Proceedings of the
International Conference on Power Engineering-09
(ICOPE-09) November 16-20, 2009, Kobe, Japan

DE-OILING ABILITY OF LOW PRESSURE FLASHING WATER CLEANER

Masahiro OSAKABE*, Sachiyo HORIKI* and Daiki ISHIHARA*

* Tokyo Univ. of Marine Science & Technology, Fac. of Marine Engineering
Etchujima 2-1-6, Koutou-ku, Tokyo, 135-8533, Japan

ABSTRACT Usually, Trichloroethane has been used for the de-oiling and cleaning of machine parts. But its production and import have been prohibited since 1995 because of its possibility to destroy the ozone layer. Generally for biological and environmental safety, the de-oiling should be done with the physical method instead of the chemical method using detergent or solvent. As one of the physical method, a cleaning by a flashing water flow through a packed bed of machine parts has been proposed. The hot water was injected and flashed into steam and water in the packed bed kept at the low pressure less than an atmospheric pressure. In the present study, a prototype flashing water cleaner was designed and its de-oiling ability was experimentally investigated with different sizes of bolts and nuts as oily machine parts. The de-oiling ability was strongly affected with the newly-defined non-dimensional parameter consisting of the injection duration, the average kinetic pressure of flashing two-phase flow defined at vacant container flow area and viscosity of oil. The de-oiling rate more than 95 % was successfully achieved at the parameter larger than 24.

Keywords: De-oiling, Machine parts, Flashing Water flow, Physical cleaning

1. INTRODUCTION

Usually, Trichloroethane or CFC-113 has been used for the de-oiling and cleaning of machine parts. These cleaning solvents are inflammable, easy to evaporate, can percolate through complicated crevices and dissolve oily smudge. So the cleaning is not difficult technology if these solvents can be applied. But its production and import have been prohibited since 1995 because of its possibility to destroy the ozone layer. Other chemical solvents also 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 using detergent or solvent.

As one of the physical method, a de-oiling by a flashing water flow through a packed bed of machine parts has been proposed. The hot water was injected and flashed into steam and water in the packed bed kept at the low pressure less than an atmospheric pressure［1~3］. The low pressure can be easily made with condensation of steam filled in a vessel or a vacuum pump. The low temperature energy exhausted from the power plants or other equipments can be used to make hot water and steam in this de-oiling method.

In the present study, a prototype flashing water cleaner larger than the previous apparatus was designed and its de-oiling ability was experimentally investigated with the different sizes of bolts and nuts. The de-oiling ability was experimentally investigated with the newly-defined non-dimensional parameter consisting of the injection duration, the average kinetic pressure of flashing two-phase flow defined at vacant container flow area and the viscosity of oil.

2. NOMENCLATURE

A	：Flow area of container[m^2]
$d1$	：Nozzle diameter[mm]
$d2$	：Orifice hole diameter[mm]
G	：Injected water flow rate[kg/s]
h	：Enthalpy[kJ/kg]
m	：Amount of attached oil[g]
P	：Pressure[kPa]
T	：Temperature[℃]
t	：Injection duration[s]
u_m	：Velocity of homogeneous two-phase flow[m/s]
x	：Quality
η	：De-oiling efficiency[%]
μ	：Viscosity [Pas]
ρ_m	：Density of homogeneous two-phase flow[kg/m^3]

subscript

S	：Saturated steam
HW	：Hot water
ini	：Initial
L	：Saturated water
Oil	：Machine oil
res	：Residual

3. Experimental Apparatus And Method

The photograph and schematic of experimental apparatus are shown in Fig.1 and Fig.2, respectively. The apparatus consists of a container for oily machine parts to be washed, a condensing heat exchanger to keep a vacuum condition, a lower plenum to hold a condensate and auxiliary tank. The volumes of main plenum and auxiliary tank are 0.03m^3 and 0.06m^3, respectively. The hot water is injected into the plenum depressurized by using a vacuum pump from a nozzle installed at the top of apparatus. The hot water is supplied from a hot water tank where the temperature is controlled. The injected amount can be calculated with the water level in the hot water tank. The injected water washes the oily machine parts with flashing flow and is kept in the lower plenum and auxiliary tank after condensed in the lower condensing heat exchanger. The condensate is taken away after the washing process and the oil in the condensate is separated with the oil-water separator.

In the previous study, the de-oiling experiments were conducted with the continuously operating vacuum pump to keep the low pressure condition. This resulted as the degradation of pump because steam was inhaled into the pump and the sealing oil was mixed with the condensate. So in the present study, the condensing heat exchanger was installed in the low pressure vessel and the low pressure could be maintained as possible without the operation of vacuum pump. The heat exchanger consists of 26 SUS tubes of 10mm in outer diameter and 250mm in length.

