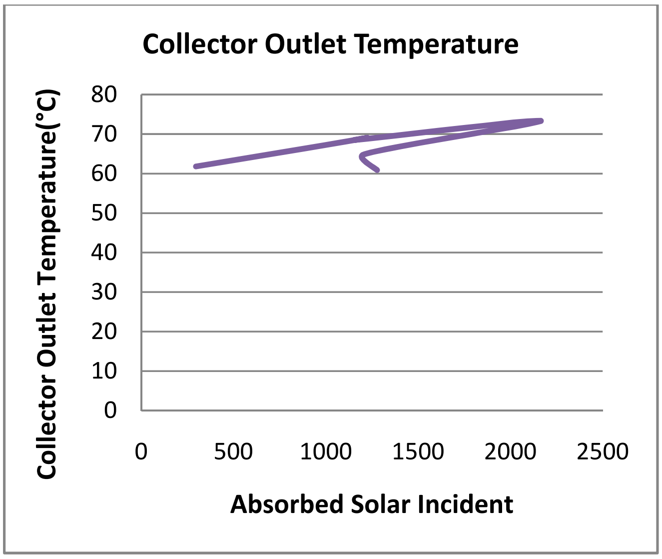

Figure 8. Collector outlet temperature variation vs variation of absorbed solar incident

In the first day of January the collector outlet temperature varies with the variation of absorbed incident radiation. Consequently if the hours of a day are an indication of the absorbed incident radiation, temperature of collector would obviously drop after the hour 14:30.

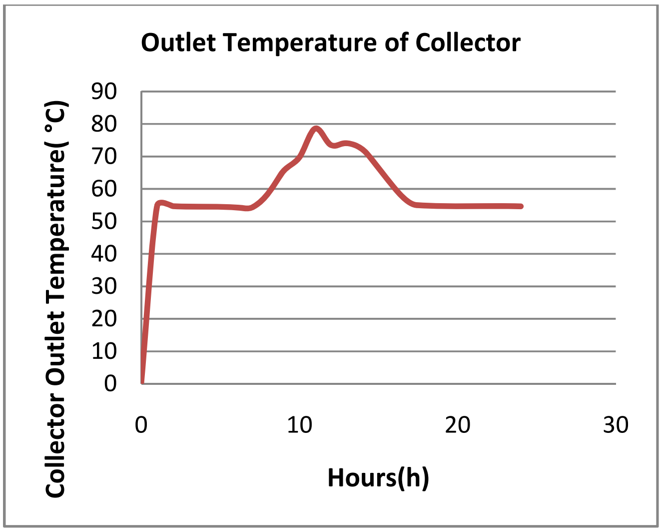

Figure 9. Collector outlet temperature variation in the first day of January

The system is simulated to investigate the outlet temperature of the heat exchanger cold side which is actually the temperature of the natural gas before entering the regulators section. Figure (10), as shown, the variation pattern of natural gas is fitted completely with the collector outlet temperature.

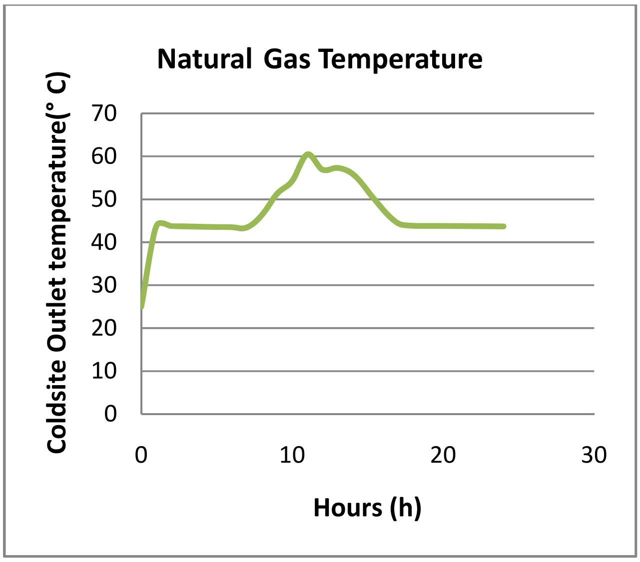

Figure 10. Heat exchanger cold side temperature variation in the first day of January

CONCLUSION

Regarding the results of analytical solution based on constant collector outlet temperature and the simulation results based on constant area and performance for the worst case of winter, some points can be concluded.

It can be well regarded that in winter days of the region, the range of time that sufficient solar incident exist is short and almost from 8 o'clock in the morning to 14:30 in the afternoon.

It can be also predicted that a peak period of 2 hours; from 11 to 13 O'clock. While the plant is used to generate electricity for refinery system, there would no peak of gas consumption which can fit the peak system.

The considerable point is that, a constant natural gas outlet temperature is required to get the best performance of plant equipment; whit a concept of constant area, the objective is not fulfilled. Therefore a instrument Control system can be applied to adjust the area of the networked collectors (number of collector in use) by reading the natural gas outlet temperature.

The short time of the bright sunshine and the decrease of solar incident energy after 14:30 restrict the application of the SWBH in winter. In order to solve the problem, two choices can be regarded, first is a system with thermal storage system, and the second is a hybrid system with gas burners as conventional heaters.

NOMENCLATURE

A	area (m2)
C	specific heat (J/kg K)
F_R	heat removal factor
I	solar incident radiation (W/m2)
$\dot{m}$	mass flow rate (kg/s)
p	specific power of solar collector (W/m2)
P	power (W)
Q	heat rate (W)
β	slope angle (degree)
S	power absorbed by area unit (W/m2)
T	temperature (K,)
U	global coefficient of heat loss (W/m2 K)

Subscripts

b	direct beam
C	solar collector
d	diffuse
c	cold side
h	hot side

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