CLEANING AND DE-OILING OF MACHINE PARTS WITH LOW-PRESSURE FLASHING FLOW

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ABSTRACT

The chemical agents such as Trichloroethane have been used for the de-oiling and the cleaning in production process of machine parts or the maintenance procedures such of the turbo-machinery. But the most chemical agents have a possibility to destroy the ozone layer or promote the greenhouse effect, and some are harmful. Generally for biological and environmental safety, the de-oiling should be done with the physical method instead of the chemical method such as using Trichloroethane. As one of the physical method, the low-pressure flashing flow was applied to the packed bed of oily machine parts. The saturated steam increases as the pressure decreases in the flashing flow through the bed. The temperature and pressure of the flashing flow were less than 100°C and atmospheric pressure, respectively.

Experimental apparatus was designed and constructed to study the cleaning and de-oiling process in the packed bed of oily small rivets as machine parts. The rivets were packed in the flashing tube which is made of transparent acrylic resin for the observation. The drain tank installed below the flashing tube was maintained at the pressure less than atmospheric pressure by vacuum pump and a hot water was supplied from the nozzle above the flashing tube. The supplied hot water was depressurized and the flashing took place in nozzle and rivet bed. The temperature of supplied hot water was 40~80℃ and the outlet pressure of rivet bed was 4~50 kPa. After several minutes of flashing, the rivets were taken out from the flashing tube and the remaining oil on the rivets was measured with a precise weight scale. The oil on the rivet could be successfully removed only when the flashing took place through the rivets bed. The de-oiling and cleaning were done even in the hole of rivets. The de-oiling rate more than 90% was achieved in the steam-water flashing region. However it was difficult to remove the oil when the flashing did not take place in the rivet bed. It was considered that the boiling and high velocity two-phase flow were effective to remove the oil from the complicated surface of rivets.

NOMENCLATURE

C_f: pressure drop coefficient
D: characteristic length of rivet
G: mass velocity
dH: small height
h: enthalpy
p: pressure
u: actual velocity in bed
x: quality
α: void fraction
ρ: density

subscript
G: steam, L: liquid, m: mixture

INTRODUCTION

Usually, Trichloroethane has been used for the de-oiling and the cleaning in production process of machine parts. But the production and import of Trichloroethane have been prohibited since 1995 because of its possibility to destroy the ozone layer. This kind of cleaning for machine parts is also used in the maintenance procedures such of the turbo-machinery. To discover and point out the damaged machine parts, the cleaning before the inspection is the very important procedure. Generally for biological and environmental safety, the de-oiling should be done with the physical method instead of the chemical method such as using Trichloroethane.

As one of the physical method, a cleaning by a steam flow in a packed bed of oily machine parts was proposed in the previous experimental study [Osakabe et al., 1997]. In the experiment, the saturated or superheated steam flow of 150~270°C was used. It was confirmed that the steam flow of high pressure and temperature successfully removed oil from machine parts in a few minutes. However this method needs a large amount of heat and sturdy facilities.

For the design of steam cleaning facility, it is very important to estimate the pressure loss through the bed of non-spherical particles such as rivets. The experiments showed that the steam mass flow rate through the bed took a maximum at a certain pressure ratio of outlet to inlet. The empirical correlation to describe the relation between the mass flow rate and the pressure loss was proposed in the previous study [Osakabe et al., 1998].

In the present study, the low-pressure flashing flow was applied to the packed bed of oily machine parts. The saturated steam increases as the pressure decreases in the flashing flow through the bed. The temperature and pressure of the flashing flow were less than 100°C and atmospheric pressure, respectively. The thermal hydraulic model to describe the flashing flow in the non-spherical bed was also proposed. In the model, the pressure loss was estimated with the same method used in the previous study for the steam flow through the rivet bed. The mechanism of the cleaning was discussed comparing with the model prediction.

