

A Study on the Operating Characteristics of the Solar District Heating System with Plate and Vacuum Tube Collector Circuits

**Baek, Nam-Choon¹ Shin, U-Chul² Lee, Jin-Kook³
Yoon, Eung-Sang⁴ Kim, Hwi-Dong⁵**

¹Korea Institute of Energy Research, Dae-jeon, Korea,
baek@kier.re.kr

²Dept. of Architecture Eng, Dae-jeon Univ, Dae-jeon, Korea,
shinuc@dju.ac.kr

³Korea Institute of Energy Research, Dae-jeon, Korea,
jklee@kier.re.kr

⁴Korea Institute of Energy Research, Dae-jeon, Korea,
yoon@kier.re.kr

⁵Dept. of Mechanical Eng, In-ha Univ, In-cheon, Korea
aero9803@naver.com

Abstract: In this study the operating characteristics was analyzed of district solar heating system. This solar system was composed of two different types of solar collector circuit, flat plate and vacuum tube collector circuits, in a system. These collectors have different thermal characteristics. So the operating characteristics and behavior of each circuit should be investigated for the system design and control. In this study setting values related to ON/OFF pump control, variation of collector outlet temperature, thermal performance of each collector circuit, etc especially were investigated. The experimental facility for this study was used the Bun-dang district solar heating system which was installed in the end of 2006.

Keywords: Solar heating system, district heating, operating characteristics, experiment, monitoring

Nomenclature

$T_{p,o}$: outlet temperature of flat plate collector

T_{rdhw} : returning district heating water

$T_{e,o}$: outlet temperature of vacuum tube collector

$T_{e,on}$: setting temperature of vacuum tube collector pump on

$T_{e,off}$: setting temperature of vacuum tube collector pump off

Δt : time delay

$T_{HX2,o}$: outlet temperature of low temperature side of vacuum tube collector heat exchanger

T_{RET} : setting temperature for electro-motion valve control

$T_{dhw,set}$: solar heating set temperature

1. Introduction

The thermal efficiency and the operation characteristics of collectors in designing

solar heating system are one of the most important factors to be considered. Over the past years, solar heating system has generally been made up of one collector. However, when the rate of temperature increase by solar heating is large, designing a system to warm up the temperature by using the different types of collectors fit for various operation temperatures shows better thermal efficiency and economic efficiency than the system using a single type of collectors. Collectors would be classified into two categories—collectors used for low temperature and the collectors used for high temperature—and be employed differently according to various operation temperatures.

Few cases have ever been found so far all over the world. However, vacuum tube collector should be used in the field where temperature increase rate is large. For example, when sample water (5–20°C) should be heated to 90°C, it is necessary to use the vacuum tube collector in the system configuration so far. If you see the thermal efficiency curve, the flat plate collector has operation range with better thermal efficiency than the vacuum tube collector under low temperature conditions without considering collector's price. Generally, the vacuum tube collector is more expensive than the flat plate collector. Therefore, considering the price of collectors, the flat plate collector will have wider temperature range with high efficiency than vacuum tube collector in operating temperature range.

The economic efficiency of solar heating system can be improved in the field with large band heating temperature if the system is designed by using more than two types of collectors—respectively employing collectors with high collector efficiency per cost.

However, in the case that more than two types of collectors are applied to one system, knowledge of operating characteristics of each collector is required. In particular, this operating characteristic is directly related to system control.

Therefore, this study aims to analyze the operating characteristics of two types of

collectors on the basis of the results from field tests on the solar heating system, which is a single system composed of the flat plate collector and the single glazed vacuum tube collector.

2. System overview

2.1 System configuration

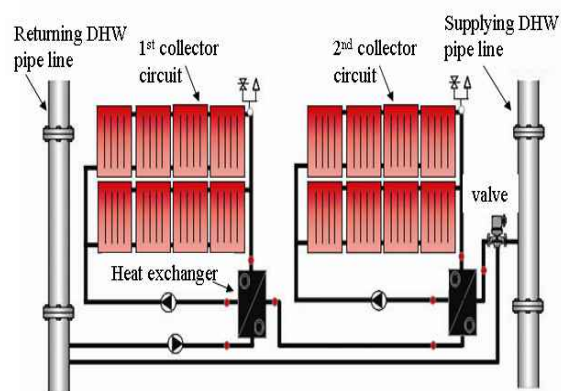


Figure 1: Connection diagram of solar heating system to district heating system

As illustrated in figure 1, the flat plate collector circuit and the vacuum tube collector circuit are respectively separated by the collector heat exchanger (indicated below as heat exchanger) in the solar heating system. While returning district heating water passes through these heat exchangers successively, it increases in temperature heated to the set temperature, and then flows into the supplying pipeline. That is, first, returning DHW is heated to the set temperature by HE1, next moves into HE2, and then heated to the set temperature, and last flows into the supplying pipe. Irrespective of the intensity of radiation and ambient temperature, when solar heating system is operated, the proportional control which can govern the working fluid and DHW flow rate is provided for DHW to be heated to the set temperature while it is passing through the heat exchanger. To maximize the amount of collecting energy, on the condition of minimum flow rate, in the case that DHW stays below the set

