EXHAUST GAS HEAT RECOVERY SYSTEM FOR PLANT BED HEATING IN GREENHOUSE PRODUCTION

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ABSTRACT

Hot air heater with light oil combustion is the most common heater for greenhouse heating in the winter season in Korea. However, since the heat efficiency of the heater is about 80%, considerable unused heat in the form of exhaust gas heat discharges to atmosphere. In order to capture this exhaust gas heat a heat recovery system for plant bed heating in the greenhouse was built and tested in the hot air heating system of greenhouse. The system consists of a heat exchanger made of copper pipes, Φ 12.7× 0.7t located inside the rectangular column of 330× 330× 900mm, a water circulation pump, circulation plastic pipe and a water tank. The total heat exchanger area is 1.5㎡, calculated considering the heat exchange amount between flue gas and water circulated in the copper pipes. The system was attached to the exhaust gas path. The heat recovery system was designed as to even recapture the latent heat of flue gas when exposing to low temperature water in the heat exchanger. According to performance test it can recover 45,200 to 51,000kJ/hr depending on the water circulation rates of 330 to 690ℓ /hr from the waste heat discharged. The exhaust gas temperature left from the heat exchanger dropped to 100° C from 270°C by the heat exchange between the water and the flue gas, while water gained the difference and temperature increased to 38°C from 21°C at the water flow rate of 690ℓ /hr. And, the condensed water amount varies from 16 to 43㎖ at the same water circulation rates. This condensing heat recovery system can reduce boiler fuel consumption amount in a day by 34% according to the feasibility study of the actual mimitomato greenhouse. No combustion load was observed in the hot air heater.

Key Word : Recovery of exhaust gas heat, Plant bed heating, Heat exchanger, Hot air heater

INTRODUCTION

The total greenhouse production costs in this country reached 31 thousand millions won in 1997, where annual heating expense and tax-free fuel supply amount increase every year by 60 and 30 %, respectively (Kyeonggido, 1999). The most universal heating method for greenhouse heating in the current time is hot air heating with light oil burning that has a definite advantage over heating of hot water circulation or solar heating in terms of heat efficiency. More precisely, when light oil is combusting in the furnace of hot air heater the air fan on the top of air heater blows air perpendicularly to the furnace and the heat exchanger pipes to supply hot air into greenhouse through ducts. During this heat supply process, about 20% of combustion heat lost in the form of exhaust gas heat, which could be recyclable if an appropriate system is available. Suppose a capacity of burner in a hot air heater is 504 thousands kJ/hr (120 thousands kcal), about 100.8 thousands kJ(24 thousands kcal), 20% of combustion heat, discharges to atmosphere that is enormous heat loss if we count the number of greenhouse spread out. Exhaust gas heat recovery is a serious issue not only for economic reasons but also rooting out pollution source. The gas has noxious components such as sulfur chemicals and carbon dioxide which are contaminating environment and aggravating greenhouse effects. By the recent research report on the advantages of plant bed heating to the yields and plant growths in greenhouse cropping, plant bed heating is spreading out rapidly, for which water heating system including boiler and underground pipings in order to supply warm water stimulating root growth is necessary – though the water temperature may vary depends on crops. Typical water temperature for plant bed heating is 20° C, thus inlet water temperature in the pipe of less than 30° C is appropriate, according to the report (Kyeonggido, 1999). The heat requirement for plant bed heating in winter season is 168kJ/hr•pyung that needs 100,800kJ of heat energy for 0.2ha greenhouse. This heat amount can be recovered from the exhaust gas heat of the air heater in 0.2 ha greenhouse. In this study, an exhaust gas heat recovery system was designed and tested to figure out its performance.

MATERIALS AND METHODS

Designing heat exchanger

Among the parts in exhaust gas heat recovery system, the most essential element is designing a gas- water heat exchanger for maximum heat recovering. However, if final gas temperature after heat exchange completed is under 100°C, cold rust on the surface of heat exchanger is unavoidable, so some measures would be required - for instance, final gas temperature adjusted to more than 100°C. Following equations adopted to calculate the heat transfer area of the heat exchanger.