EXPERIMENTAL APPARATUS AND METHOD

Shown in Figs. 1 and 2 are schematics of experimental apparatus. Experimental apparatus was designed and constructed to study the cleaning and de-oiling process in the packed bed of oily small rivets as machine parts. The rivets were packed in the test section(flashing tube) which is made of transparent acrylic resin for the observation. The flashing tube was 210 mm in length and 14.4 mm in inner diameter. The drain tank installed below the flashing tube was maintained at a pressure less than atmospheric pressure by vacuum pump and hot water was supplied from the nozzle above the flashing tube. The supplied hot water was depressurized and the flashing took place in nozzle and rivet bed.

The hot water was supplied from a boiler. The temperature and the flow rate of the hot water were measured with T-type thermocouple and float type flow meter, respectively. The temperature of supplied hot water was 40~80℃ and the outlet pressure of rivet bed was 4~50 kPa. The measured flow rate of hot water was 3.3~5.7 g/s. When the flashing took place, the pressure difference between the rivet bed was measured with the manometer as shown in Fig.2.

Shown in Fig. 3 is the rivet used in this study. The rivets with a cutting oil on the surface were used for the cleaning experiment. The inner, outer diameter and length of rivet are 1.2, 2 and 6.2 mm, respectively. The 305 rivets were packed in the flashing tube and the bet height was maintained at 110mm. The rivets were hold with a nylon mesh at the bottom of flashing tube. It was considered that the pressure loss through the mesh could be neglected. The measured void fraction of rivet bed was 0.696.

After the experiment, the rivets were taken away from the flashing tube. The remaining oil on the rivets was removed with a hexane and measured with the precise weight scale. De-oiling ratio was defined as the oil weight on rivets before the cleaning to that after the cleaning.