temperature but keeps above a certain degree temperature, DHW coming from the heat exchanger is designed to flow back into the return pipe. It is controlled by switching the valve, V1 and V2

2.2 Overview of solar heating system and sensor installation plan

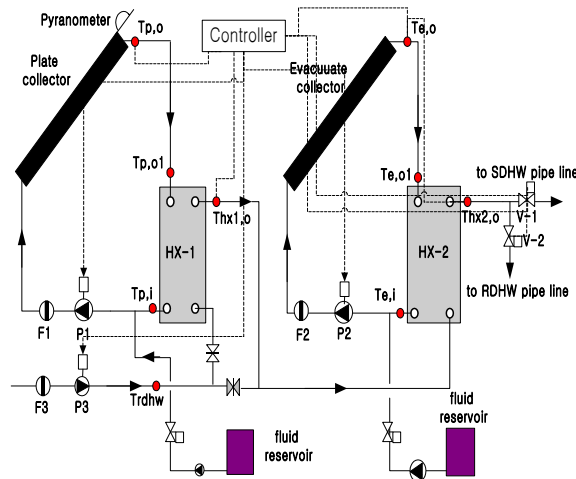


Figure 2: Solar system configuration and sensors

Figure 2 shows the sensor installation plan needed for the configuration and the control of the solar heating system and its performance measurement. Thermo couple was installed in each inlet and outlet of collector circuit, and the flowmeter for measuring DHW flow rate which passes through the heat exchanger at each collector circuit and pyranometer in solar panel were installed.

Table I: Specification of district solar heating system

item		specification
Collector area	Flat plate	430m ²
	vacuum tube	637m ²
Solar collector type	flat plate	= 0.79 =4.94kcal/m ² h °C
	vacuum tube	= 0.65 =1.5kcal/m ² h °C

Collector tilt angle and azimuth	36.5° south
Heat exchanger	Plate type
Collector fluid	30% Propylene glycol

From Table I, the used collector can be seen together with the specification of an installed flat plate collector and a single vacuum tube collector. Figure 3 contains thermal efficiency. As can be seen from this thermal efficiency curve, the flat plate collector achieved relatively high efficiency at low temperature range but the vacuum tube collector showed comparatively high efficiency at high temperature range. To analyze the system operating condition and results, the monitoring system was configured as shown in Figure 4.

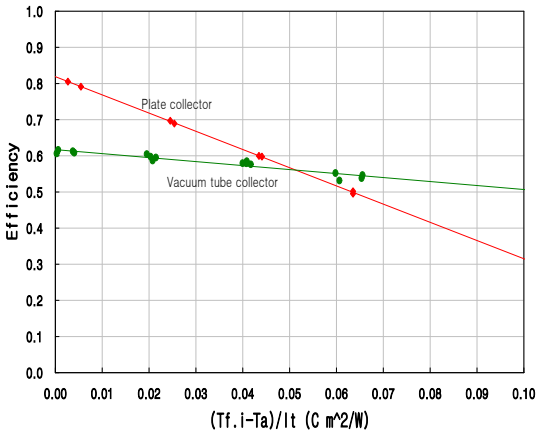


Figure 3: Collector efficiency curves

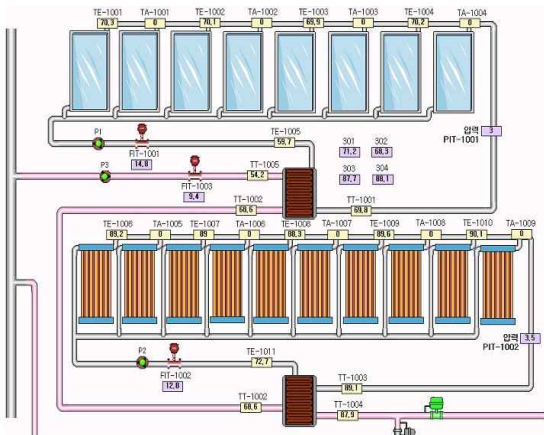


Figure 4: Monitoring of solar heating system

2.3 System control

Solar heating system control is a serial proportional control for a fixed temperature which controls flow rate by controlling On/Off switch and RPM of the pump to make the temperature of DHW passing through the heat exchanger reach the set temperature. The control of pump RPM is performed using PDI control system. The intensity of radiation is regarded as the largest variable in the pump RPM. The stronger the intensity becomes, the more RPM increases. Since DHW circuit pressure is always higher on the side of the return pipe which is connected to the heating exchanger (the pressure change depends on the season), the flow rate flows to a certain extent if the electro motion valve, V1 or Vs is open in the case that pump P 3 does not work. The concrete numbers used in control are as follows:

