HEAT PIPE TYPE EXHAUST HEAT RECOVERY SYSTEM FOR HOT AIR HEATER

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ABSTRACT

Area of greenhouse increases rapidly up to 45,265ha by the year of 1998 in Korea. Hot air heater with light oil combustion is the most common heater for greenhouse heating in the winter season. However, exhaust gas heat discharged to atmosphere through chimney reaches up to 10~20% of total heat of the oil combusted in the furnace. In order to recapture the heat of this exhaust gas and to recycle for greenhouse heating, the heat pipe type exhaust heat recovery system was manufactured and tested in this experiment.

The exhaust heat recovery system was made for space heating in the greenhouse. The system consisted of a heat exchanger made of heat pipes, Ø15.88 × 600mm located in the rectangular box of 600 × 550 × 330mm, a blower and air ducts. The rectangular box was divided by two compartments where hot chamber exposed to exhaust gas in which heat pipes could pick up the heat of exhaust gas, and by evaporation of the heat transfer medium in the pipes it carries the heat to the cold compartment, then the blower moves the heat to greenhouse. The number of heat pipe was 60, calculated considering the heat exchange amount between flue gas and heat transfer capacity of heat pipe. The working fluid of heat pipe was acetone because acetone is known for its excellent heat transfer capacity. The system was attached to the exhaust gas path.

According to the performance test it could recover 53,809 to 74,613kJ/hr depending on the inlet air temperature of 12 to -12℃ respectively when air flow rate 1,100m³/hr. The exhaust gas temperature left the heat exchanger dropped to 100℃ from 270℃ by the heat exchange between the air and the flue gas, the temperature difference was collected by the air and the warm air temperature was about 60℃ at the air flow rate of 1,100m³/hr. This heat pipe type exhaust heat recovery system can reduce fuel cost by 10% annually according to the economic analysis.

Key Word: Heat pipe, heat exchanger, Greenhouse heating, Hot air heater, Exhaust gas heat recovery system,

INTRODUCTION

After 1922, horticultural facilities area increases rapidly every year by 45,265ha in 1998 and greenhouse-heating area accounts for 21% by 9,290ha (Ministry of agriculture and forestry, 1999). The most universal heating method for greenhouse heating in the current time is hot air heating and hot water heating with light oil burning. Hot air heating accounts for the most part for greenhouse heating in this country which has a definite advantage such as faster temperature rising of air, higher heat efficiency using heater and cheaper heating cost than any other means (Kim, 1999). The supply of hot air heater increased about four folds, 96,169 units in 1998, compared to the 1993 and annual fuel consumption amount reached 966 thousands *kl* that accounts for 0.8% of total kerosene supplied and 39% of tax-free fuel. Hot air heater consists of gun type burner, furnace, heat exchanger, blast fan, ducts and automatic temperature control system (Yun, 1998). During hot air 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 burner capacity in a hot air heater is 504 thousands kJ/hr, amount of heat discharged to atmosphere is about 100.8 thousands kJ/hr, 20% of combustion heat. Exhaust gas heat recovery is a serious subject not only for economic reasons but also erasing pollution source, of which the noxious components in the gas such as sulfur chemicals and carbon dioxide are very harmful to environment and aggravating greenhouse effects. In this study, in order to recapture the exhaust gas heat and to recycle for greenhouse heating, the heat pipe type exhaust heat recovery system was manufactured and tested.

MATERIALS AND METHODS

Manufacture heat pipe type heat exchanger

The heat exchanger, as shown in Figure 1, is composed of heat pipe, separation plate, fan, exhaust gas inlet & outlet duct, air inlet & outlet duct and drain cock. Heat exchanger was manufactured as counter flow form where gas moves crossing over the heatpipes and the heat exchange occurs in the other side of the compartment. The overall size of heat exchanger is 600 × 550 × 330mm, rectangular shape, of which fin-tube type heat pipe of Ø15.88 × 600mm fixed by inclined angle of 5 ° against horizontal plane in crossing form and the total number of heat pipe is sixty (Table 1). In order to increase heat transfer efficiency, it has condensation part area by 2/3 of total area. The rectangular box was divided into two compartments; where one chamber is exposed to exhaust gas in which heat pipes could pick up the heat of exhaust gas. And by evaporation of the heat transfer medium in the pipes the phase changed medium carries the heat to the cold compartment, i.e., other end, then where an air suction fan blows the heat as form of warm air to greenhouse.

