TEST Engineering & Management

November-December 2019
ISSN: 0193-4120 Page No. 1671 – 1676

A Study on the Improvement of the Spraying Performance of a Washing System That Sprays High Temperature and High-Pressure Hot Water

Dong-Hyun Cho
The University of Daejin, 1007, Hogukro, Pocheonsi, Gyeinggodo, 11159,South Korea, chodh@daejin.ac.kr

Article Info
Volume 81
Page Number: 1671 – 1676
Publication Issue:
November-December 2019

Article History
Article Received: *5 March 2019*
Revised: *18 May 2019*
Accepted: *24 September 2019*
Publication: *09 December 2019*

Abstract

In this study, a high temperature high pressure washing system for energy saving in which the exhaust gas at 543 K that escapes from the furnace after heating cold water introduced into the boiler is recovered through a heat exchanger to dramatically reduce the exhaust gas temperature was developed. In addition, an experimental system 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 rate control system. In addition, an experimental system for the performance of a washing system that sprays high temperature and high-pressure hot water was configured to produce performance experiment results. In addition, in this study, the results of development of a low temperature boiler system and a high temperature high pressure pump that can be used at high temperatures were applied to derive study findings that can reduce the load of the boiler per se required in existing systems due to the durability required to high pressure boilers. Since the washing system developed in this study is based on energy recovery, the study findings can maximize efficiency more than existing technologies thereby greatly contributing to energy saving. The thermal efficiency of the high pressure washing system was enhanced by installing an exhaust gas waste heat recovery system at the exit of the exhaust gas of the system to recover the waste heat of the exhaust gas and using the waste heat to pre-heat the combustion air before being supplied. Consequently, the amount of lamp oil used by the high-pressure washing system was reduced so that energy saving was implemented.

Keywords: *Washing System, Hot Water, Spraying Performance, High Temperature, High-Pressure.*

I. INTRODUCTION

A high temperature high pressure washing system that sprays high temperature and high pressure hot water at temperatures of 333-353 K sprays hot water at flow rates of at least 10L/min to wash diverse contaminated machines. In order to operate a washing system of such a capacity, high temperature and high-pressure hot water should be supplied through a washing gun. In the case of existing prominent high temperature high pressure washing systems, which have been widely studied and reported, high pressure is secured through a high pressure pump, but in order to obtain high temperature hot water, it is necessary to burn diesel in a boiler to raise the temperature of hot water to 333-353 K[1~3]. Since lamp oil, which is a fossil fuel, is supplied as the fuel, the necessity to improve the existing high-pressure washing systems is coming to the fore because of the heavy economic burden due to excessive fuel prices[4,5]. Not only the energy costs are high due to the use of fossil fuel as such and the high-pressure washing system per se is expensive but also such high-pressure washing systems are becoming an obstructing factor to low carbon dioxide emissions and green growth by discharging large amounts of carbon dioxide[6~9]. Therefore, since temperature of the exhaust gas discharged from the boiler is 543 K, if the waste heat is collected and contributes to hot water supply, at least 30% of the energy consumed by the boiler is expected to be saved. Furthermore, the foregoing is judged to considerably contribute to the reduction of nitrogen oxide and greenhouse gas, which is problematic due to recent in global warming because it will reduce the temperature of the exhaust gas by 353 K ~ 373 K. On reviewing study reports at home and abroad, it can be seen that many studies in the field of electric instantaneous heater type high pressure washing systems have been reported. According to study reports in this field, the heater capacities are in a range of 26 ~ 39KW with relatively excessive electric charges indicating that energy is not drastically saved although such washing systems are eco-friendly compared to the existing burner systems using diesel oil[10,11]. Therefore, in this study, a high temperature high pressure washing system for energy saving in which the exhaust gas at 543 K C that escapes from the furnace after heating cold water introduced into the boiler is recovered through a heat exchanger to dramatically reduce the exhaust gas temperature was developed. In addition, a high temperature and high pressure pump that can be used for boiler systems and at high temperatures was developed and applied to the developed washing system so that the load of the boiler per se required in existing systems due to the durability required to pressure-resistant boilers can be reduced. Since it is based on energy recovery, it has contributed significantly to energy savings as a study result that maximizes efficiency over existing technologies.