1) Control of pump P1

a. Valve V1

- Open condition:

When pump P3 is on (when $T_{HX2,o} > T_{dhw,set}$)

- Close condition:

When pump P3 is off (when $T_{HX2,o} < T_{RET}$)

b. Pump P1

-Open condition:

$T_{p,o} - T_{rdhw} \geq \Delta T_{e,on} (\doteq 10^{\circ}\text{C})$

-Off condition:

$T_{p,o} - T_{rdhw} < \Delta T_{e,off} (\doteq 4^{\circ}\text{C})$

c. Pump P2

-Open condition:

$T_{e,o} \geq T_{e,on} (\doteq 84^{\circ}\text{C})$

- Off condition:

$T_{e,o} < T_{e,off} (65^{\circ}\text{C})$

d. Pump P3

-Open condition: Δt (about two minutes) later after P1 or P2 pump is on

-Off condition: $T_{HX2,o} < T_{RET} (\doteq 79^{\circ}\text{C})$ (flow by pressure difference)

-On condition: $T_{HX2,o} > T_{dhw,set} (\doteq 85^{\circ}\text{C})$

e. Electro-motion valve, V2

-Open condition:

Two minutes later after pump P1 or P2 is on

When pump P1 or P2 is on and

$T_{HX2,o} < T_{RET}$, then V2 is open

-Close condition:

When pump P1 and P2 are off

When $T_{HX2,o} > T_{dhw,set}$

f. Electro-motion valve, V1

-Open condition:

When pump P3 is on (when $T_{HX2,o} > T_{dhw,set}$)

- Close condition:

When pump P3 is off (when $T_{HX2,o} < T_{RET}$)

When pump P1 and P2 are off

2) Flow rate control: PID control

a. Flow rate control by pump P1:

$T_{p,o}$ becomes equal to $T_{rdhw} + \Delta T_p$ by flow rate control(Herein ΔT_p is the temperature to be warmed up in the flat plate collector circuit and should be controlled according to season and kept around 12°C)

b. Flow rate control by pump P2:

$T_{e,o}$ becomes equal to $T_{dhw,set} + \Delta T_e$ by flow rate control(Herein ΔT_e is the value decided based on the efficiency of heat exchanger)

c. Flow rate control by pump P3:

$T_{HX2,o} = T_{dhw,set}$ controls the flow rate

3. Results and discussion

3.1 Initial operating characteristics of system

Figure 5 shows the operation condition after system starts to operate initially in the morning. From the results, it can be seen that different from flat plate, outlet temperature of the collector circuit in the vacuum tube collector has increased rapidly up to the set temperature during a certain period of time as soon as pump turns on. This phenomenon worsens and may be the cause of overheating in the case that there is low flow rate. Thus, the rapid temperature risen in initial operation appears to be most

significant in the vacuum tube collector circuit. It is considered due to the characteristics of collectors associated with the heat pipe. That is, regardless of the intensity of radiation, a lot of the heat exchange appears to occur in a moment due to the latent heat in the working fluid for the heat pipe. Nevertheless, a deeper examination should be required to be followed. Therefore, initial operating flow rate in the collector circuit of the vacuum tube collector should be kept full enough. In addition, in the case that set temperature is high like the system shown in Figure 5, the pump should be on below the set temperature to prevent overheating.