$q = m_w c_{pw}(\Delta T_w)$ .... (1)

$q = UA\Delta T_m$ .... (2)

m_w : mass flow rate of water in the heat exchanger, kg/hr

c_{pw} : specific heat of water, kJ/kg · K

ΔT_w : temperature gained by water in the heat exchanger, K

U : total heat transfer coefficient, kJ/m^2 · hr K

A : total heat transfer area, m^2

ΔT_m : logarithmic mean temperature difference, K

Heat exchanger was designed as counter flow form, where gas downwards from top side to bottom side but water forced to flow from bottom to top by a circulation pump. For maximum heat transferring between gas and water, the wall of heat exchanger has two layers as shown in Figure 1. Overall size of heat exchanger was 330X330X750mm, rectangular shape, of which copper of Ø 15mm pipe wound in spiral form. Total heat transfer area was about 1.5m^2, and a drain valve was installed in the bottom to carry condensate out.

Plant bed heating system with recycling exhaust gas heat

The system, as shown in Figure 2, is composed of a hot air heater, a burner, a heat exchanger, a water tank and a circulation pump (Table 1).

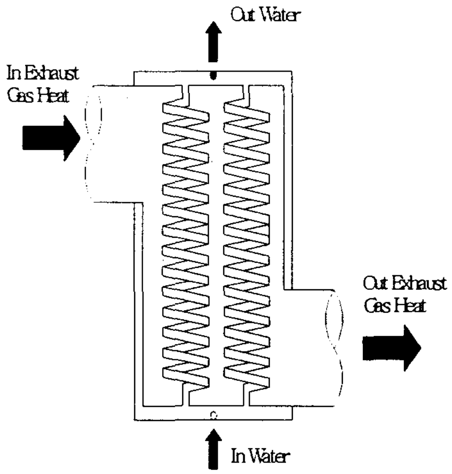

Figure 1. Overview of the heat exchanger used in this experiment

Table 1. Major components of the exhaust heat recovery system for plant bed heating

major components		Specifications	Remarks
heat exchanger	size	330× 330× 920	stainless steel
	heat transfer pipes	12.7× 0.9t× 2rows× 16steps	Copper
water circulation	pump	220/380V, 0.5kW	
Air Heater	burner	shinhung SHG-30G, 3.75gals	130,000 ㎉/hr
	combustion chamber	Φ 700× L1440× 2.5t	
	heat transfer pipes	Φ 75× L1440× 1.5t, 2steps	

The air heater used in this investigation has Sinhung SHG-30G burner with hago nozzle of 14.17liters per hour, theoretical heat value of 546,000kJ/hr. The power consumption of circulation pump is 0.3kW and suction head is 3m, and its on-off switch is connected to the blower of the air heater which enables to recover exhaust gas heat only for air heater operation. The hot water heated by exhaust gas heat was carried to the boiler water tank, consequently that could reduce fuel consumption for making hot water, as shown in Figure 2.