II. EXPERIMENTAL APPARATUS AND METHOD

2.1 Experimental Apparatus

Figure 1 shows a schematic diagram of the washing system that sprays hot water at high temperature and high pressure and Figure 2 shows the washing system that sprays hot water at high temperature and high pressure. As shown in Figure 1 and Figure 2, an experimental system 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 rate control system. The boiler is configured to raise the temperature of cold water from room temperature to 373 K using the combustion heat from the boiler. The cold-water temperature at the inlet and the hot water temperature at the outlet of the boiler were measured by installing Pt 100Ω temperature sensors. In addition, a hot water flow rate meter was installed at the boiler inlet to measure the water flow rate. A temperature controller which can control the temperature of water was installed to control the water temperature at the outlet of the boiler. The experimental system was configured so that the low pressure boiler supplies heated water to the water compressor to raise the pressure of the hot water so that high temperature high pressure water is discharged through the outlet of the compressor and sprayed through the spray nozzle to wash machines. In addition, the washing system for spraying hot water at high temperature and high pressure developed in this study relates to a high temperature / high pressure washing system equipped with an exhaust gas waste heat recovery system. This washing system was configured excluding the cold-water storage unit for storing cold water and placing a high pressure pump at the rear end of the hot water boiler so that the tube for heat exchange at the hot water boiler can be configured with low pressure tubes. Therefore, not only the material cost for manufacturing of the washing system can be reduced and the wait of the washing system can be reduced but also the heat of the exhaust gas being discharged can be used to heat the air and supply the heated air to the supply fan of the fuel combustion unit so that fuel consumption can be reduced. An experimental study was conducted with the high temperature/high pressure washing system configured as such.

November-December 2019
ISSN: 0193-4120 Page No. 1671 – 1676

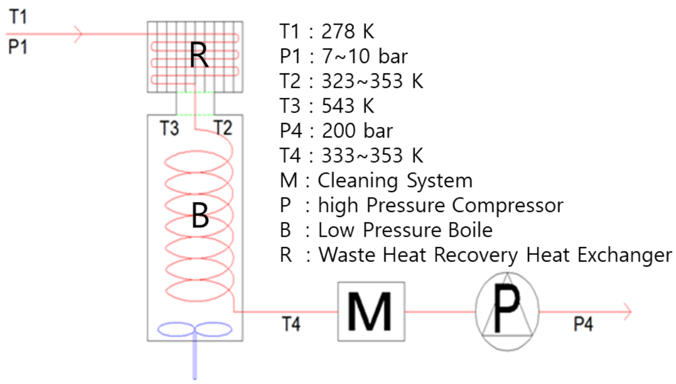


Figure 1. Schematic Diagram of the Washing system that Sprays High Temperature High Pressure Hot Water

Figure 2. The Washing System that Sprays High Temperature High Pressure Hot Water

2.2. Experimental Method

Figure 3 shows a performance experimental system for the washing system that sprays high temperature high pressure hot water. As shown in Figure 3, experiments were conducted under three high pressure pump spray pressure conditions of 100 bar, 150 bar, and 200 bar. A pressure controller was installed on the high-pressure compressor and configured to control the water injection pressure from 1 to 300 bar. As such, the high temperature high pressure water washing system was configured so that low pressure cold water in the boiler is heated to a temperature range of 333 ~ 353 K by supplying diesel combustion heat, the hot water is sent to the compressor where the pressure of the water is raised to 300 bar to make high temperature high pressure water, and the water is sprayed through the spray nozzle. Thereafter, the performance of the high temperature high pressure washing system according to changes in water temperature and changes in the pressure of the compressor was experimented. When the diesel combustion heat is supplied to the water flowing inside the boiler coil, the water temperature rises, and after a certain time, the temperature is stabilized at a constant temperature. As described above, the performance test of the washing system spraying high temperature high pressure hot water was conducted under all conditions in normal states.

Figure 3. Performance Experimental System for the Washing System that Sprays High Temperature High PressureHhot Water

III. Experiment and Result

Fig. 4 shows the thermal equilibrium between the electric power energy supplied to the hot water in the hot water boiler and the thermal energy absorbed by the hot water in the low-pressure hot water boiler. The electric energy from the electric heater was transformed into thermal energy and supplied to a hot water boiler. The electric power energy generated by the electric heater was obtained by equation (1).

$$Qh = V \quad I \tag{1}$$

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).

$$Qw = mCp(T2 - T1)$$
(2)

Where, Qw represents the calorie (J) obtained by the hot water in the low-pressure boiler. m represernts the mass flow rate(kg/s) of the hot water, T1 represents the initial temperature(K) of the water, and T2 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 achieved well at 5%. Therefore, the experimental results in this study are considered to have secured reliability.