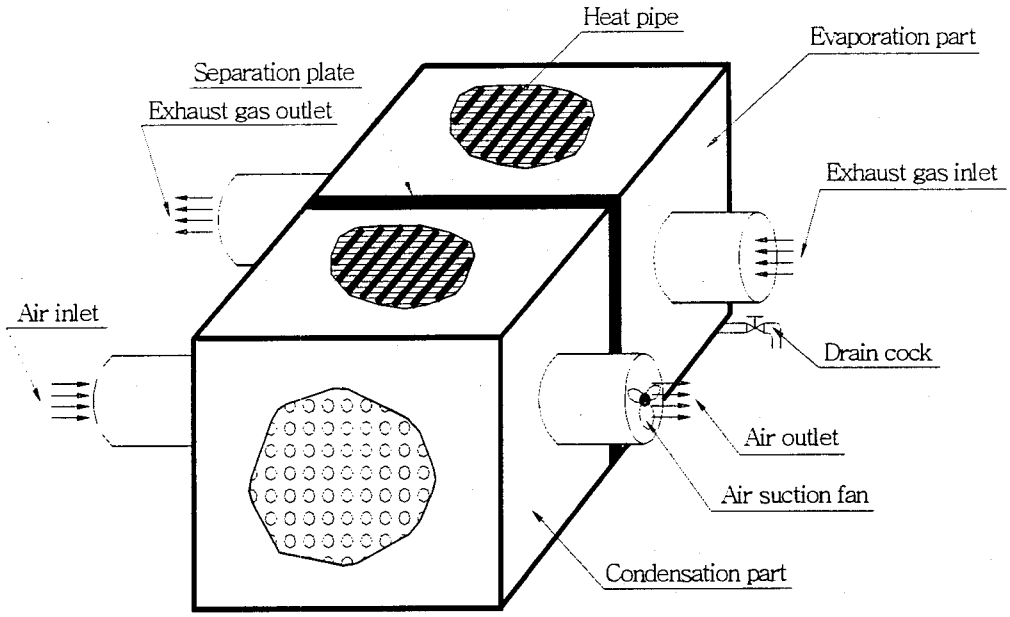

Figure 1. Overview of the heat exchanger used in this experiment.

Table 1. Specification of heat pipe used for heat exchanger

Items	Specification
Size(O.D × t × L)	Ø15.88 × 0.8 × 600mm
Material	SUS304 stainless steel
Degree of vacuum	1.4×10^{-7} kg/cm^2
Working fluid	acetone
Wick or groove existence	No
Filling ratio of working fluid	5, 7.5, 10, 12.5, 15%

Heat pipe type exhaust gas heat recovery system

Air heater used in this investigation has Sinhung SHG-30G burner with hago nozzle of 15.24 liters per hour, theoretical heat value of 585,200kJ/hr. The power consumption of air suction fan is 230J/sec and air flow rate is 2,500m^3/hr, and its on-off switch is connected to the blower in the air heater which enables to recover exhaust gas heat only for air heater operation period. The hot air heated by exhaust gas heat was carried to inner part of the greenhouse by air suction fan, thus that could reduce fuel consumption for making hot air, as shown in Figure 2 and Table 2.

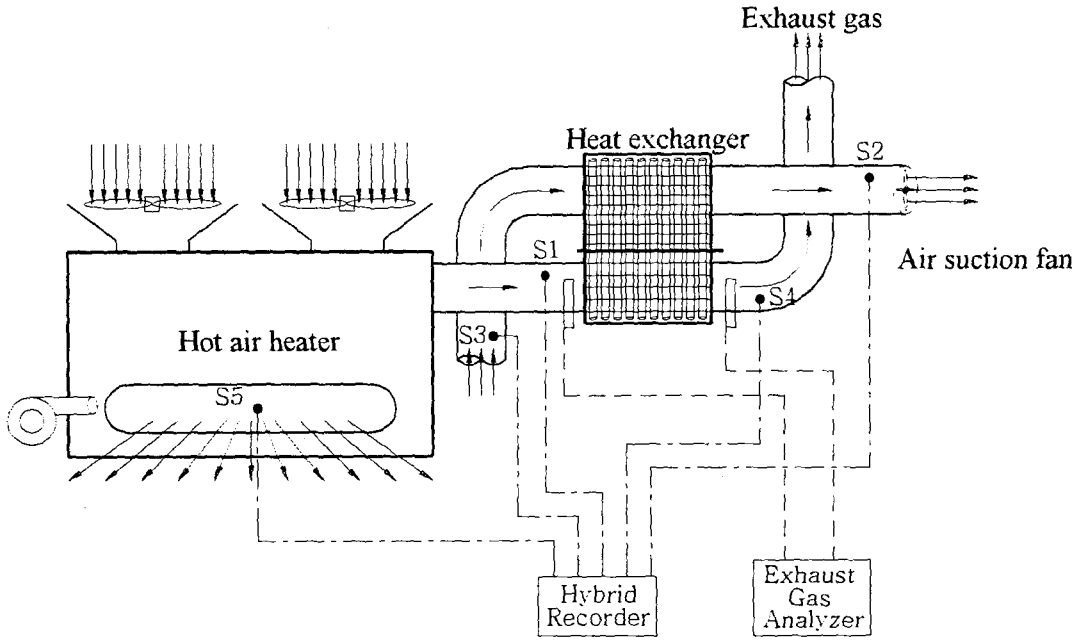

Figure 2. Schematic diagram of heat recovery system using discharged heat of exhaust gas from the hot air heater and measuring point of temperature and exhaust gas.