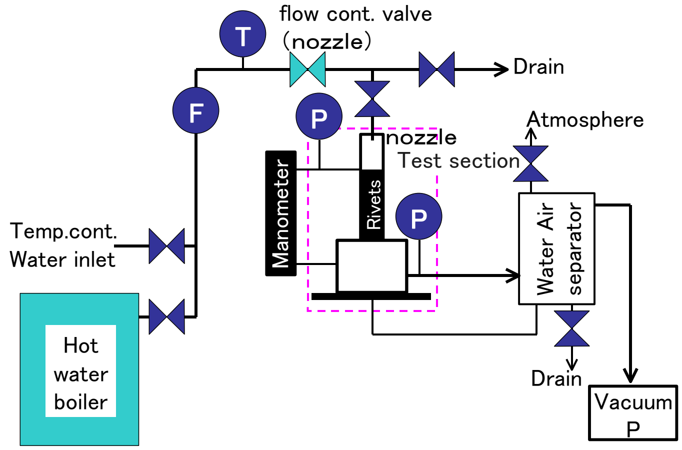

Fig.1 Schematic of experimental apparatus

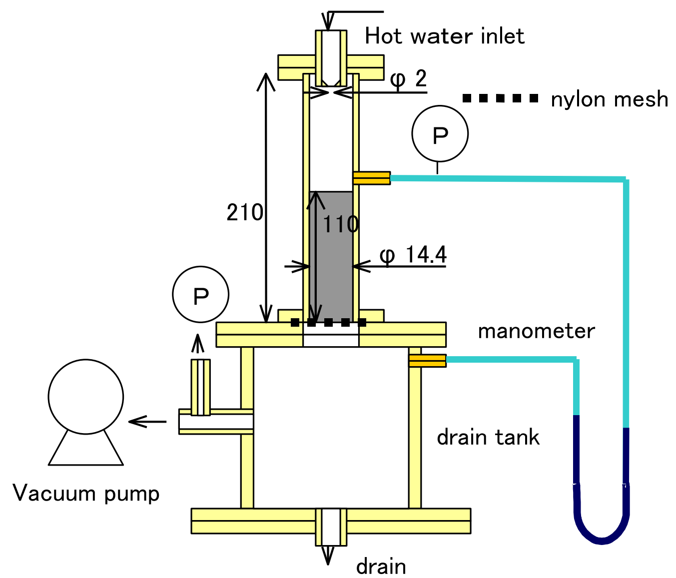

Fig.2 Schematic of test section

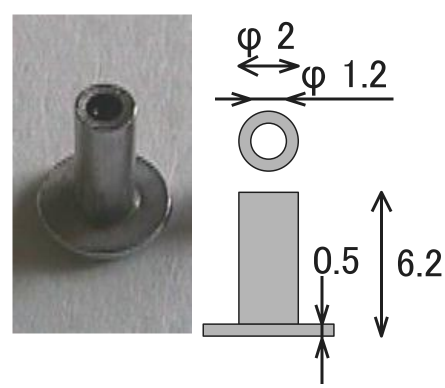

Fig.3 Rivet for present test

Four experiments were conducted to clarify the effect of flashing duration on the de-oiling ratio. The experimental conditions for inlet temperature and flow rate of hot water, and outlet pressure of bed were approximately the same. Shown in Fig. 4 is the relation of de-oiling rate and flashing duration. The better de-oiling rate was obtained at the longer duration of flashing. The de-oiling ratio increases with an increase of flashing duration and takes a nearly constant value after 60 seconds. So, in the following de-oiling experiment, the flashing duration was fixed at 60 seconds.

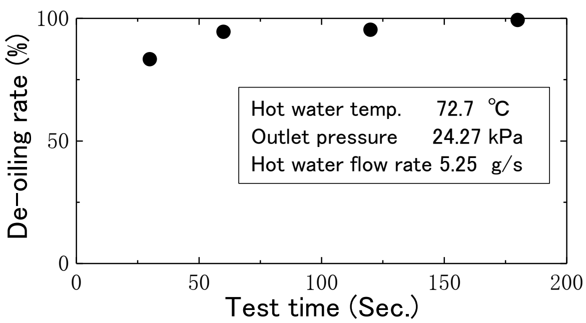

Fig.4 Relation of de-oiling rate and test time

EXPERIMENTAL RESULTS AND DISCUSSIONS

De-oiling experiment

Shown in Fig. 5 is de-oiling map of rivet in the relation between the outlet pressure of rivet bed and hot water temperature. The flashing in the rivet bed takes place at the region below the saturated liquid line. The de-oiling ratio almost exceeds 75 % at the flashing region. The generation of steam in the rived bed is very important for the de-oiling process. Sometimes the liquid can not flow through the small holes in the rivet due to the high surface tension, but the steam or small droplets accompanying with steam can penetrate through the small holes. Generally, the steam generates at the surface of rivets and it is also very effective to detach and remove the remaining oil from the surface. The higher hot water temperature results as the better de-oiling ratio. The higher temperature also reduces the viscosity of oil and helps to be removed from the surface. The symbols indicated as Test 1 and 2 are described later in detail.

Shown in Fig.6 is a de-oiling map for the rivet bed pressure difference and hot water temperature. At the same temperature of hot water, the larger pressure difference results as the higher de-oiling rate. The larger pressure difference generated at rivet bed means the higher momentum flux in the bed. One of the cleaning mechanism is considered to be due to the scrubbing with the steam/water high momentum flow.

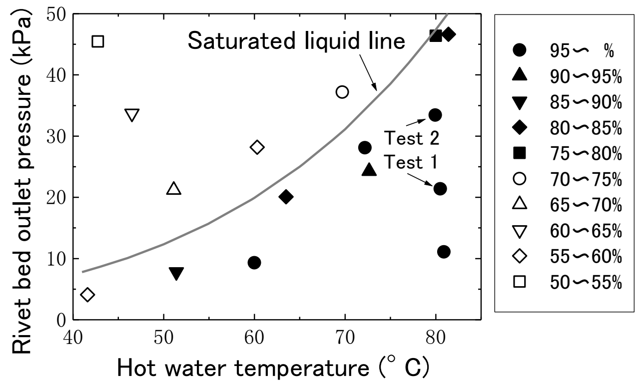

Fig.5 De-oiling map in relation between outlet pressure and hot water temperature

