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Factors Affecting Performance of a Proto type Windheat Generation System

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Abstract: A wind-heat generation system was developed and the system consisted of an electric motor, a heat generation drum, a heat exchanger, two circulation pumps and a water storage tank. The heat generation drum is an essential element determining performance of the system. Frictional heat was generated by rotation of a rotor in the drum filled with a working fluid, and the heat stored in the fluid was used to increase water temperature through the heat exchanger. Effects of some factors such as rotor shape, kind and amount of working fluid, rotor rpm and water flow rate in the heat exchanger, affecting the system performance were investigated. Amounts of heat generated were varied, ranging from 126,000 to 32,760 kJ/hr, depending on combination of the factors. Statistical analysis using GLM procedure revealed that the most influential factor to decide the system performance was amount of the fluid in the drum. Experiments showed that the faster the speed of the rotor, the greater heat was obtained. The greatest efficiency of the heat generation system, electric power consumption rate vs gained heat amount of water, was about 70%. Though the heat amount was not enough for plant bed heating of a 0.1-ha greenhouse, the system would be promising if some supplementary heat source such as air- water heat pump is added.

Keywords: Wind Energy, Fluid Frictional Energy, Heat Generation Drum, Greenhouse Heating

Introduction

As area of greenhouse is rapidly expanding as well as that of heating greenhouse, fuel consumption for greenhouse heating is increasing during the cold season of Korea. Consequently, the situation requires development of appropriate alternative energy sources substituting for fossil fuel for greenhouse heating. Presently, the solar heating system, the only available alternative energy system, provides hot water for heating greenhouse plant bed or animal-caring purposes. However, system efficiency of solar water heating is relatively low considering the initial investment. On the contrary, the use of wind power for this purpose seems very promising according to many scientific data. Wind power is not only available for 24 hours but also does not cause any air pollutions. Transformation of wind power into heat can be achieved either by a hydraulic circuit in which wind energy is used as a power source pressuring fluid or by a heat generation drum where frictional fluid is used to generate heat. In this aspect, utilization efficiency of wind power is superior to that of solar or any other alternative energy. At this time, wind speed of 3 m/sec or above can rotate a wind turbine for generating 10 kW of heat energy, but with less wind speed 10 kW heat generation can be easily achieved in the area of direct transformation of wind energy to heat. According to Mohri et al. (1982) the wind power system consisted of hydraulic circuit and vertical axis wind turbine could produce accumulative energy of 24.19 MJ/year at average daily wind speed of 8.1 m/sec and 3.59 MJ/year at 4.3 m/sec, at which the energy transformation efficiency was 68%, exceeding the theoretical maximum efficiency, called Betz limit, of 59%, for horizontal axis wind turbine. The study conducted by Matzen (1978) reported that the wind power with a water brake could produce 67℃ -130 ℓ of hot water for a long term outputting 25,000 kW in a year, and he developed experimental equations employing relationships between rpms and diameters of water brakes and powers. On the other hand, small scale wind power system in the less wind favorable regions supplementing power such as heat pump, diesel and solar cell is required in functioning wind power devices (Kim et al. 2001)

Overall objective of this study was to develop a wind power based hot water supply system incorporating heat pump for farm sites. Specific objectives of this study were to develop a wind power- heat generation drum and to investigate factors affecting the heat generation performance of the drum.

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Materials and Methods

1. Experimental Set-up for Windpower- Heat Converting

Figure 1 shows the wind power - heat converting system consisted of a heat generation drum, a heat exchanger, a motor and an inverter, circulation pumps and a water storage tank. Specifications of each component are listed in Table 1.

Principle of heat generation is that rotor rotating by the motor makes friction with the working fluid contained in the drum. Kim et al. (2001) conducted an experiment on the effect of rotor rpm, friction fluid and fluid amount on the heat generation amount. They developed a theoretical equation to estimate heat generation amount in which they assumed the rotational fluid movement inside the drum for Couette flow.

The heat generated by the frictional movement between rotor and working fluid circulates to the heat exchanger, where the heat is transferred to the incoming water that increases water temperature, and which will be stored in the water storage tank for later uses. But, in this test, the warm water was discharged to outside all the time.

2. Experimental Design

Independent variables were kind of working fluid, filling amount of working fluid, shape of rotor and interval between rotor and stator. And, dependent variable was heat transferred amount through the heat exchanger. Table 2 shows the independent variables and their levels tested in this experiment.