Table 2. Specification of the air heater and air suction fan

Item		Specification
Burner	Type	Gun type pressure atomizing
	Fuel consumption amount	15.24 litters/hr
Furnace and heat exchanger	Capacity	585,200 kJ/hr
	Furnace	Ø700(O.D) × 1,740(L) × 2.5(t)mm
	Heat exchanger	Ø75(O.D) × 1,440(L) × 1.5(t)mm, 2 steps
Air suction fan	Type	Sirocco
	Max. airflow rate	2,500 m^3/hr
	Power Consumption rate	230 J/sec

Measurement of temperature and exhaust gas

Figure 2 shows measurement points and instruments used in this study, of which T type thermocouples and gas analyzer were used to monitor air temperature change in the heat exchanger and gas components in the air heater.

RESULTS AND DISCUSSIONS

Heat recovery amounts and thermal efficiency by different air temperatures

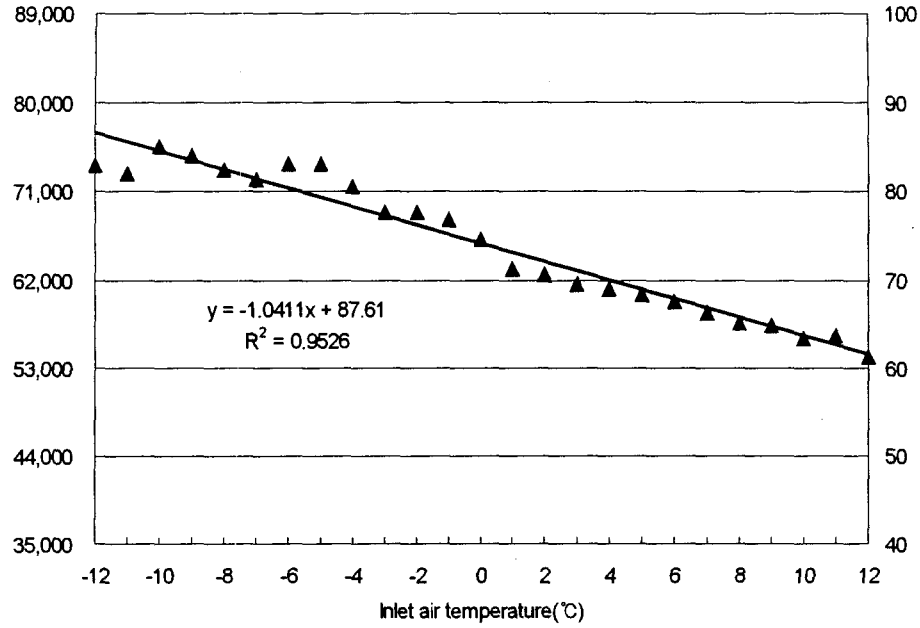

Figure 3. Heat recovery amounts and thermal efficiencies by the different inlet air temperatures in the heatpipe heat exchanger

Figure 3 shows the performance of the heatpipe heat exchanger attached to the hot air heater at fan airflow rate of 1,100m^3/hr. Recovered heat amount and thermal efficiency varied with inlet air temperature that indicates lower inlet air temperature bigger heat recovery amount. The greatest heat gain, 74,613kJ/hr, occurred when inlet air temperature was −10℃, the smallest, 53,809kJ/hr at 12℃. The thermal efficiency of the air heater was 85%, thus 61.3~85% of exhaust gas heat was recovered by this heat exchanger.

Heat recovery amounts by airflow rate

Figure 4 shows the recovered heat amount by the airflow rates that indicate bigger airflow rate bigger heat recovered. The largest heat gain, 91,931kJ/hr, happened when airflow rate was 1,920m^3/hr, the smallest, 47,025kJ/hr at 580m^3/hr.

Combustion condition

Table 3 tells the combustion conditions both with the heat exchanger and without heat exchanger attached to the air heater. According Table 3, no significant difference was detected in the content of O_2, CO_2, CO and air ratio except the flue gas temperature, 100°C and 270°C, that means no combustion load by the heat exchanger to the furnace and the capacity of burner blower is big enough to overcome the load caused by the heat exchanger. In the designing stage we worried about back flame or combustion load, fortunately, no such accidents were observed in this study.