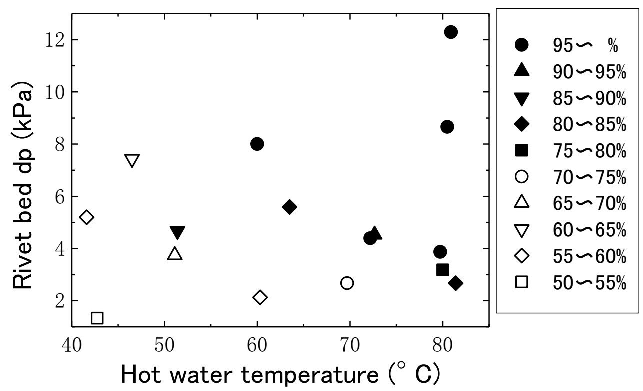

Fig.6 De-oiling map in relation between pressure difference and hot water temperature

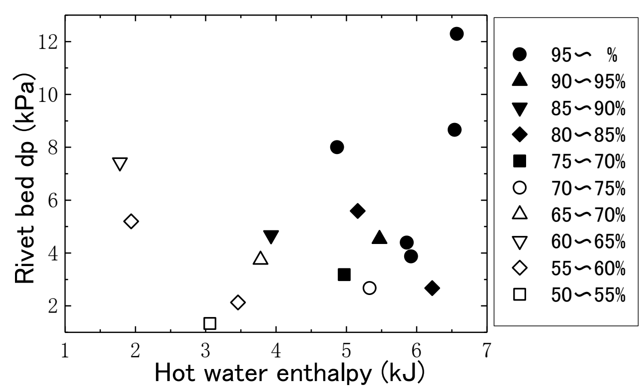

Fig.7 De-oiling map in relation between pressure difference and hot water enthalpy

Hot water flow rate was 3.3~5.7 g/s depending on the vacuum pressure. The hot water enthalpy expresses the total thermal energy brought into the rivet bed. Shown in Fig.7 is de-oiling map in the relation between the rivet bed pressure difference and hot water inlet enthalpy. The larger enthalpy and pressure difference condition results as the better de-oiling ratio.

Flashing flow characteristics

Hot water flows through rivet bed with flashing. The rivet bed was divided into 20 nodings in the flow direction and the thermal hydraulic conditions of each noding were calculated with the following four equations. As same as the previous studies for the spherical particle bed [Achenbach, 1982, Foumeny, 1993], the pressure difference at a small height of rivet bed, dH, is:

$$dp = C_f \frac{dH}{D}\frac{\rho_m u^2}{2} \tag{1}$$

where C_f is pressure drop coefficient, D is characteristic length of rivet, ρ_m is density of steam-water fluid, u is the velocity defined as,

$$u = \frac{G}{\alpha \ \rho_m} \tag{2}$$

where α is the void fraction in bed. The mass velocity G is defined at the empty pipe. The steam-water mixture flows through the rivet bed with depressurizing and flashing. The density of steam-water mixture is :

$$\frac{1}{\rho_m} = \frac{x}{\rho_G} + \frac{1-x}{\rho_L} \tag{3}$$

where x is steam quality, ρ_G and ρ_L are saturated gas and liquid density at each depressurized pressure calculated with the steam table. The steam quality can be calculated with the law of energy conservation:

$$xh_G + (1-x)h_L + \frac{u^2}{2} = h \tag{4}$$

where h is the supplied hot water enthalpy, h_G and h_L are saturated gas and liquid enthalpy at each depressurized pressure. The rivet bed was divided into the 20 nodings in flow direction as Fig.8. The thermal hydraulic conditions of each noding were calculated with above four equations.

The thermal hydraulic study was conducted with the clean rivet bed after de-oiling. The hot water temperature was 54 ~85 ℃, the rivet bed inlet pressure was 18 ~36 kPa and the hot water flow rate was 4.5 g/s. Shown in Fig.9 is the relation between the measured and predicted pressure difference. The pressure drop coefficient C_f was experimentally determined as 1.26.

Shown in Fig.10 is comparison of the predicted and the maximum pressure difference measured in de-oiling experiment. During the experiment, the pressure difference took a maximum and then tended to decrease with the de-oiling process. It is considered that the oil film on the rivet surface increases the pressure drop through the bed. The measured maximum pressure difference is slightly larger than the predicted value.