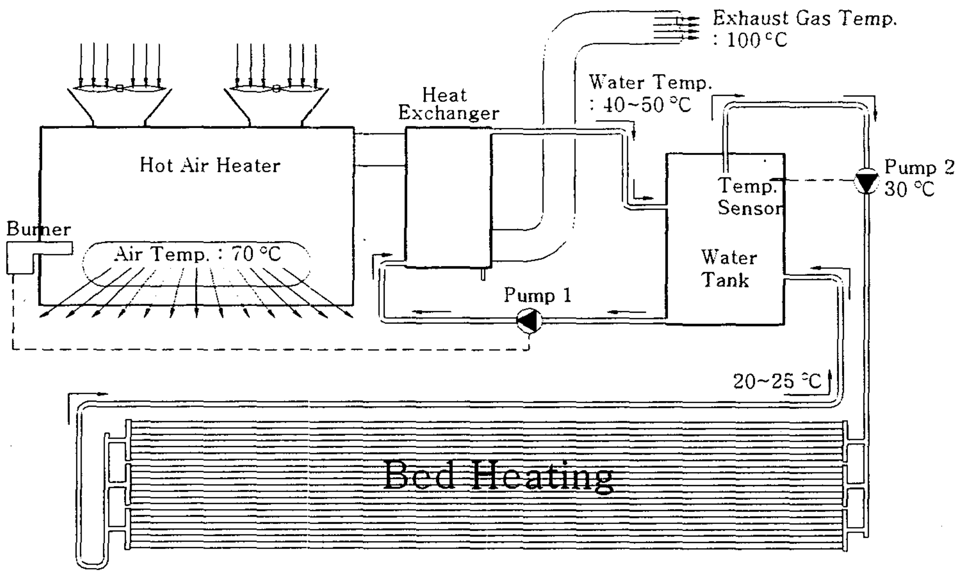

Figure 2. System diagram of plant bed heating system using exhaust gas heat of hot air heater

Measurement of temperature and exhaust gas

Figure 3 shows measurement points and instruments used in this study, of which T type thermocouples and gas analyzer were used to monitor water temperature change in the heat exchanger and air temperature and gas components in the air heater.

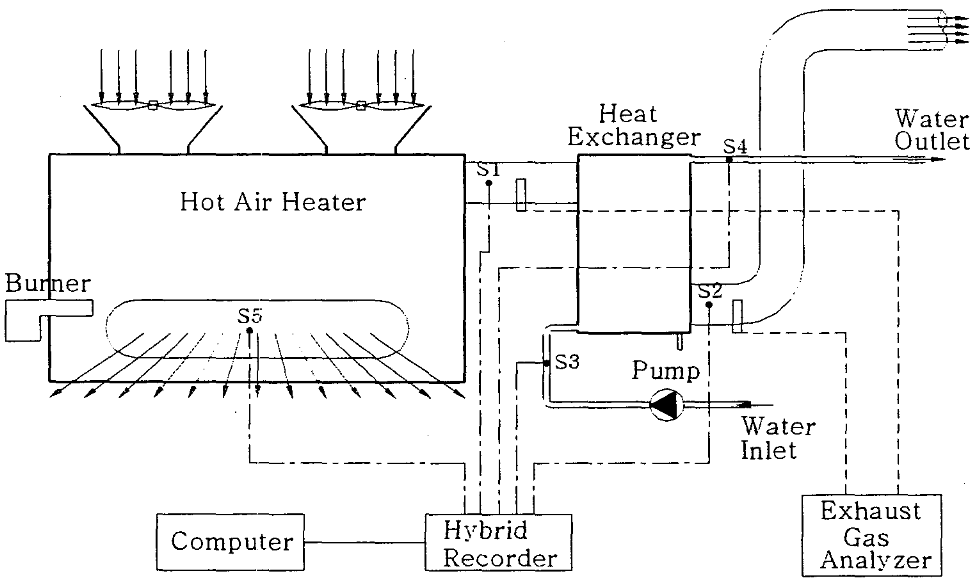

Figure 3. Measuring points of temperatures and exhaust gas in the heat recovery system

Feasibility test

The system moved to an actual greenhouse site and was installed in mini-tomato growing greenhouse of 700 pyung located in Chungjun-Si to check any difficulties in use. The greenhouse has two air heaters and a light oil boiler for bed heating, where the heat recovery system developed was attached to the gas path in the air heater and all other instrumentation were identical to the test accomplished in the institute.

