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Performance analysis of evacuated tube solar collector for residential heating in Mongolia

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Abstract

This paper presents initial result of measurement and experimental work in smoky and dusty location of Ger district, Ulaanbaatar Mongolia, as well as some problems while using the solar water heating system for residential heating in Mongolian harsh and cold climate condition. By this research, the measurement devices were placed on the forced circulation evacuated tube solar collector system installed on the top of the residential house then the measurement had been done from December to April for last two years. As a result of this study, the average collector efficiency was 65.7 % and the system efficiency was 31.5 % in real condition during for the four months of measurements.

Keywords: *Mongolian harsh and cold climate, electric heater, evacuated tube solar collector, residential house, Ger district.*

Explanation: Ger district where more than half of the capital's residents live without access to basic public services like water, sewage systems and central heating.

1. Introduction

Converting solar energy into thermal energy is useful in Mongolia where lots of thermal utilizations are. Because, thermal energy is indispensible to all residential houses due to the average ambient temperature during the most months is below +2 ^{0}C in Mongolia. On the other hand, Mongolia has much solar resource for example the annual sunshine duration is about 2900 to 3300 hours [1] and yearly solar radiation is about 1450 to 1840 kWh m^{-2} year $^{-1}$ [2].

Type of equipments that converts solar energy into thermal energy such as flat plate and evacuated tube solar collector is rarely used in Mongolia. The reasons are up to now the capacity of recent solar collectors for the whole year has not been estimated accurately in Mongolian actual condition, also high initial investment of it is not attracting consumer's interest.

In recent years, the air pollution has been evidently increasing in populated Ulaanbaatar city, because of the number of households in Ger district who burn raw coal to heat their house have been growing. It is confirmed by several studies such as The World Bank Studies [3]. This is a sign of expressing that it is time to refuse raw coal application and to use new resources of thermal energy which is harmless to the environment and productive for household's economics.

Another big concern for Ger district of Ulaanbaatar city is the deficit and improper infrastructure of electric power. As a result of it, to use an electric heater has difficulties in residential houses. But the main reason of coal burning still in use for heating in Ger district is because of expensive electric bill for long heating season. Therefore we began to seek most convenient and harmless heating system and started setting up some evacuated tube solar collector on a few objects for undergoing the operation in the winter time.

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Ultimate goals of this research work contain to research hybrid heating systems with solar water heating device in Mongolian harsh and cold climate condition for a long time, and to estimate efficiency of evacuated tube solar collector in the actual usage as well as to modify it for Mongolian climate condition and application feature. In this paper, we present a preliminary outlook of measurement and experiment that includes collector efficiency, system efficiency and some problems encountered in the real operation.

2. Methodology

2.1 System description

The measurement was done in the residential house with area of 54 square meter located in Chingeltei Ger district of Ulaanbaatar city (see **Fig. 1**). The solar water heating system combined with electric heater was installed on it in 2013. Since the end of 2013 the sytem has been used for house heating. The hybrid heating system consists of evacuated tube collector which contains four sections that have 120 pieces of heat pipe, heat storage tank that has capacity of 500 liter (see **Fig. 2**), auxiliary electric heater of 3 kW located in the heat storage tank, radiator system for heating the house, and the solar circuit pipes. The length of solar circuit pipes to supply is 11 meters (5 meters inside of the house and 6 meters outside) and the return pipe length is 12 meters (5 meters inside of the house and 7 meters outside) (see **Fig. 3**).

Fig.1: Overview of the experimental system

Fig. 2: The tank and controller of system

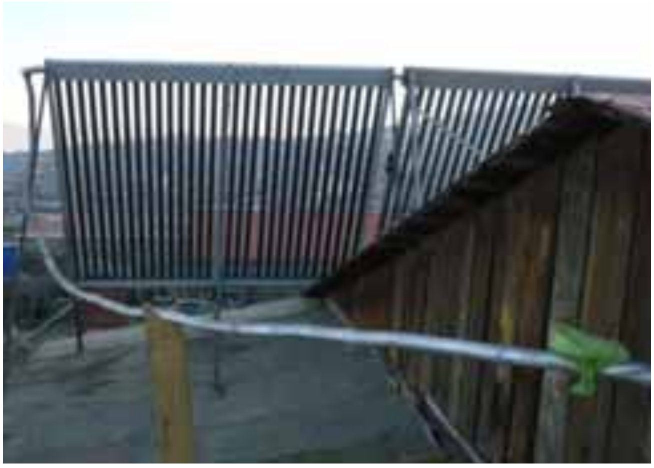

Fig. 3: Solar circuit pipe to return

2.2 Measurement and devices

Measurement was done twice in between from 2013.12.05 to 2014.04.11 and from 2014.12.03 to 2015.04.13. The following devices was used: flow meter (Ultrasonic-TDS-100), solar meter (Pyranometer-Ms-802), temperature sensors (Pt-100), power meter for measuring electrical consumption (Kyoritsu-Model-6300), data logger that stores and collects the data every 2 minute (Datamark-Ls-3000Ptv). The following temperatures such as ambient temperature (T_1), inside temperature of the house (T_2), solar fluid temperature at the collector outlet (T_3), solar fluid temperature at the collector inlet (T_4), solar fluid temperature at the tank outlet (T_5) and solar fluid temperature at the tank inlet (T_6) were measured (see **Fig. 4**).