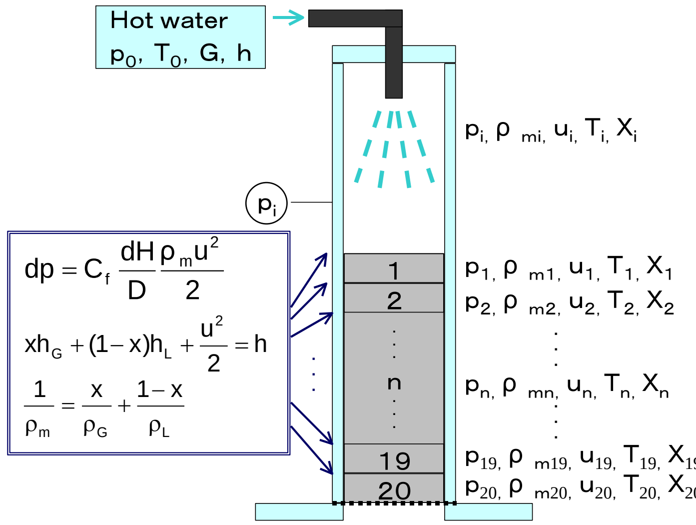

Fig.8 Calculation procedure for fluid characteristics

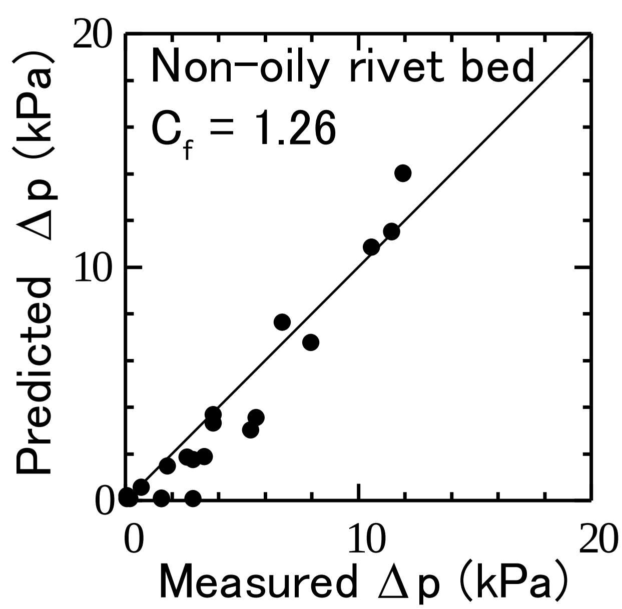

Fig.9 Determination of pressure drop coefficient C_f

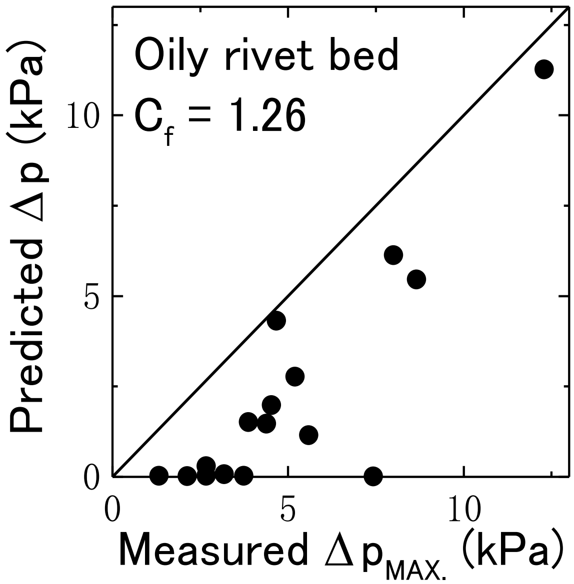

Fig.10 Relation of predicted and measured differential pressure

The typical experimental conditions for the good de-oiling result are shown in Table.1. The both experiments were conducted at approximately the same inlet temperature of hot water and the different outlet pressure of 21.4 and 33.4 kPa. The inlet temperature of hot water are 80.5 and 79.8 ℃, and the flow rate of hot water are 5.7 and 5.2 g/s, respectively. The de-oiling ratios obtained in the both experiments were 99.29 and 97.01 %, respectively.

