A Study on a High-Temperature/High-Pressure Washing System in which High-Temperature Water is Generated in a Low-Pressure Boiler and High-Pressure Water is Generated Thereafter in a Compressor

Dong-Hyun Cho[*,#]
[*]DAEJIN University

저압보일러에서 고온의 온수 생성 후 압축기에서 고압수를 생성하는 고온·고압 세척시스템에 관한 연구

조동현[*,#]
[*]대진대학교 컴퓨터응용기계공학과

ABSTRACT

This study was conducted on a high-temperature/high-pressure washer in which low-pressure cold water in a boiler is heated to a temperature range of 70~80°C by supplying diesel combustion heat. The high-temperature water is sent to a compressor to increase its pressure to 200 bar, thereby making high-temperature/high-pressure water, which is sprayed through a spray nozzle. In the results of this study, the spray temperature of the high-pressure washing was shown to be the highest when the ratio between the actual amount of combustible air and the theoretical amount of air was 1:1 and the energy consumption rate of the low-pressure boiler type high-pressure washer was shown to be much lower than that of the high-pressure boiler type high-pressure washer.

Key Words : Washing System(세척시스템), Low Pressure Boiler(저압보일러), Compressor(압축기), High Temperature/High Pressure Spray Water(고온고압세척세척수), Fuel Consumption Rate(연료소비율), Hot Water Spray Rate(온수분사율)

1. Introduction

The high temperature/high pressure washer sprays hot water at rates of at least 10L/min and washes various contaminated devices by spraying hot water at high temperatures of about 60~80°C. To operate a washer with a capacity as such, high temperature·high pressure hot water should be supplied through the washing gun. In the case of past leading high temperature/high pressure washers, whereas high pressure was secured through a high pressure pump,

Corresponding Author : chodh@daejin.ac.kr
  Tel: +82-31-539-1973, Fax: +82-31-539-1970

==

diesel oil was combusted at a boiler to obtain high temperature hot water used for washing by raising the temperature of the hot water to 60~80℃ using the combustion heat[1,2]. However, since lamp oil, which is a fossil fuel, was supplied as a fuel, many studies on the improvement of the performance of high pressure washers made using the existing system have been reported due to the excessive economic burden of excessively high fuel prices[3]. Due to the use of the fossil fuel as such, not only the energy costs and high pressure washer prices are high but also the high pressure washers become a factor that hinders the low carbon green growth by emitting massive carbon dioxide[4]. In addition, many of studies on high pressure washers in and out of the country currently reported are regarding electric instantaneous heater based high pressure washing. Since the capacities of the electric heaters are 26~39KW, relatively excessive electric charges should be paid. Therefore, although the new high pressure washers are more environment friendly compared to the existing burner systems using diesel oil, they do not epochally reduce energy consumption[5,6]. On reviewing related studies in foreign countries, Lavor (kerosene high temperature high pressure washer) in Italy, Tecno,mec (kerosene high pressure washer) in Italy , Comet (kerosene high temperature/high pressure washer) in Italy, Kranzel and Alto in Germany can be found but studies on ground-breaking high temperature/high pressure washers are insufficient[7]. In addition, studies have been conducted on high temperature/high pressure washers in which the pressure of cold water is increased to 200 bar in a compressor to make high pressure hot water, which is then supplied to a boiler, where it is heated to a temperature range of 70~80 ℃ by supplying diesel combustion heat to make high temperature/high pressure water, which is sprayed through a spray nozzle[8]. Since water is compressed by the compressor to have high pressure and used

to produce high temperature/high pressure water at a boiler, compressor prices are increasing drastically because compressor efficiency is low and high pressure boilers that can stand high pressure are required. In addition, epoch-making studies of high temperature/high pressure washers that will use electricity while enabling energy saving are acutely required. Therefore, this study was conducted on a high temperature/high pressure washer in which low pressure cold water in a boiler is heated to a temperature range of 70~80 ℃ by supplying diesel combustion heat to make high temperature water, which is sent to a compressor to increase its pressure to 200 bar thereby making high temperature/high pressure water, which is sprayed through a spray nozzle. Thanks to the results of this study as such, the thermal efficiency of the boiler will increase, the boiler manufacturing cost will decrease drastically, and the performance of the compressor will improve substantially because hot water will be produced in low pressure boilers.