RESULTS AND DISCUSSIONS

Water temperature variation by the heat exchange amount

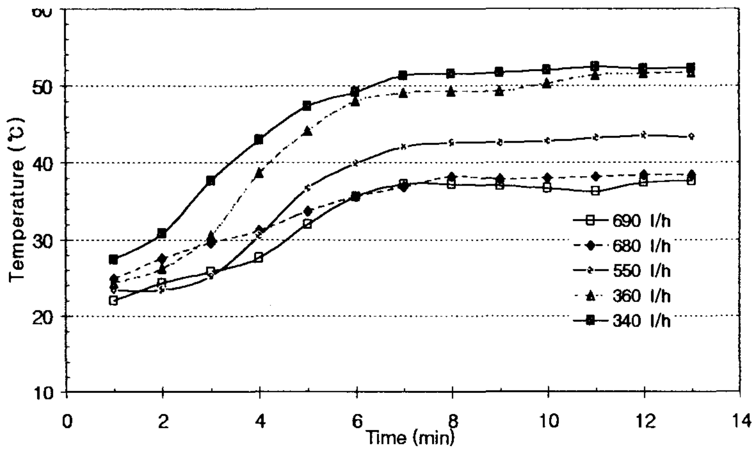

Figure 4. Water temperature variation with water flow rate

Water temperature in the outlet rose to 37 ~ 55°C when inlet temperature was 22~ 27°C after 7 minutes of water circulation and the flow rate of 340~690 l/hr, in which the highest temperature was 53°C at 340 l/hr, the lowest 37°C at 690 l/hr.

Heat recovery amount by the water flow rate

Figure 5 shows the heat gained by the water flow rate that indicates bigger flow rate bigger heat gained. The largest heat gain, 51,240kJ/hr, occurred when flow rate was 690 l/hr, the smallest, 45,350kJ/hr at 340 l/hr.

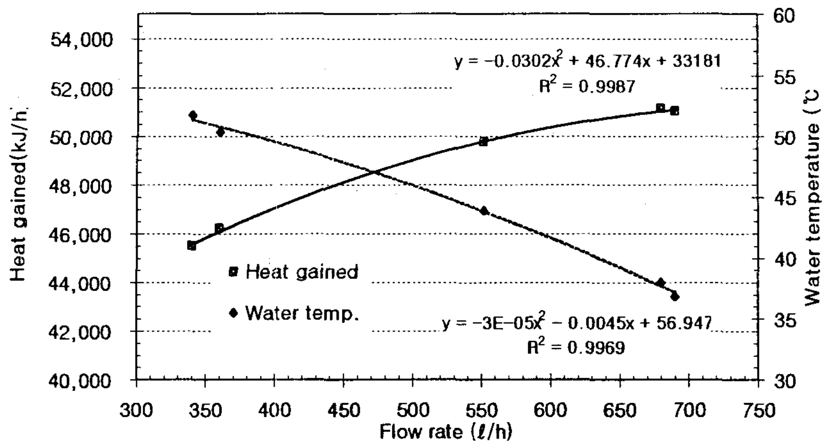

Figure 5. Relationship between heat gained and wate temperature

The thermal efficiency of the air heater was 85%, thus about 63% of exhaust gas heat was recovered by this heat exchanger.

Combustion condition

Table 2 tells the combustion conditions both with the heat exchanger and without heat exchanger attached to the air heater.

Table 2. Comparison of exhaust gas components between with or without heat exchanger in the hot air heater

	flue gas temp.(℃)	O_2(%)	CO_2(%)	CO (ppm)	air ratio
With heat exchanger	130	3.4	12.9	10	1.18
Without heat exchanger	270	3.5	12.8	9	1.2

According Table 2, no significant difference appeared in the content of O_2, CO_2, CO and air ratio except the flue gas temperature - 130°C and 270°C, that means no combustion load by the heat exchanger to the furnace and the capacity of burner blower was big enough to overcome the load, if any, caused by the heat exchanger. In the designing stage we worried about back fire or combustion load, fortunately no such incidents were observed in the pretest and feasibility test as well.

Feasibility study

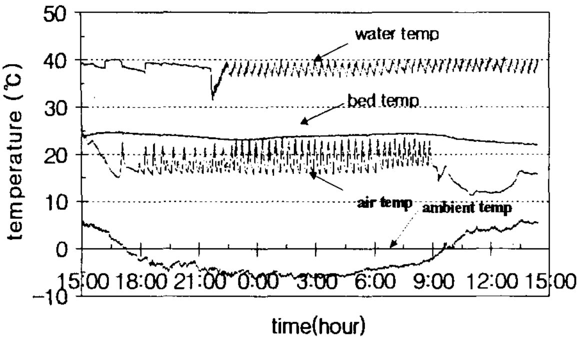

Figure 6. Temperature changes of the greenhous

Temperature variation in the greenhouse

Temperature variations inside the greenhouse are shown in Figure 6. Water temperature within the water tank varied up to 40°C by the intermittent operation of the air heater, i.e., periodic operation of the heat exchanger. About 8°C difference was monitored in the air temperature inside the greenhouse, at this time outdoor air temperature dropped to -8°C, the plant bed maintained at 23°C rather steadily.

