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Influence of Superheated Steam Temperature in Steam Circulation-type Degreasing Systems on Improved Degreasing of Oily Metal Waste

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Abstract

In order to improve the purity of recycled metal, it is important to remove impurities from metal waste. In this paper, a demonstration of an oily metal waste degreasing system using superheated steam is introduced, and the process condition was examined. Here, a practical steam circulation-type degreasing system was introduced for oily metal waste recycling. Superheated steam has special characteristics, such as being an inactive gas and having a high heat capacity. An aluminum cutting chip with water-soluble cutting oil was introduced as a waste material disposed from a milling machine, or lace from metalworking factories. The degreasing system processed oily waste material continuously under the inert gas atmosphere. The target of the adhesion rate of oil on waste metal was less than 1 %. The degreasing rate depends on the process temperature, and the experiments were conducted under the several process temperatures. The system performance was evaluated in terms of the system's electric consumption, adhesion rates and condition of degreased metal. As a result, the adhesion rate improved by increasing the process temperature, and it reached less than 1 %. However, a part of the metal was melted at higher process temperatures. Therefore, it is important to set up an optimum operation temperature suitable for the material.

Keywords: Superheated steam, Temperature dependence, Degreasing, Material recycling

1. Introduction

Recycling for materials such as waste metal has become a serious issue for the sustainable development of industry and human activity. Oily metal waste disposed of from metalworking factories is usually melted directly by an electric steelmaking furnace or a blast furnace. However, this method leads to low quality metal overall, because an ingredient included in the oil acts as an impurities. Therefore, it is important to remove oil from the metal waste. There are some possible methods of removing oil from oily metal waste, such as centrifugal separation, or chemical dissolution. A centrifugal separation method cannot remove oil well enough from metal because cutting chips have a complex shape. On the other hand, if oil is removed with chemicals, the oil is dissolved into a chemical substance and it is then difficult to separate oil from the chemical agent. In addition, it is also difficult to dispose of liquid waste that includes a chemical substance from an environmentally-conscious standpoint. Accordingly, the systems using superheated steam have been very useful in waste processing. Superheated steam is introduced to improve the quality of metal waste disposed of by metalworking factories as recycling material[1-5]. The steam evaporates waste oil from oily cutting chips and removes it from the metal.

Superheated steam is a very popular heat source for industrial and municipal applications such as air conditioning and boilers. It is an inactive gas, and this kind of steam creates several advantages for material processing systems. Superheated steam is generated by heating saturated steam until it reaches 100 ºC or higher[6,7]. Generally, superheated steam shifts to a higher efficiency at around 170 ºC, and is better fit for industrial application compared to the efficiency of hot air at the same temperature[8,9]. The performance and thermal efficiency of superheated steam, such as drying a moisture material or heating a material, improves as the steam temperature increases. However, as a matter of course, the energy consumption for the process also increases.

In this paper, influence of superheated steam temperature in steam circulation-type degreasing systems on the degreasing of oily metal waste is examined. The process temperature is set around 400, 450 and 500 ºC in these experiments. The system's energy consumption, adhesion rates and condition of degreased metal are experimentally evaluated and compared for each process temperature.

2. System Configuration and Experimental Apparatus

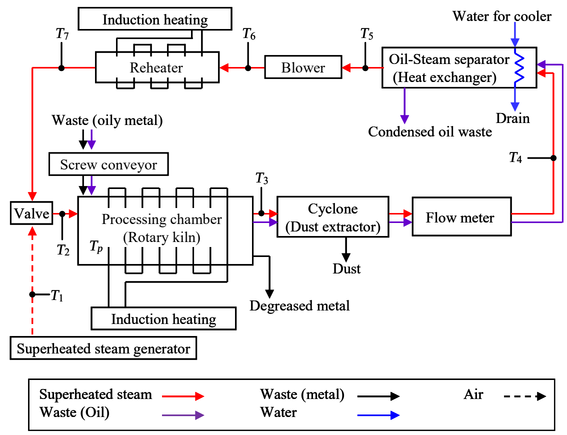
The superheated steam degreasing demonstration system employed in this experiment is shown in Fig. 1. The system configuration designed for the degreasing system using superheated steam is shown in Fig. 1(a). The system consists of a superheated steam generator (Fuji Electric; IHSS-05), a screw conveyor, a processing chamber with IH (Fuji Electric; HFR200C7K-2), a cyclone, a steam flow meter (Oval; VXR1050-N41S-1016C), an oil-steam separator, a high pressure blower (Showa Denki; KSB-H07BGHT), a reheater with IH (Fuji Electric; HFR5.0C11K-2) and valves. These equipments were connected with piping. Here, induction heating was applied to heat the superheated steam and waste materials.