Heat transferred amount was calculated by the water

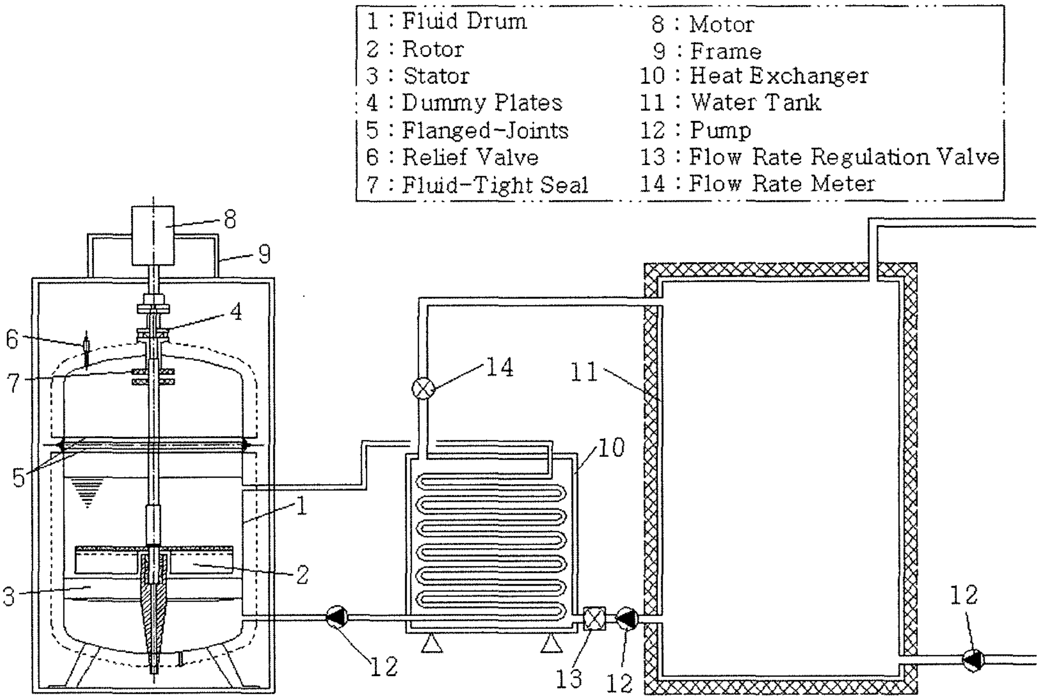

Fig. 1 Heat generation and exchange system used in this study.

Table 1 Specifications of the heat generating system

Component		Dimension (mm)	Remarks
heating part	axle	Φ35～40	revolving power → friction energy
	heat generator	Φ480×L665	
	rotor	350 × 6	
	stator	360 × 8	
driving part	motor	18.5 kW	variable
	inverter	0～1000 Hz	
heat exchange part	flat plate type heat exchanger	20,000 kcal/hr	water and viscous fluid

Table 2 Factors studied in the experiment affecting the amount of heat generation

Factor	Level	Remarks
Kind of working fluid	2	A oil: 136.8cSt@40℃ (1.368 × 108 m^2/s) B oil: 1000cSt@40℃ (1.0 × 109 m^2/s)
Amount of working fluid	3	70, 90, 110ℓ (0.07, 0.09, 0.11 m^3)
Shape of rotor	3	impeller design (R1, R2, R3)
Interval between rotor and stator	3	5, 15, 25 mm

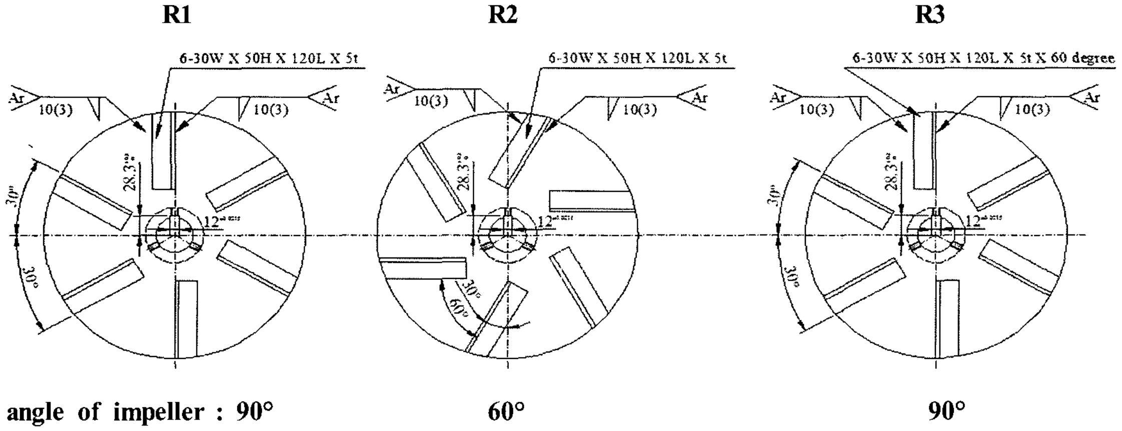

Fig. 2 Three types of impeller tested in this study.