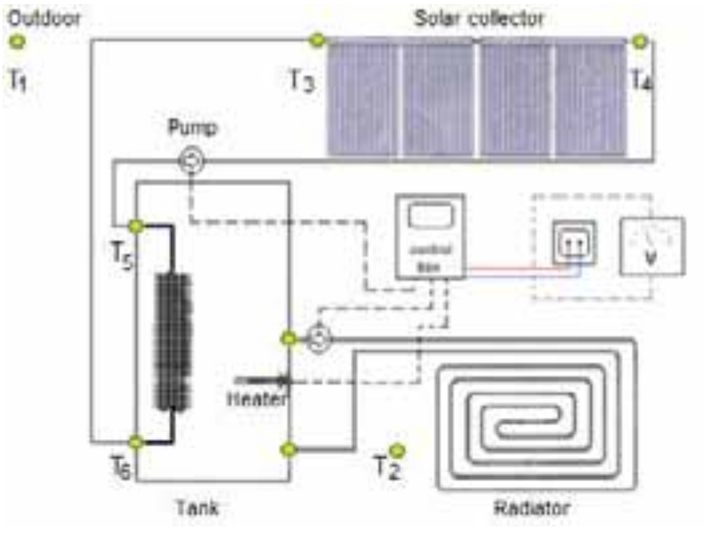

Fig. 4: The scheme of solar water heating system for house heating, and the green points indicate the temperature measurements

2.3 Calculation

Useful energy collected by the solar collector was calculated as:

$$Q_K = \dot{m}\, Cp\, (T_3 - T_4) \qquad \text{(eq. 1)}$$

To calculate the heat delivered in the tank, the solar fluid temperature data at the tank outlet and inlet was used:

$$Q_T = \dot{m}\, Cp\, (T_6 - T_5) \qquad \text{(eq. 2)}$$

The collector efficiency was calculated as:

$$\eta_к = \frac{Q_k}{A_c G} \qquad \text{(eq. 3)}$$

The system efficiency was calculated as:

$$\eta_s = \frac{Q_T}{A_c G} \qquad \text{(eq. 4)}$$

By these calculation methods above [4-6], the measurement data was processed on a specific day when the sky is more clearly. From every measured month the clearest sky day was selected. Then total daily energy collected by the solar collector and delivered to the tank was calculated on those days. As well as daily and monthly average collected and delivered energy was computed and compared. The measurement data from 2014.12.03 to 2015.04.13 used in the calculation.

3. Results and discussion

3.1 Performance of clear sky days

The days of 2014.12.13, 2015.01.21, 2015.02.15 and 2015.03.09 from every month measured were picked to compare daily energy performance. The daily global solar radiation on the collector's surface was 89 MJ day^{-1} on 2014.12.13, 110 MJ day^{-1} on 2015.01.21, 176 MJ day^{-1} on 2015.02.15 and 212 MJ day^{-1} on 2015.03.09. Daily useful energy collected by the solar collector was 64 MJ day^{-1}, 80 MJ day^{-1}, 128 MJ day^{-1} and 154 MJ day^{-1} respectively above. Daily heat energy delivered in the tank was 44 MJ day^{-1}, 43 MJ day^{-1}, 66 MJ day^{-1} and 73 MJ day^{-1}. Comparative estimate of daily energy was shown with **Fig. 5**.

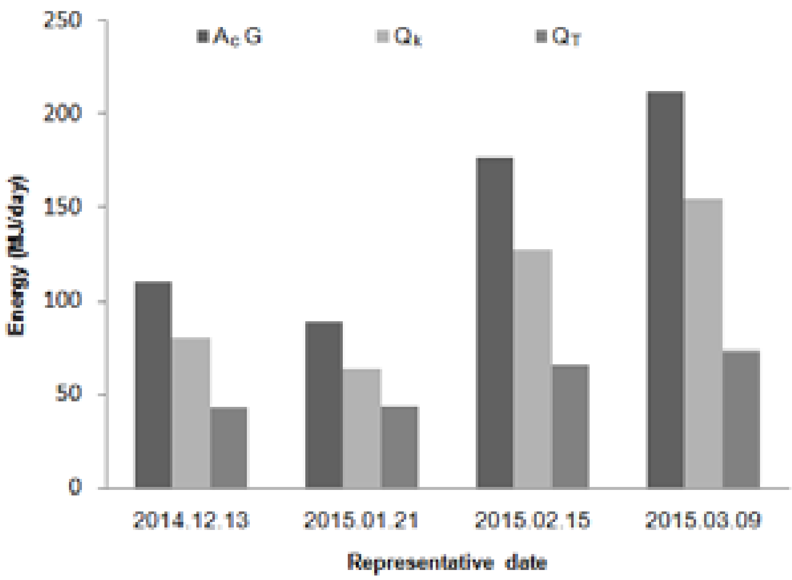

Fig. 5: Daily solar radiation on collector's total surface (Ac G), daily energy collected by solar evacuated tube collector ($Q_к$), daily energy delivered to the tank (Q_T)

3.2 Comparisons of the months

In this part of calculation, monthly total energy collected by the solar collector and total energy delivered to the tank wasn't computed, as we had lost some days' measurement data in February and March a few times because of capacity of data logger. In order to compare the performance of each month measured, the monthly average numbers were shown by percentage. Monthly average collector efficiencies were 64.9 % in December, 65.3 % in January, 66.1 % in February and 67.3 % in March. The reason why the collector efficiency about 65 % in December and January was, while the efficiency increased to about 67 % in February and March was connected with glass cleaning of the collector. The first half of the collector glass tube was wiped on February 11 and the rest of the part was cleaned on March 14.