While the superheated steam passes through the processing chamber, oily waste metal is heated more than the evaporation temperature of cutting oil, while the oil is evaporated under the inactive gas field. Then the mixed gas flows out from the chamber and passes through a cyclone for dust extraction. In the steam circulation-type system, only the evaporated oil is condensed in the oil-steam separator, and steam passes through the separator in a superheated state. The steam is pressurized using a high pressure blower and heated again by the reheater. After that, the heated steam flows into the processing chamber when the system is operated in a steady state condition, while the steam that comes from the generator is closed off. In this case, latent heat of water to generate steam is not consumed. Finally, the superheated steam can be repeatedly circulated in the degreasing system.

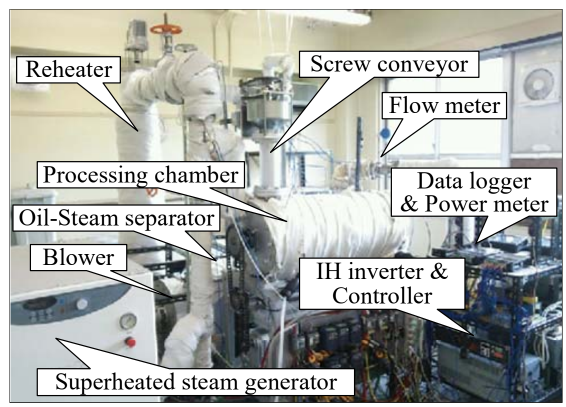
Typical local temperatures, shown by T_i (i; 1-7) in the system, are measured by K-type sheath thermocouples and recorded by a multi-channel data logger (HIOKI; 8422-50). Five local steam temperatures are measured inside the processing chamber. T_P is an averaged temperature of superheated steam in the chamber. Electric consumption of each equipment is measured by clamp-type power meter (HIOKI; 3169-01).

Before introducing steam to the degreasing system, the steam passage is heated by hot gas more than 100 ºC in order to prevent the condensation of steam in the equipment and ducts. Hot gas is generated by induction heating installed in the processing chamber and reheater, and the gas is circulated by a blower. Then, the processing chamber and steam passage are displaced by superheated steam, which comes from the superheated steam generator. After that, the superheated steam that comes from the generator is closed off, and steam circulates inside the system. Then, the oily waste material flows into a processing chamber. Degreased metal is discharged from the processing chamber and exhaust gas, containing the evaporated oil from waste, passes through a cyclone and flows into an oil-steam separator. Here, only the evaporated oil is condensed and collected in liquid state.

Figure 1(b) shows a demonstration of the superheated steam degreasing system. The size of the processing chamber is 300A (12B) in diameter, 1,000 mm length, and made of SUS430. The oil-steam separator consists of a condenser to cool steam and two laminated metal screens to trap oil mist. There are steam agitators inside a reheater. The ducts and equipment are covered with a thick layer of heat-insulation material. Waste material was aluminum cutting chips (A7075) which were discharged from a milling machine, as shown in Fig. 1(c). Water-soluble cutting oil adheres to the cutting chips.



(a) System configuration of degreasing systems using superheated steam, and the position of typical local temperatures



(b) Photo of demonstration system

(c) Example of oily metal waste

Figure 1. Superheated steam degreasing demonstration system

3. Experimental Results and Discussion

3.1 Experimental Procedure and Typical Examples of Experimental Results

Typical examples of progressions of local temperatures in each position of the degreasing system are shown in Fig. 2. Experimental conditions are decided based on the preliminary experiment as shown in Table 1.

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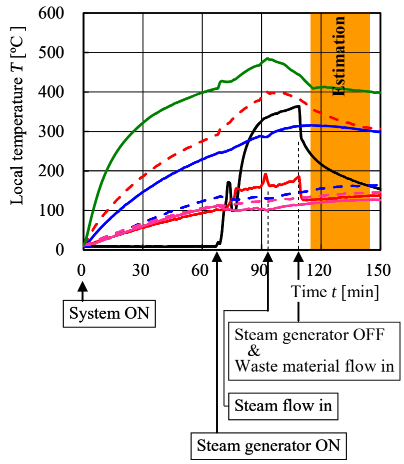
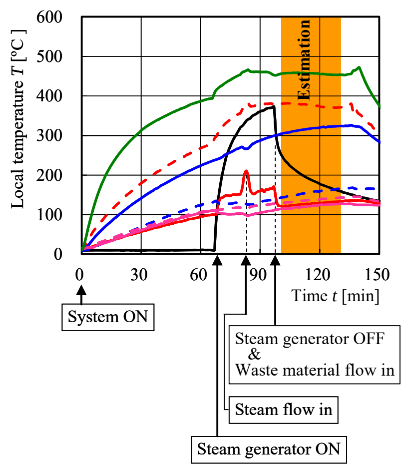
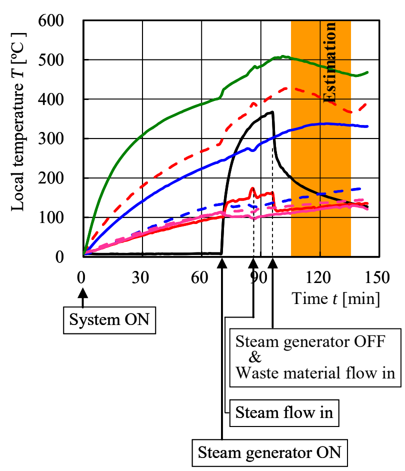