temperature rise times the water flow rate outing from the heat exchanger. Water temperatures were measured by T type thermocouples and recorded at interval of 10 seconds on a hybrid recorder. Motor speed was regulated by an inverter and checked by a laser tachometer. Power consumption was monitored by three phase electricity analyzer. Fluid circulation rates were adjusted by flow rate regulation valves and monitored by an ultrasonic flow rate meter. Three different rotor shapes are shown in Figure 2.

Results and Discussion

1. Heat Transfer Amounts by the Different Variables Combinations

Figure 3 and 4 show some results of the heat transferred amounts by the different treatments combinations.

Motor speeds and circulation flow rates were determined based on the previous research results conducted by Kim et al. (2001). Since B oil was ultra high viscosity, it was very hard to fill the fluid drum. So, no data were obtained for B oil. From the figures, it showed that the most significant factor on the heat transferred amount was filling amount of the working fluid in the drum. The greatest heat transfer amount occurred by the variables combination of R^2 rotor, filling amount of 110ℓ, interval between rotor and stator of 15 mm and A oil, that could generate 32,760 kJ/h when motor speed was 600 rpm and water circulation rate was 500ℓ/h (Figure 4). With this combination, the system efficiency represented by the heat transfer amount versus power consumption rate was 68%. 110ℓ was the maximum capacity the drum can hold. Reasonable explanation of this tendency is that more friction could occur with larger filling amount, which was observed during the experiment. When there was empty space in the drum, the working fluid moved upward in the drum by the centrifugal force formed by rotor's rotational movement that resulted in less frictional heat generation. This implied that drum height is more critical than drum diameter in heat generation drum design. This tendency was confirmed by the following statistical analysis.

2. Statistical Analysis for the Treatment Effects on the Heat Generation Amounts

The statistical model for the treatment effects on the heat generation amounts is stated in the following equation.

$(\text{heat generation amount})_{ijk} = (\text{effect of filling amount})_{i} + (\text{effect of rotor type})_{j} + (\text{effect of interval between rotor and stator})_{k} + (\text{error})_{ijk}$