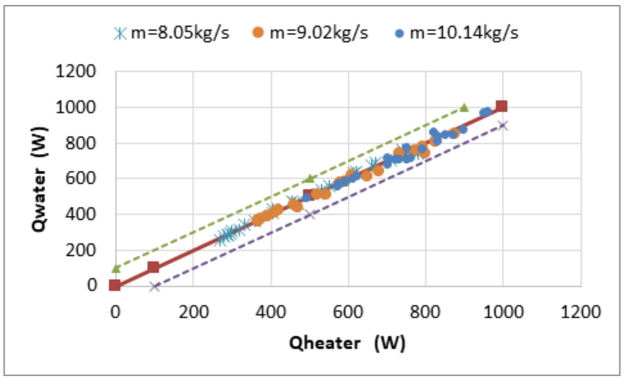
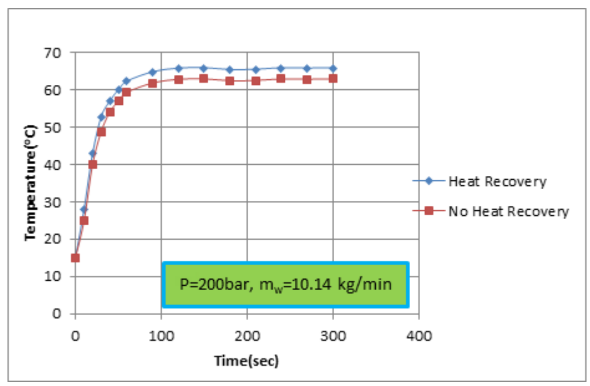
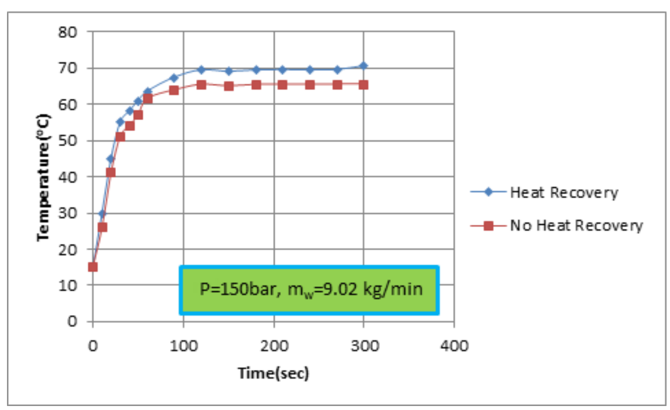


Fig. 4 Equilibrium between the Electric Power Energy Generated by the Electric Heater and the Thermal Energy supplied to the Hot Water in the Low Pressure Boiler

Figure 5 shows the discharge temperature of the washing system for zero hot water heating time. As shown in Figure 5, when the boiler was initially operated, the temperature of the hot water soared to 342 K when the pressure of the high-pressure pump was 100 bar. It took about 353 K seconds to soar to 342 K. After soaring to 342 K, the temperature of the hot water remained constant. When the pressure of the high-pressure pump was 150bar, the temperature of hot water soared to 344 K. It took about 95 seconds to soar to 244 K. After soaring to 344 K, the temperature of the hot water remained constant. When the pressure of the high-pressure pump was 200bar, the temperature of the hot water soared to 352 K and remained constant thereafter. It took about 110 seconds to soar to to 352 K. As the pressure of the high-pressure pump increased, the amount of water sprayed increased, and the time taken to reach the steady state increased as the pressure of the high-pressure pump increased. As such, the spray temperature of the high-pressure washing system installed with the waste heat recovery system increased by 276 ~ 278 K more than the spray temperature of the high temperature and high-pressure washing system without the waste heat recovery system. The time to reach the steady state was also reduced by more than 10 seconds. Therefore, by installing the exhaust gas waste heat recovery system at the exhaust gas outlet of the high-pressure washing system, the thermal efficiency of the high-pressure washing system was enhanced because the waste heat recovered from the exhaust gas was used to preheat the combustion air. As a result, the amount of lamp oil used by the high-pressure washing system was reduced so that energy saving was realized.

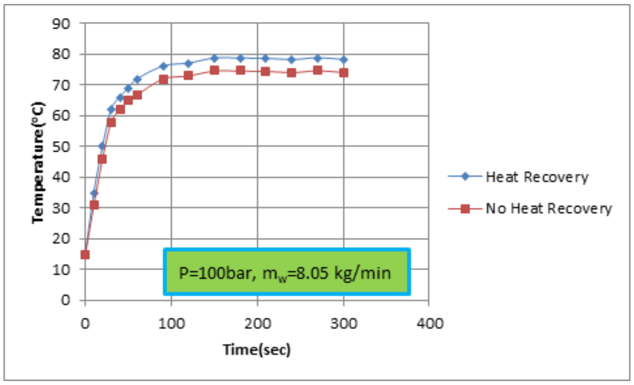


(a) P = 200 bar



(b) P = 150 bar

November-December 2019
ISSN: 0193-4120 Page No. 1671 – 1676



(c) P = 100 bar

Figure. 5 Discharge Temperature of Washing System for Hot Water Heating Time

Figure 6 shows changes in the discharge temperature of the washing system with respect to the water spray rate. The experiment was performed under three water spray rate conditions of the high-pressure pump at 8.05, 9.02, and 10.14 kg / min. As shown in Figure 6, as the pressure and water spray rate of the high-pressure washing system increased, the discharge temperature of the high-pressure washing system decreased. The hot water discharge temperature was measured to be in the range of 338 ~ 351 K in all three experimental ranges of three pressures and three water spray rates of the high-pressure pump. Based on the experimental results, the washing system developed in this study was operated in normal states. Its total volume was smaller by 23% compared with the existing washing systems, and the coil thermal resistance was smaller by 4.8 times.