2. Experimental equipment and method

Fig. 1 shows the high temperature/high pressure washer. As shown in the figure, the experimental equipment was configured with a low pressure boiler, a driving motor, a high pressure pump, a spray nozzle, and a hot water pressure, temperature, and flow rae control system. The boiler was configured so that cold water at room temperature can be heated to 100 ℃ using diesel combustion heat. In addition, Pt 100Ω temperature sensors were installed at the inlet and outlet of the boiler to measure the temperatures of the cold water at the inlet and the hot water at the outlet and a hot water flowmeter was installed at the inlet of the boiler to measure water flow rates. Furthermore, a temperature controller that can control water temperatures was installed to control the water

A Study on a High Temperature/High Pressure Washing System in Which High Temperature Hot Water Is Generated in A
Low Pressure Boiler and High Pressure Water Is Generated Thereafter in A Compressor
: 한국기계가공학회지, 제18권, 제1호
===

temperature at the boiler outlet. The experimental equipment was configured so that the hot water after the temperature increase in the low pressure boiler is supplied to the water compressor to increase the pressure of the water to make the water into high temperature/high pressure water when it comes out from the compressor outlet so that it can be sprayed through the spray nozzle for washing. The high pressure compressor was installed with a pressure controller so that the water spray pressure can be adjusted in a range of 1~300 bar. As such, the high temperature/high pressure water washer was configured so that low pressure cold water is heated to a temperature range of 70~80 °C in the boiler by supplying diesel combustion heat to make high temperature water, which is sent to the compressor to increase the pressure to 200 bar to make high temperature/high pressure water, which is then sprayed through the spray nozzle. Thereafter, the performance of the high temperature/high pressure washer was experimented with changes in the water temperature and with changes in the compressor pressure.

Fig. 1 High temperature/high pressure washer in which the low pressure boiler supplies hot water

Fig. 2 shows a high temperature high pressure washer in which a high pressure pump makes high pressure cold water and supplies it to a high pressure boiler so that the high pressure boiler can supply hot water for washing. As shown in Fig. 3, in this high temperature/high pressure washer, the pressure of cold water is increased by the compressor to 200 bar to make high pressure cold water, which is supplied to the high pressure boiler, where diesel combustion heat is supplied so that the water is heated to a temperature range of 70~80 °C to make high temperature/high pressure hot water, which is sprayed through the spray nozzle. Since water is compressed by the compressor to have high pressure as such and used to produce high temperature/high pressure water at a high pressure boiler, compressor prices are increasing drastically because compressor efficiency is low and high pressure boilers that can stand high pressure are required. Fig. 3 shows the washing system designed in this study, in which a low pressure boiler produces hot water, which is compressed by a high pressure compressor to produce high temperature/high pressure hot water, and the high temperature/high pressure water is sprayed through the spray nozzle. As shown in Fig. 3, an experimental study was conducted with the high temperature/high pressure washer, in which low pressure cold water in a low pressure boiler is heated to a temperature range of 70~80 °C by supplying diesel combustion heat to make high temperature water, which is sent to a compressor to increase its pressure to 200 bar thereby making high temperature/high pressure water, which is sprayed through a spray nozzle. Thanks to the results of this study as such, the thermal efficiency of the boiler will increase, the boiler manufacturing cost will decrease drastically, and the performance of the compressor will improve substantially because hot water will be produced in low pressure boilers.
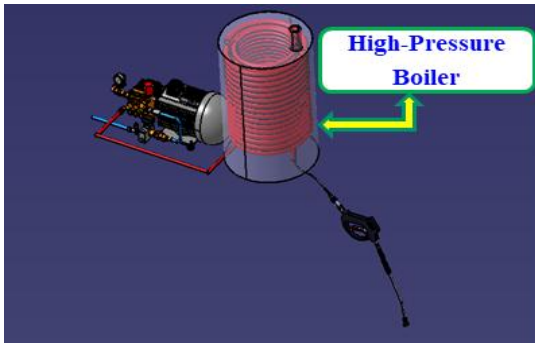
Fig. 2 Three-dimensional design diagram of the high temperature/high pressure washer in which a high pressure pump supplies high pressure cold water to a high pressure boiler, which supplies hot water
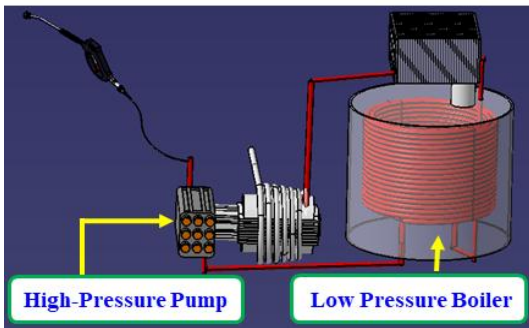