Heat recovery system analysis

Figure 7 shows the gas and water temperature variation of the heat exchanger on the date of 15th December, 1999.

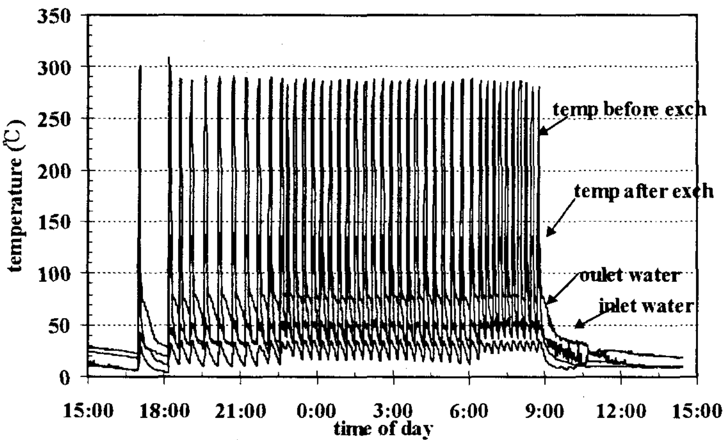

Figure 7. Temperature variations of the different positions of the heat recovery system

The operation interval of the air heater was 20 minutes - 5 minutes working and 15 minutes idling. The air heater has a nozzle, spraying capacity of 15.12 l/hr. Exhaust gas temperature difference between inlet, 280 °C, and outlet, 130 °C, of the exchanger was 150°C, that indicates the difference was absorbed by the heat exchanger to heat water. This absorbed heat increased water temperature from 32°C to 52°C, resulting temperature difference 20 °C between inlet and outlet water temperature. It led that total heat recovery amount 57,960kJ/hr multiplied flow rate, specific heat and temperature difference, and one day heat value can be obtained by multiplying hour heat recovery value and operation time. Suppose a house has two of this air heater the recovered heat would satisfy the heating needs of 0.2 ha greenhouse, therefore considerable fuel saving in water boiler is foreseeable.

Heat recovery amount in a day

Daily basis heat recovery rate can be calculated by multiplying water temperature difference between inlet and outlet, flow rate, specific heat and total air heater working time. Normal practice of air heater running is no operation in day time, setting auto run in switching board since 17 o'clock. The heat recovered from 18 to 9 o'clock the next day was 220,235kJ which is equivalent to 5.74 Liters of light oil. Everyday 11.48 liters of light oil can be saved by this heat recovery system in a greenhouse of two air heaters installed, which is 34% of daily fuel consumption in a boiler (Kim, 2000).

CONCLUSIONS

Followings are the major findings from this study of exhaust heat recovery system for plant bed heating.

1. A heat recovery system recycling exhaust gas heat of hot air heater for plant bed heating in greenhouse was built and tested. The system is composed of a hot air heater, a heat exchanger, a circulation pump and a water tank.
2. Dimension of the heat exchanger is 330X330X720mm of a rectangular column. Heat transferring accomplished through copper pipe and the double wall inside the exchanger where gas flows from top to bottom while water flow the opposite direction, bottom to top.
3. The bigger flow rate the greater heat recovery rate, in which the greatest, 51,240kJ/hr, occurred in the flow rate of 690 L/hr that the water gained 17.6°C while the gas temperature dropped to 114 °C from 252°C.
4. The heat recovery system recovered 63% of total gas heat but the efficiency could vary by other parameters, e.g., air heater capacity and thermal efficiency of heater.
5. No combustion load, and backfire were observed. Combustion was normal, according to the exhaust gas analysis.
6. The heat recovery amount in a day was 220,235kJ which is equivalent to 5.74 Liters of light oil. Everyday 11.48 liters of light oil can be saved by this heat recovery system in a greenhouse of two air heaters installed, which is 34% of daily fuel consumption in a boiler

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