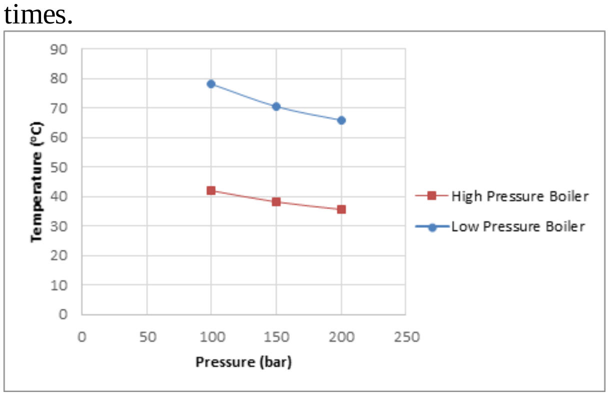


Figure. 6 Changes in the Discharge Temperature of the Washing System According to the Change in the Water Spray

IV. CONCLUSION

In this study, a high temperature high pressure washing system for energy saving in which the exhaust gas at 543 K that escapes from the furnace after heating cold water introduced into the boiler is recovered through a heat exchanger to dramatically reduce the exhaust gas temperature was examined and the following results were derived.

As the pressure of the high-pressure pump increased, the water spray rate increased, and the time taken to reach the steady state increased as the pressure of the high-pressure pump increased. As such, the spray temperature of the high-pressure washing system installed with the waste heat recovery system increased by 276 ~ 278 K more than the spray temperature of the high temperature and high-pressure washing system without the waste heat recovery system. The time to reach the steady state was also reduced by more than 10 seconds. Therefore, by installing the exhaust gas waste heat recovery system at the exhaust gas outlet of the high-pressure washing system, the thermal efficiency of the high-pressure washing system was enhanced because the waste heat recovered from the exhaust gas was used to preheat the combustion air. As a result, the amount of lamp oil used by the high-pressure washing system was reduced so that energy saving was realized.

In addition, the total volume was reduced by 23% compared with the existing washing system, and the coil thermal resistance was reduced by 4.8 times.

REFERENCES

1. Kim, D. S., Kim, K. H., Lee, H. S. and Seo, J. H. S., "Status and Project of Carbon Nanotube Commercialization", KIC News, Vol. 10, No. 4, 2007.
2. Harris, P. J. F., "Carbon nanotube composites", International Materials Reviews, Vol. 49, No. 1, 2004.
3. Mo, C. B., Jeong Y. J., Lim, B. K. and Hong, S. H., "Fabrication Process and Mechanical/Electrical Properties of Carbon Nanotube/Metal Nanocomposites", Polymer Science and Technology, Vol. 18, No. 6, 2007.
4. Shahinpoor, M. and Kim K. J., "Ionic polymer-metal composites: I. Fundamentals", Smart Mater. Struct., 10, 819, 2001.

5. Bar-Cohen Y., Leary S., Yavrouian A., Oguro, K., Tadokoro, S., Harrison, J., Smith, J. and Su, J., "Challenges to the application of IPMC as actuators of planetary mechanisms", Proc. of SPIE, 3987, 21, 2000.
6. P. S. Huang, C. S. Chiang, C. P. Chang, and T. M. Tu, "Robust spatial watermarking technique for colour images via direct saturation adjustment," Vision, Image and Signal Processing, IEE Proceedings -, vol. 152, pp. 561-574, 2005.
7. K Kwon, H. J., Lee, H S., Lee, J. H., Jun, C. B. and Kang, J. H., "SWCNT/Nafion Composite Debelopment for Improvement of Mechanical Properies of IPMC", Jouranl of the Korean Society of Manufacturing Process Engineers, Vol. 10, No. 1, pp. 47-53, 2011.
8. K Kim, S. H., Cho, S. M., Lee, D. W., Park, Y. C. and Kang, J. H., "A study of manufacture of IPMC actuator and the high molecule finite element analysis", Jouranl of the Korean Society of Manufacturing Process Engineers, Vol. 7, No. 4, pp. 24-30, 2008.
9. Lee, H. S., Yun, C. H., Kim, H. M. and Lee, C. J., Persistence Length of Multiwalled Carbon Nanotubes with Static Bending", J. Phys. Chem. C, Vol. 111, No. 51, pp. 18882-18887, 2007.
10. 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 , pp. 1 ~ 13, 2005.
11. 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