Fig. 3 Three-dimensional design diagram of the high temperature/high pressure washer in which a low pressure boiler supplies hot water

3. Results and Discussion

Fig. 4 shows the thermal equilibrium between the electric power energy supplied by the electric heater to the hot water in the low pressure hot water boiler and the thermal energy absorbed by the hot water in the low pressure hot water boiler. The electric energy was transformed into thermal energy by the electric heater and the thermal energy was supplied to the hot water boiler. The electric power energy supplied by the electric heater to the hot water in the low pressure hot water boiler was

obtained using equation (1).

$$\dot{Q}_{heater} = VI \tag{1}$$

where, V represents voltage and I represents current. The calorie obtained by the hot water in the low pressure boiler was obtained using equation(2).

$$Q_w = m_w Cp_w (T_2 - T_1) \tag{2}$$

where, Q_w represents the calorie(J) obtained by the hot water in the low pressure boiler. m_w represents the mass flow rate (kg/s) of the hot water, T_1 represents the initial temperature(K) of the water, and T_2 represents the final temperature of the water. As shown in Fig. 4, the thermal equilibrium between the electric power energy supplied by the electric heater to the hot water in the low pressure hot water boiler and the thermal energy absorbed by the hot water in the low pressure hot water boiler was well achieved at $\pm 5\%$. Therefore, the experimental results in this study are considered to have secured reliability.

Fig. 5 shows the values of rises of the temperature of the hot water sprayed through the spray nozzle according to changes in the initial operating time of the high temperature·high pressure washer. The experiment was conducted under three high pressure pump spray pressure conditions of 100bar, 150bar, and 200bar. The quantity of the fuel supplied for boiler combustion was 0.052kg/min for all the three conditions. As the high pressure pump spray pressure increased, the quantity of hot water sprayed increased. Since the quantity of water sprayed increased as the spray pressure increased while the quantity of the fuel supplied to the boiler was identical under the three conditions, the spray temperature dropped as the spray pressure increased.
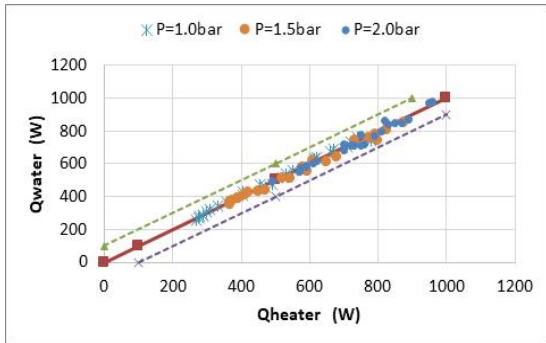
A Study on a High Temperature/High Pressure Washing System in Which High Temperature Hot Water Is Generated in A
Low Pressure Boiler and High Pressure Water Is Generated Thereafter in A Compressor
: 한국기계가공학회지, 제18권, 제1호

Fig. 4 Equilibrium between the electric power energy and the thermal energy supplied to the hot water in the washer

Fig. 5 High pressure washer discharge temperatures according to hot water heating time

In cases where the boiler is initially operated, as shown in Fig. 5, when the pressure of the high pressure pump was 100bar, the temperature of the hot water rapidly increased to 65°C. About 90 sec. was taken for the temperature to rapidly increase to 65°C. After the rapid increase to 65°C, the hot water temperature was maintained constantly. When the pressure of the high pressure pump was 150bar, the temperature of the hot water rapidly increased to 68°C. About 105 sec. was taken for the temperature to rapidly increase to 68°C. After the rapid increase to 68°C, the hot water temperature was maintained constantly. When the pressure of the high pressure pump was 200bar, the temperature of the hot water rapidly increased to 73°C and was maintained constantly thereafter. About 120 sec. was taken for the temperature to rapidly increase to 73°C. As the high pressure pump pressure increased, the hot water spray rate increased. The time taken to reach the steady state after increases in the spray rate and the temperature increased as the high pressure pump pressure increased. In addition, the high temperature·high pressure washer was operated in a non-steady state in the early stage of operation.