Also monthly average system efficiencies were 38.5 %, 32.7 %, 27.9 %, and 26.8 % respectively. The process that collector system efficiency improves when the ambient temperature decreases during the coldest time of a year and the system efficiency reduces when the ambient temperature gets warmer was observed. It depends on water temperature in the tank. The water in the tank chills while circulating through the house heating radiator. Chilled water absorbs heat well from the solar fluid that was heated by solar collector. Thus the system efficiency in the winter time, when heat load is highest in December and January, is higher than that of the others. **Fig. 6** shows monthly average system efficiency and collector efficiency.

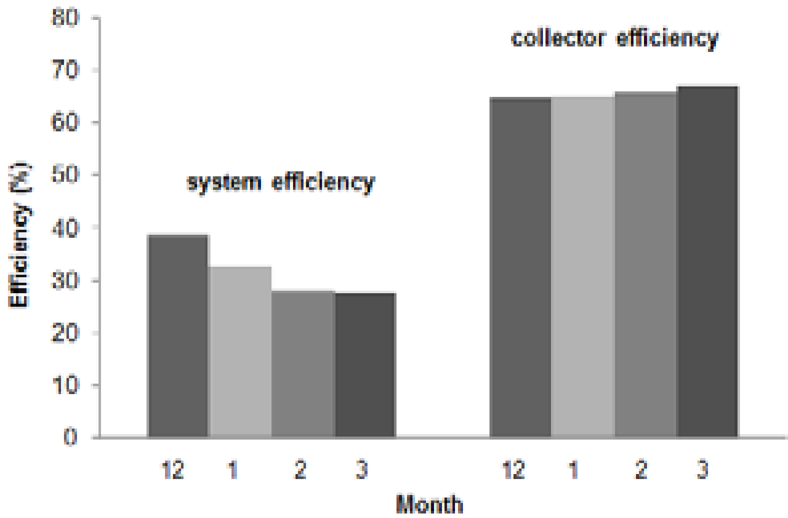

Fig. 6: Monthly average system efficiency and collector efficiency

From here, 59.3 % in December, 50.0 % in January, 42.2 % in February and 40.5 % in March of total energy collected by the solar collector were transferred into the tank, and the rest of the collected energy was lost when the energy was passing through the solar circuit pipes from the solar collector to the tank and from the tank to the solar collector.

3.3 Problems encountered

The surface of the collector glass tubes which transmits solar radiation were quite contaminated by soot and dust during the duration of experimental work (see **Fig. 7**).

Fig. 7: The glass tube contamination during the measurement (2014.01.10)

The main reason of decreasing the system efficiency is heat loss in the solar circuit pipes. During the measurement the heat insulators of the solar circuit pipes were renovated twice, but heat loss of pipes was not kept decreasing for a long time. Because material structure of the heat insulators deformed and material's body decayed and became thin due to temperature up and down during the operation time (-40 ^{0}C to +150 ^{0}C) and environmental various effects (see **Fig. 8**)

Fig. 8: Three months after heat insulator of solar circuit pipe changed (2014.01.10)

4. Conclusions

In order to estimate collector system efficiency in Mongolian actual smoky and dusty condition, the solar water heating system combined with an electric heater for heating the residential house was experimented and measured. As the result, the system efficiency was 31.5 % and the collector efficiency indicated 65.7 % averaged during the four months' measurement. Also 52 % of total energy collected by solar collector during the four months measured was lost through the solar circuit pipes. After full cleaning of collector's glass tube, the collector efficiency increased by over 2 %.

The solar fluid was overheated by the collector during the power outage in several times, because of a solar water heating system with an evacuated tube collector uses an electrical circulation pump. Therefore, to operate the circulation pump continuously during the daytime, a small alternative resource of electric power should be used in the Ger district with electrical deficiency.

To decrease the air pollution level of Ulaanbaatar city, coal usage has to be eliminated in Ger district by finding new, convenient and harmless heating system. One of the reasonable heating systems is solar water heating systems combined with an electric heater. It is important to develop appropriate systems suitable for Mongolian climate condition and heat demand.

Nomenclature

T_i	temperature	(K)
$\dot{m}$	solar fluid mass flow rate	(kg s^{-1})
C_p	specific heat capacity	(J kg^{-1} K^{-1})
A_c	collector area	(m^2)
G	total global solar radiation at the collector's surface	(W m^{-2})

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