(a) 400 ºC



(b) 450 ºC



(c) 500 ºC

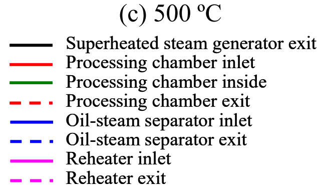


Figure 2. Progressions of local temperature in each position

Table 1. Experimental condition

	Process temperature (ºC)		
	400	450	500
Mass flow rate of metal (x10^{-3} kg/s)	5.79	5.75	5.93
Mass flow rate of oil (x10^{-3} kg/s)	0.72	0.73	0.67
Processing time of oily metal in the chamber (min)	6.0		

At the beginning of the experiment, each piece of equipment and the ducts were heated by hot air in order to prevent condensation of the superheated steam inside the system. Electric consumption of each piece of equipment was set the same, except for the induction heating of the processing chamber. Air temperature in the system increased gradually. It took about 70 minutes to heat the system over 100 ºC. Then, the superheated steam generator was started and steam was introduced into the system. Here, temperature of steam exiting the superheated steam generator was around 350 ºC. After air, which contains oxygen, was replaced from the processing chamber by superheated steam, the waste material flowed into the processing chamber, and the degreasing was started. At the same time, the superheated steam that comes from the generator is closed. In this case, superheated steam was circulated inside the system by blower.

Local temperature and electric consumption were estimated from extracted data for 30 minutes in the steady state condition, as shown in Fig. 2. Average local temperatures at the steady state condition are shown in Table 2. The pressure inside the processing chamber was almost equivalent to the ambient pressure.

Table 2. Average local temperatures at the steady state condition in each operation condition

		Process temperature (ºC)		
		400	450	500
Superheated steam generator exit (ºC)	T_1	closed		
Processing chamber inlet (ºC)	T_2	132	128	127
Processing chamber inside (ºC)	T_p	407	456	484
Processing chamber exit (ºC)	T_3	329	376	402
Oil-steam separator inlet (ºC)	T_4	310	316	333
Oil-steam separator exit (ºC)	T_5	159	155	158
Reheater inlet (ºC)	T_6	123	121	121
Reheater exit (ºC)	T_7	140	137	136

During the degreasing process, the average temperature inside the processing chamber was kept at around 400, 450 and 500 ºC. It was difficult to keep the processing temperature around 500 ºC in this system. It is considered that sensible heat to heat waste material, until operation temperature is reached, consumes induction heat to the processing chamber. The gas temperature at the oil-steam separator exit was kept around 150 ºC because the specification of evaporation temperature of the cutting oil is around

150 - 250 ºC. The lowest temperature through the system was kept above 100 ºC, which is the condensation temperature of steam.

The influence of the process temperature on system performance was evaluated in terms of its electric consumption and adhesion rate of oil.

3.2 System Performance of Degreasing Conditions

Electric consumptions estimated from each operation temperature were compared. Table 3 and Fig. 3 show the amount of electric consumption at the steady state condition in each condition. Supplement equipment refers to the screw conveyor, rotary kiln in the processing chamber, and steam agitator in the reheater. The electric consumption for the high pressure blower, micro-heater heating for the ducts, and conveyance systems were set the same in each condition. Therefore, the difference of electric consumption between these conditions are thought to have been caused by induction heating of steam and waste, because mass flow rates of waste were almost the same as shown in Table 1.