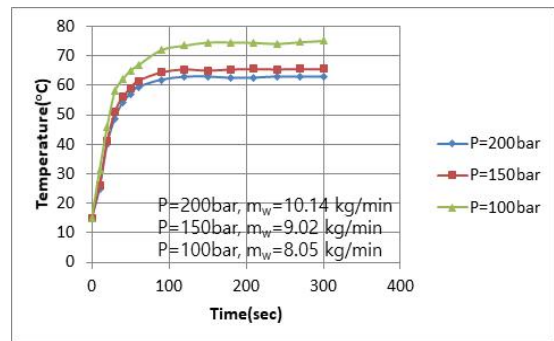The water temperature rapidly increased when diesel combustion heat was supplied to the water flowing inside the boiler coil and was stabilized to a constant temperature thereafter when a certain time had passed.

Fig. 6 shows the values of rises of the temperature of the hot water sprayed through the spray nozzle according to changes in the air-fuel ratio. The experiment was conducted at a high pressure pump spray pressure of 100bar, a water spray rate of 8.05kg/min, and a fuel consumption rate of 0.05kg/min. Three ratios between the actual amount of combustible air and the theoretical amount of air of 1.0, 1.1, and 1.2 were used in the experiment. The air-fuel ratio in this experiment was calculated using equation (1).

$$\alpha = \frac{m_{air}}{m_{feul}} \tag{3}$$

where, α represents the air-fuel ratio, m_{air} represents the mass of the air supplied for the combustion of the diesel supplied to the boiler, and m_{feul} represents the mass of the diesel supplied to the boiler.

In Fig. 6, A_{th} represents the theoretical amount of air and A_{re} represents the actual amount of air supplied for the combustion. A_{re}/A_{th} represents the
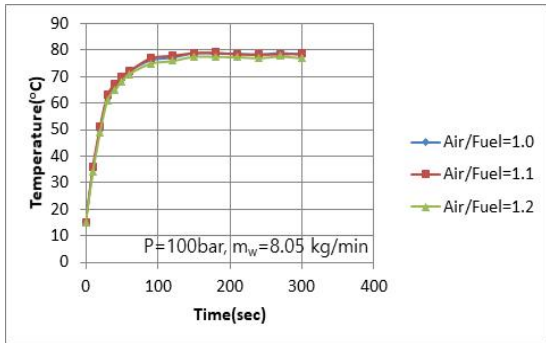
Fig. 6 High pressure washer discharge temperatures according to changes in the amount of combustible air

ratio between the actual amount of combustible air and the theoretical amount of air. As shown in Fig. 6, the spray temperature was shown to be higher when the ratio between the actual amount of combustible air and the theoretical amount of air was 1.1 than when the foregoing ratio was 1.0. When the combustion experiment was conducted after increasing the ratio between the actual amount of combustible air and the theoretical amount of air from 1.1 to 1.2, the spray temperature decreased. As such, the spray temperature for high pressure washing was shown to be the highest when the ratio between the actual amount of combustible air and the theoretical amount of air was 1.1. Given the results as such, when the ratio between the actual amount of combustible air and the theoretical amount of air is higher than 1.1, the amount of excessive air not involved in combustion is too large and the excessive air absorbs the heat for temperature increases and is discharged as the exhaust gas leading to reductions in the thermal efficiency. The reductions in thermal efficiency as such are considered attributable to the decrease in the high pressure washer spray temperature.