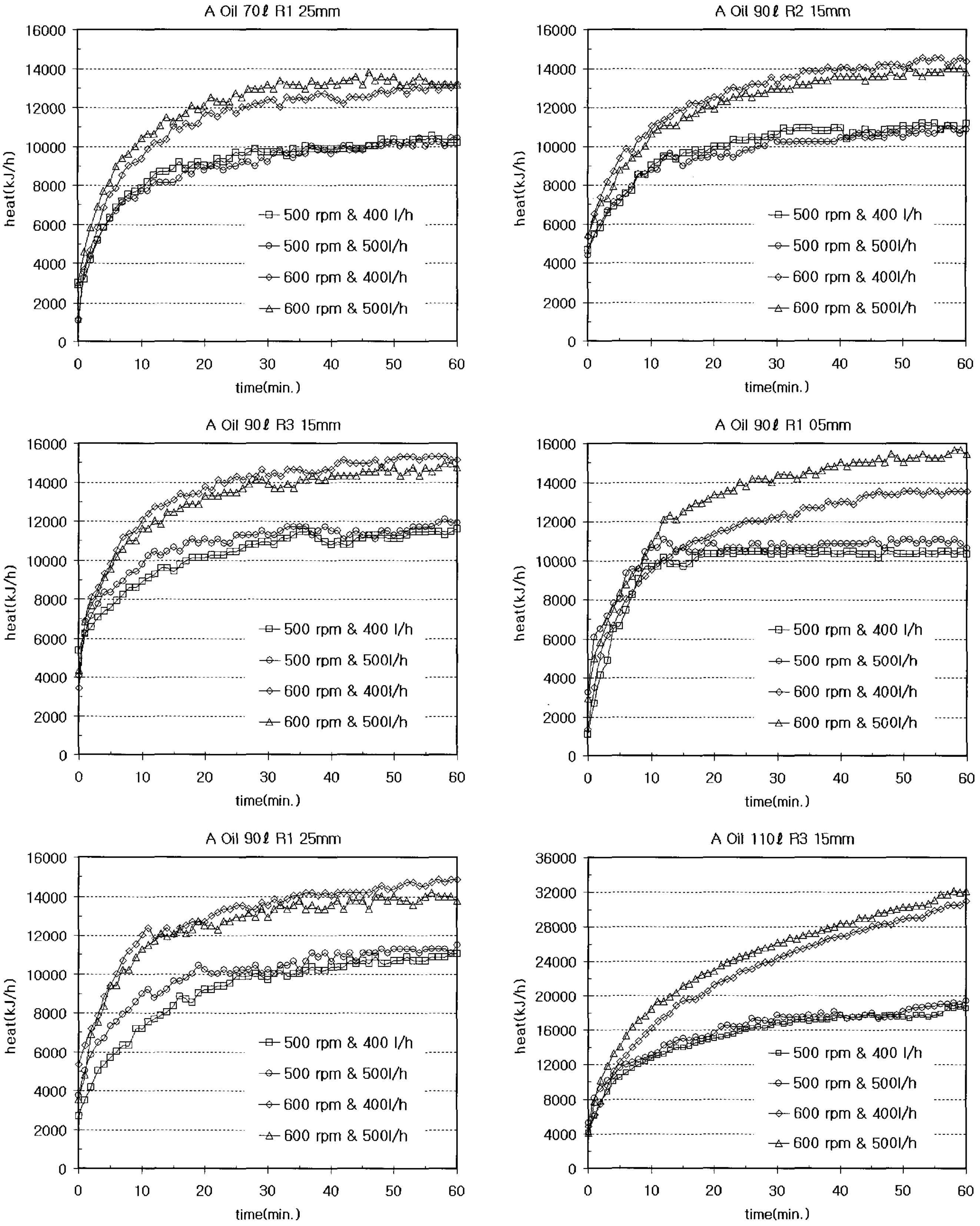

Fig. 3 Heat exchange rate at the different treatment combination.

Table 3 Statistical analysis of the variables affecting the heat generation amounts

Variable	df	SS	MS	F value	Pr > F
Filling amount	2	15801071	7900535	26.12	0.13
Rotor type	2	42500	21250	0.07	0.93
Interval	1	62500	62500	0.21	0.72

* Model : Pr > F = 0.23, R^2 = 0.98

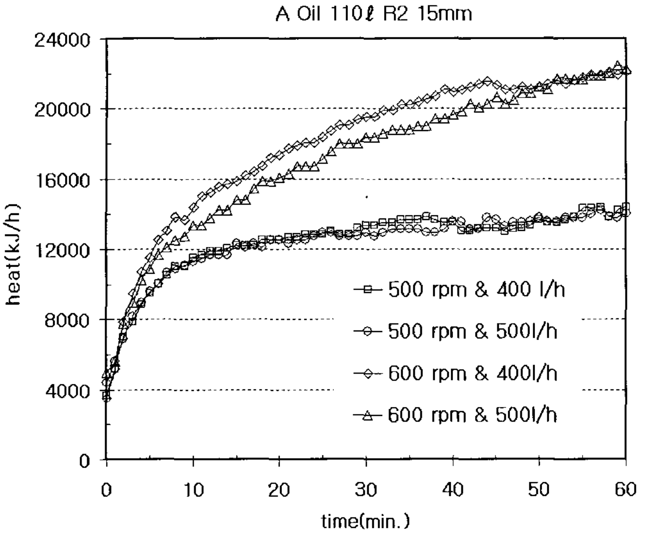

Fig. 4 The best heat exchange rate of the different treatment combinations.

Statistical analysis technique used for this equation was SAS GLM (Generalized Linear Model). ANOVA table by processing PROC GLM is shown in Table 3.

Accuracy level of the statistical model by PROC GLM was F = 0.23 with R^2 = 0.98. It showed that the most important variable affecting heat generation amounts was filling amount whose significant level was 13%, however, rotor shape and interval did not contribute as much as that of filling amount in the heat generation amounts. These trends can be observed in Figure 3 as well.

Conclusions

In this study, a heat generation system consisted of a heat generation drum, a motor, a rotor and stator, two circulation pumps and a heat exchanger was built and tested for its heat generation performance. Several factors affecting the heat generation capacity of the system were investigated. Factors and their levels selected were filling amount of working fluid by three levels, kind of working fluid by two levels, type of rotor by three different shapes and interval between rotor and stator by three levels. The greatest heat generation capacity was found 32,760 kJ/hr with the treatment combination of R^2 rotor, filling amount of 110 ℓ, interval between rotor and stator of 15 mm with A. According to SAS GLM procedure on the data where dependent variable was heat generation capacity, filling amount was the most significant variable showing confidence level of 13%. However, rotor type and interval did not contribute in heat generation capacity as much as we have anticipated. This study results can be applied to designing this type of fluid heat generation drum.

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