Table 3. Electric consumption in steady state condition

	Process temperature (ºC)		
	400	450	500
Induction heating for Processing chamber (kW)	8.5	10.5	11.5
Induction heating for reheater (kW)	1.6		
Blower (kW)	0.1		
Duct heaters (kW)	2.0		
Supplement equipment (kW)	0.2		
Total (kW)	12.4	14.4	15.4
Specific energy consumption (kWh/kg)	0.53	0.62	0.65

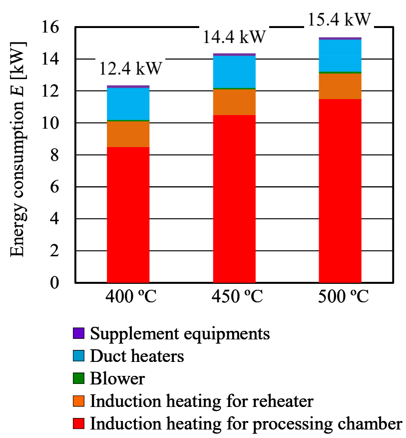


Figure 3. Electric consumption in steady state condition

Energy consumption of induction heating for the processing chamber was increased to keep the mean temperature T_p in the chamber. About 70% of total energy is consumed by induction heating installed in the processing chamber. The reheater heats the steam to keep it at a temperature higher than its condensation point. If inlet steam temperature for the processing chamber is increased by the reheater, a heating load of the processing chamber may be reduced. As a result, electric consumption is increased as the process temperature increases, because the mass flow rate of the steam in the system is almost the same. The specific energy consumption increases as the process temperature increases, too.

The degreasing performances were compared. Table 4 and Fig. 4 show the adhesion rates of oil to metal waste at each operation temperature. The rates, ζ_{before} and ζ_{after}, were estimated for before and after processing by Eqs. (1) and (2), respectively.

$$\zeta_{before} = \frac{\rho_{oil} - \rho}{\rho} \times 100 \quad (1)$$

$$\zeta_{after} = \frac{\rho_{deg} - \rho_w}{\rho_w} \times 100 \quad (2)$$

Here, ρ and ρ_w are bulk densities of the metal without oil, while ρ_{oil} and ρ_{deg} represent the bulk densities of the waste metal including oil. ρ_w was estimated by washing the waste material with water after degreasing, in order to estimate only the mass of the metal. The waste metal was slightly compressed during the processing, because the waste metal was transported by a rotary kiln. Therefore, the bulk densities of waste material after degreasing increase rather than those obtained from before processing. Therefore, the adhesion rate of the oil must be estimated singly for before and after the processing.

Initial adhesion rates were set at around 10 – 11 % in these experiments. After the degreasing, the rate decreased to 2.0 – 0.7 % in each condition. The final target of the adhesion rate of oil is set to be less than 1 %. This target is difficult to achieve by compression or centrifugal separation methods. The target is satisfied by the experimental conditions at 450 and 500 ºC. However, the process temperature is too high for the aluminum waste. A part of the aluminum waste was melted inside the processing chamber, as shown in Fig. 5. It is considered that the wall temperature of the processing chamber may exceed 500 ºC even though the steam temperature is set around 500 ºC. The superheated steam and waste material which comes into contact with the chamber wall inside the processing chamber are heated by heat transfer from the chamber wall, which is heated by the induction heating. It does not matter, for the degreasing of waste material, that the metal is melted. However, it is important to avoid clogging of metallic ingots in the rotary kiln.

As a result, the optimum operation temperature to remove cutting oil from aluminum waste is suggested to be around 450 ºC in this experiment.

Table 4. Bulk density of waste material in each condition

	Process temperature (ºC)		
	400	450	500
Metal ρ (kg/m^3)	189	188	193
Oily metal ρ_{oil} (kg/m^3)	210	209	213
Degreased metal ρ_{deg} (kg/m^3)	195	210	227
Metal (After washing) ρ_w (kg/m^3)	191	209	225

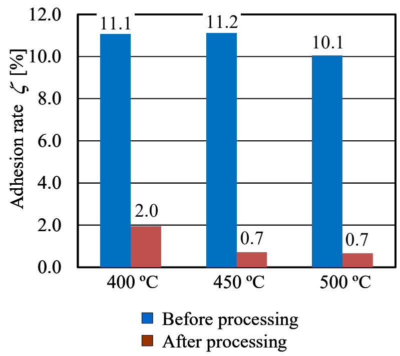


Figure 4. Adhesion rates of oil in each system

(a) 400 ºC (b) 450 ºC (c) 500 ºC

Figure 5. Degreased aluminum waste for each operation temperature

4. Conclusion

The performance of a practical steam circulation-type superheated steam degreasing system was evaluated at several process temperatures. Here, the performance was evaluated based on the specific energy consumption and adhesion rate of oil. The adhesion rate is improved by increasing the process temperature. However, a part of the metal was melted at higher temperature. It is important to set up an optimum operation temperature suitable for the material. The temperature of the superheated steam in the processing chamber is strongly influenced by energy input into the processing chamber because the reheater is only introduced to keep the steam temperature higher than its condensation point. However, the heat-resistant temperature of the processing chamber, which is made of magnetic material, is not so high. Therefore, it is important to harmonize the processing and heat-resistant temperatures of the system. Furthermore, optimum steam temperature, processing time and steam flow rate in the processing chamber may increase system performance.

5. Acknowledgements

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