Fig. 7 shows the energy consumption rates of a high pressure washer in which a low pressure boiler
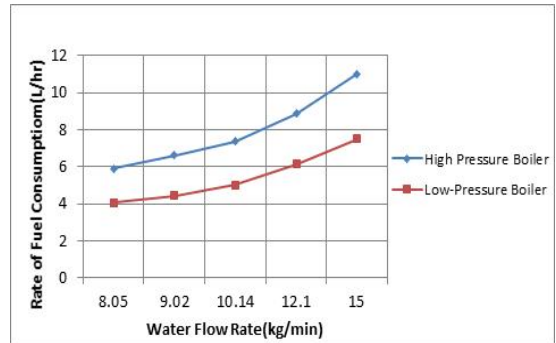

Fig. 7 The fuel consumption rates of the high temperature-high pressure high pressure washing system according to the water spray rates

supplies hot water and a high pressure boiler type washer in which the water temperatures is increased by a high pressure boiler before the water is sprayed. The energy consumption rates were measured at five different water spray rates, which are 8.05, 9.02, 10.14, 12.1, and 15.0kg/min. As shown in Fig. 7, as the hot water spray rate increased, the energy consumption rate increased. When the water spray rates were in a range of 8.05~15.0kg/min, the energy consumption rates of the high pressure boiler type high pressure washer were in a range of 5.9~11.1 L/hr. The water spray rates of the low pressure boiler type high pressure washer were shown to be in a range of 5.9~11.1 kg/min and the energy consumption rates were shown to be in a range of 4.07~7.48L/hr. The reason why the energy consumption rates of the low pressure boiler type high pressure washer were shown to be much lower than those of the high pressure boiler type high pressure washer as shown in Fig. 7 is considered to be the fact that the boiler coil shape of the low pressure boiler type high pressure washer was made into a U shape to for two pass flows and turbulent flows of the combustible air to greatly improve the thermal

===

efficiency.

4. Conclusion

This study examined a high temperature/high pressure washer in which low pressure cold water in a low pressure boiler is made into high temperature hot water by supplying diesel combustion heat, the hot water is sent to a compressor to compress the hot water to make high temperature/high pressure washing water, and the water is sprayed through a spray nozzle to derive the following results.

1. The thermal equilibrium between the electric power energy supplied by the electric heater to the hot water in the low pressure hot water boiler and the thermal energy absorbed by the hot water in the low pressure hot water boiler was well achieved at $\pm 5\%$.

2. Hot water spray rates increased as the high pressure pump pressure increased and the time taken to reach the steady state after increases in the spray rate and the temperature increased as the high pressure pump pressure increased.

3. The spray temperature for high pressure washing was shown to be the highest when the ratio between the actual amount of combustible air and the theoretical amount of air was 1.1.

4. The energy consumption rates of the low pressure boiler type high pressure washer were shown to be much lower than those of the high pressure boiler type high pressure washer.

References

1. Kim, S. I., Park, S. H., Park, G. I., "A Study on the Flow Characteristic around Automobile Engine Cylinder Head," Proceedings of the KSMPE Autumn Conference 2017, pp.188~189, 2017.

2. Lee, D. Y., "Plastic Processing," Moon Un Dang Pub, pp. 74-76, 2004.

3. Tehrani, M. S., and Hartley, P. and Naeini, H. M. and Khademizadeh, H., "Localised Edge Buckling in cold Roll-Forming of Symmetric Channel Section," Thin-Walled Structures, Vol. 44, No. 2, 2006.

4. Lee, S. Y., "Analysis of Roll Forming Process for Pipe using Rigid-Plastic Finite element method," Thesis of Degree of M.Sc. Sogang Univ., pp.50-61 , 2001.

5. Choi, G. G., "A Study about Analysis of Roll Forming Process using Rigid-Plastic Finite Element Method and Forming Limit in Sheet Metal Forming," Thesis of Degree of M.Sc. Sogang Univ, pp 42-44, 2001

6. Yang, D. H., Park, H. K., "Numerical Analyses of Fuel Sprays in a Constant Volume Chamber," KSME, pp. 975-977, 2003.

7. Kuk, Y. H., Choi, H. J., "Analysis of Fluid-Structure Interaction of Cleaning System of Micro Drill Bits," Journal of the Korean Society of Manufacturing Process Engineers, Vol. 15, No.1, pp.8~13, 2016.

8. Choi, H.-J., S, Y.-B., Park, C.-W., Lee, S.-Y, Choi, S.-D., "Study of Turbine Module Design for Die Casting Mold Release Injection Robot System," Journal of the Korean Society of Manufacturing Process Engineers, Vol.14 No.5, pp. 1~7, 2015.