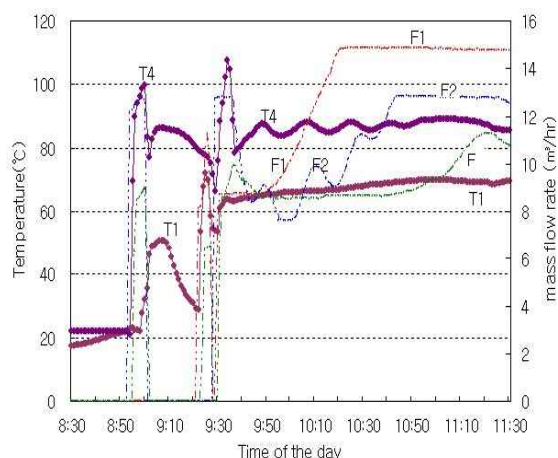


Figure 5: ON/OFF operating characteristics of each collector field

3.2 Thermal efficiency characteristics

Considering the operating characteristics of collectors as described earlier, the system was operated when initial flow rate was held full enough at the moment of turning the pump on. From February to May, Figure 6 presents the daily collection and system efficiency from solar heating system, and Figure 7 indicates the daily radiation. Daily collector efficiency of the flat plate collector was kept in the range of 15% to 50%, but that of vacuum tube collector had a range of 40 to 60%. Whereas the efficiency of the flat plate collector was changed considerably according to radiation and ambient temperature, that of the vacuum

tube collector was little affected by radiation or ambient temperature. That is, when the radiation gets worse and the ambient temperature gets lower, there is a significant collector efficiency difference between the flat plate collector and the vacuum tube collector. In other words, in the case of the collector with large heat loss coefficient, collector efficiency was greatly affected by the radiation as well as the difference between collector temperature and ambient temperature.

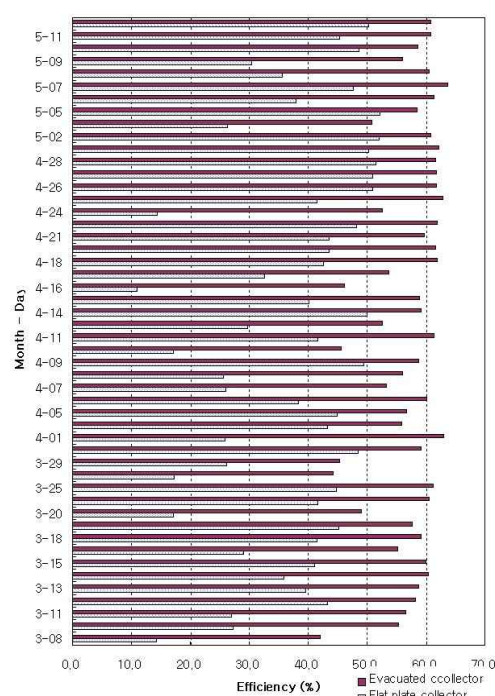


Figure 6: Solar system daily efficiency

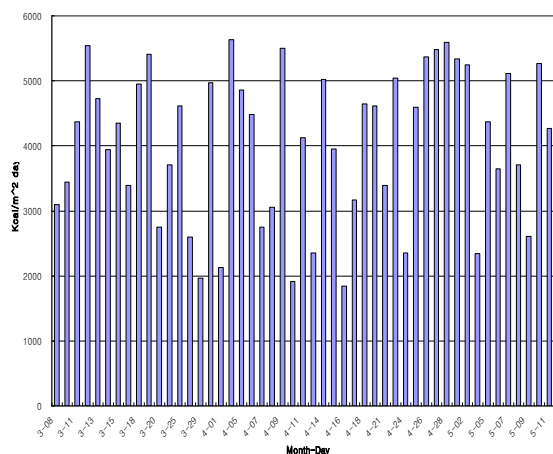


Figure 7: Daily solar radiation

4. Conclusions

This study examined the solar heating system for the district heating which produces and serves the desired temperature directly from collector without the thermal storage tank. Solar heating system is divided into the flat plate collector and the single vacuum collector circuit. It uses the way RDHW is warmed up to the set temperature while it passes through the heating exchanger. It is a system composed of two different types of collectors within one system.

This study analyzed the operating characteristics of respective collecting circuit and was summarized as follows:

- If there is much thermal load continuously such as district heating, the solar heating system can be designed with the method which produces the desired temperature without the thermal storage tank like this system. This method makes it possible to simplify the solar heating system and improve the system efficiency.

- Due to the initial operation characteristics of the collector circuit of vacuum tube collector in the morning, unlike the flat plate collector, the phenomenon occurs-collector outlet temperature increases substantially during several minutes (around 3 to 5 minutes) as soon as circulating pump turned on. Several problems may arise along with it. Therefore, in the case of the vacuum tube collector, initial operating flow rate can not be lowered, because of that phenomenon. In addition, when the set temperature is high around 100°C, the temperature turning the pump on should be fully lowered below 100°C and it prevents the collector from the instant overheating.

- These factors must be reflected in the control.

- As a result of approximately three-month operations from mid-February to mid-May, the daily collector efficiency changed

dramatically according to the radiation and ambient temperature. As the radiation was small and the ambient temperature was low, a large collector efficiency difference between the flat plate collector and the vacuum tube collector were found.