Shown in Figs.11, 12, 13 and 14 are the thermal hydraulic conditions in the rivet bed calculated for the two tests. As the fluid flows through the rivet bed, the flashing takes place and the steam quality increases. The increase of quality increases the momentum flux of steam-water mixture. When the inlet temperature of hot water is the same, the lower outlet pressure of the bed results as the higher momentum flux and the lower temperature of the flowing steam-water mixture. As the higher de-oiling ratio was obtained in the lower outlet pressure, the larger momentum is considered to be more important than the higher temperature of the flowing mixture.

Table. 1 Typical experimental conditions for good de-oiling result

	Test 1	Test 2
Outlet pressure (kPa)	21.4	33.4
Inlet temperature (℃)	80.5	79.8
Flow rate (g/s)	5.7	5.2
De-oiling ratios (%)	99.29	97.01

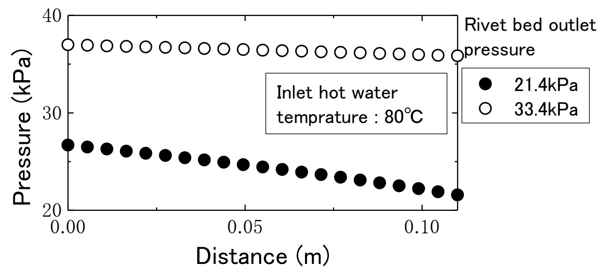

Fig.11 Comparison of pressure transitions at outlet pressure of 21.4 and 33.4 kPa

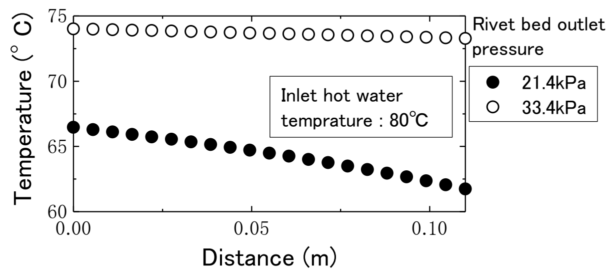

Fig.12 Comparison of temperature transitions at outlet pressure of 21.4 and 33.4 kPa

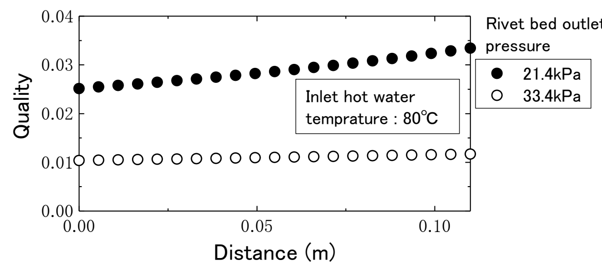

Fig.13 Comparison of quality transitions at outlet pressure of 21.4 and 33.4 kPa

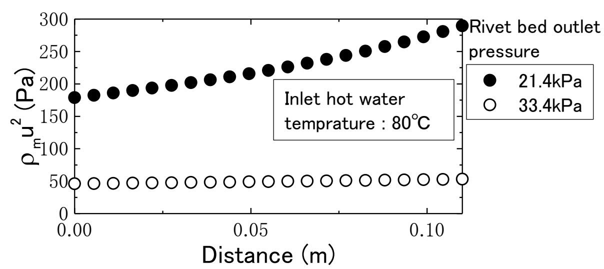

Fig.14 Comparison of momentum transitions at outlet pressure of 21.4 and 33.4 kPa