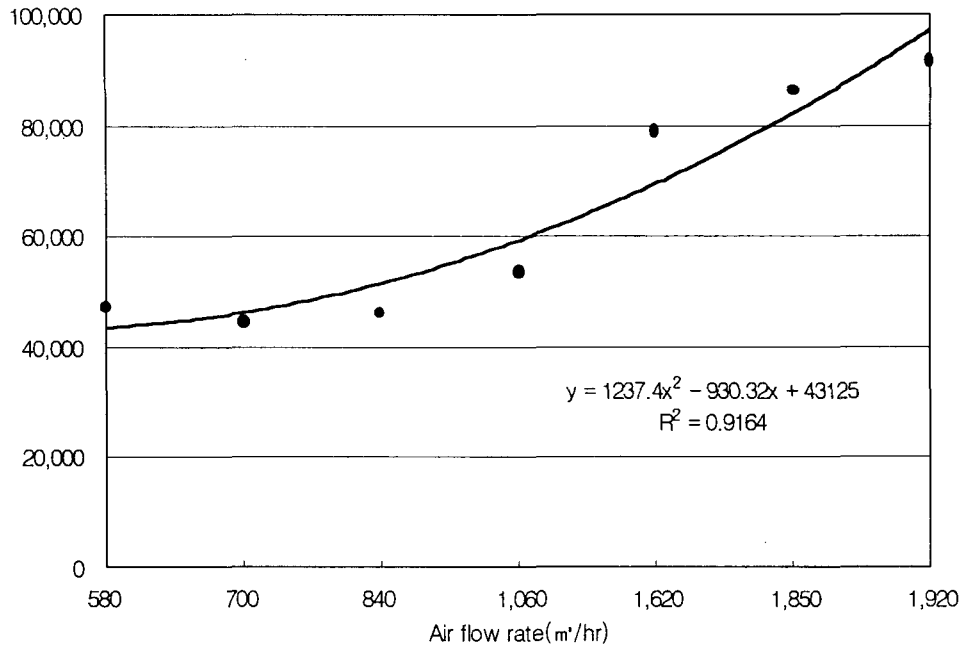

Figure 4. Rate of recoved heat by airflow rate in the exchanger.

Table 3. 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	100	3.5	12.8	10	1.17
Without heat exchanger	270	3.6	12.7	9	1.2

Economic analysis

Table 4 tells the economic analysis both hot air heater with the heat exchanger and without heat exchanger. According Table 4, annual fixed cost increases to about 200,000won by purchase of the heat exchanger, but annual operating cost is reduced by about 10%.

Table 4. Economic analysis and comparison between the hot air heater with heat exchanger and without heat exchanger

Items		Light oil air heater	Light oil air heater with heat exchanger
Purchase price(won)		4,000,000	4,850,000
Durable year(yr)		6	6
Total use(hr/yr)		659	659
Annual fixed cost(won/yr)	Depreciation	666,667	808,333
	Repair cost	200,000	242,500
	Interest	80,000	97,000
	Sum	946,667	1,147,833
Fixed cost(won/hr)		1,437	1,742
Operating cost(won/hr)	Fuel	**5,761(100)**	**5,185(90)**
	Electricity	117	133
	Sum	5,878	5,318
Total cost(won/hr)		7,315	7,060
Annual operating cost(won/yr)		**3,873,602(100)**	**3,504,562(90.5)**
Annual cost(won/yr)		**4,820,585(100)**	**4,652,540(96.5)**

*1. Disposal rate: 0% 2. Annual repair rate: 5%
3. Annual interest: 4% 4. Fuel cost: 378won/liter(light oil, tax free for boiler)
5. Farm electricity cost: 36.7won/kWh
6. Air heater capacity: 585,200kJ/hr
7. Rate of fuel consumption: 15.24liter/hr
8. Purchase price of heat exchanger: 850,000won
9. Purchase price of air heater: 4,000,000won

CONCLUSIONS

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

1. A heat recovery system to recycle exhaust gas heat from hot air heater for greenhouse heating was built and tested. The system is composed of hot air heater, heat exchanger of the heat pipe type and air suction fan.
2. Dimension of the heat exchanger is 600 × 550 × 330mm of a rectangular column. Heat transferring is accomplished by the phase changing heat transferring medium, acetone, placed in inside of the fin-tube type heat pipes.
3. The lower inlet air temperature the greater heat recovery rate, in which the greatest, 74,613kJ/hr, occurred in the air temperature of −10℃ at airflow rate of 1,100m^3/hr.
4. The heat recovery system recovered 61.3~85% of total gas heat but thermal efficiency

could vary by other parameters, e.g., air heater capacity and thermal efficiency of heater.

5. The recovered heat amount by airflow rate indicates bigger airflow rate bigger heat recovered. The largest heat gain, 91,931kJ/hr, happened when airflow rate was 1,920m^3/hr.
6. No combustion load and backfire were observed.
7. The heat pipe type exhaust heat recovery system can reduce fuel cost by 10% annually according to the economic analysis.

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