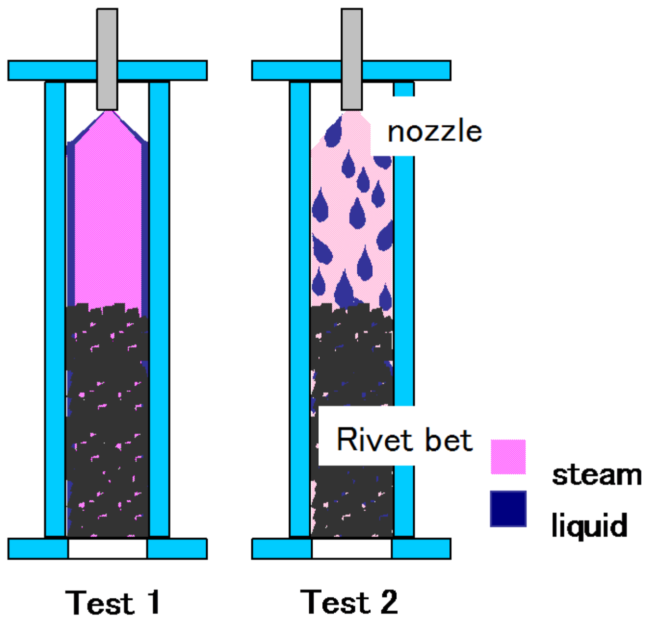

Fig.15 Schematic flow pattern at 21.4 and 33.4 kPa

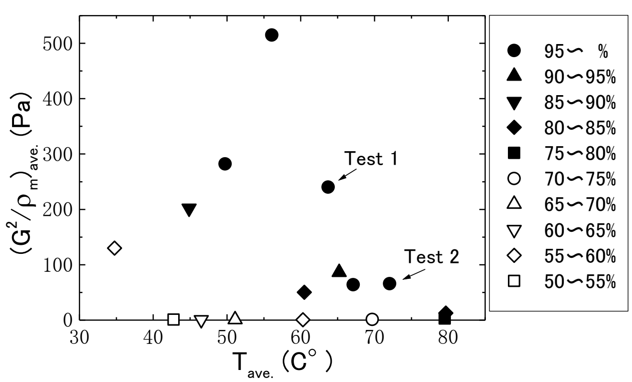

Fig.16 De-oiling map in relation of average momentum and average temperature

Shown in Fig.15 is flow patterns observed at the different outlet pressure of bed as Table 1. When the rivet bed outlet pressure was 21.4 kPa, the hot water entering into the flashing tube formed an annular flow. When the rivet bed outlet pressure was 33.4 kPa, the steam flow with droplets could be observed. The steam flow with droplets indicates the smaller quality and the lower velocity than that in the annular flow.

Previous de-oiling maps are rearranged by calculated results. Shown in Fig.16 is de-oiling map in the relation of the average momentum and the average temperature of the flashing flow in rivet bed. When the average momentum is approximately zero, the de-oiling ratio is less than 80% in the most cases. In these cases, the flashing does not take place and the steam quality and the momentum are kept at the lower values. However, it should be noted that the relatively good de-oiling ratio was obtained at the higher average temperature even when the average momentum is relatively small. Generally, the higher de-oiling ratio is obtained at the higher momentum and the higher average temperature.

CONCLUSION

1. The low-pressure flashing flow was applied to the packed bed of oily machine parts and de-oiling was successfully conducted. The de-oiling was done without the oil vaporization.
2. The generation of steam in the rived bed is very important for the de-oiling process. Sometimes the liquid can not flow through the small holes in the rivet due to the high surface tension, but the steam or small droplets accompanying with steam can penetrate through the small holes. Generally, the steam generates at the surface of rivets and it is also very effective to detach and remove the remaining oil from the surface.
3. The higher hot water temperature results as the better de-oiling ratio. It is easy to flows through the rivet bed for the high temperature fluid due to the lower surface tension and viscosity. The higher temperature also reduces the viscosity of oil and helps to be removed from the surface.
4. The analytical method was proposed to predict the low-pressure flashing flow in non-spherical particle bed. According to the analytical results, the successful de-oiling was obtained at the higher temperature and higher momentum of flashing two-phase flow.

REFERENCES

Achenbach, E., 1982,Heat transfer and pressure drop of pebble beds up to high Reynolds number, Proc. of 7th Int. Heat Transfer Conference., vol.6, 1

Foumeny, E.A. et al., 1993,Correlation of pressure drop in packed beds taking into account the effect of confining wall, Int. J. Heat Mass Transfer. 36(2), 536

Osakabe, M., Ka, K., Haze, I., Ito, T., Amano, T., 1997, Steam cleaning of small machine parts, Proceeding of Multi phase flow symposium, 203

Osakabe, M., Ka, K., Haze, I., Ito, T., 1998, Characteristics of steam flow in non-spherical particle bed, Journal of M.E.S.J., 33(4), 294