The schematic of SUS container for the oily machine parts to be washed is shown in Fig.3. The bottom is mesh plate where the flashing water can go through. The distance from the injection nozzle to the machine parts bet was between 30 to 45 mm. The bolts and nuts in different size were used for the present experiment as shown in Fig.4. The number of parts stored in the container was 4000 for M4 bolts, 900 for M6 bolts, 200 for M12 bolts, 11500 for M4 nuts and 550 for M12 nuts. The machine parts before the de-oiling were dipped in the machine oil and the condition just after the machining was simulated.

The three kinds of nozzle were used in the experiments. The schematics of straight, orifice and rotational nozzles are shown in Fig.5. The nozzle diameter *d1* and orifice hole diameter *d2* are shown in Table.1.

Fig. 1 Photograph of experimental apparatus

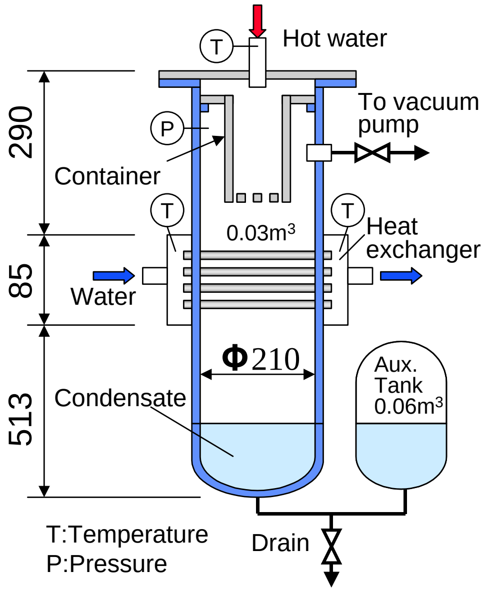

Fig. 2 Schematic of experimental apparatus

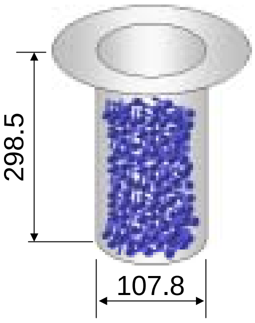

Fig.3 Schematic of container

Fig.4 Bolts and nuts of different size

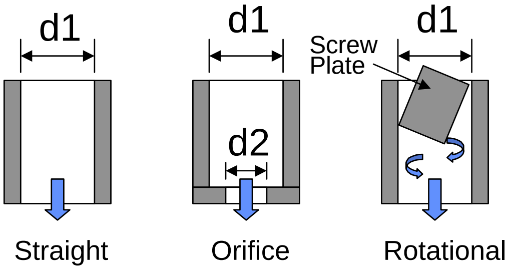

Fig.5 Schematic of nozzle confuguration

Table 1 Sizes of nozzles

	d1 (mm)	*d2* (mm)
Straight	3.0/4.5/6.0/8.0/10.0/12.0	
Orifice	8.0	3.0/4.5/6.0
Orifice	10.0	8.0
Orifice	12.0	10.0
Rotational	3.7	

The followings are the experimental procedures.

1. The machine parts to be washed were dipped in the oil and heated up to 40℃ with heater to simulate the condition just after the machining.
2. The excess oil was removed by holding the machine parts on the mesh during 10 minutes.
3. The machine parts were hold in the container. The container was set in the vacuum vessel and depressurized to approximately 5 kPa. The cooling water for the heat exchanger in the vacuum vessel was supplied continuously during the experiment.
4. The hot water was injected for a certain duration.

After the injection, the machine parts was removed from the container and the residual oil remained on the parts was measured as followings.

1. The machine parts were naturally dried in beaker.
2. The machine parts were dipped in the hexane poured into the beaker. The beaker was put in the supersonic cleaning chamber and the residual oil remained on the parts was completely solved into the hexane.
3. The machine parts were removed from the beaker with a mesh.
4. The hexane was naturally evaporated and the remained oil in the beaker was measured with a precise weight scale.

The de-oiling efficiency was defined as follows with the weight of residual oil m_{res}.

$$\eta = \frac{m_{ini} - m_{res}}{m_{ini}} \times 100 \qquad (1)$$

where m_{ini} is the initial amount of oil attached on the machine parts without the injection of hot water. The initial amount was measure just before the hot water injection in the above procedures. Thought the initial amount of oil depends on the room temperature, the measured value at 10℃ was used in the present paper.

4. EXPERIMENTAL RESULTS

4.1 Pressure response experiment of M6 bolts

The pressure in the container is one of the important parameters dominating the flashing behavior of hot water. As the vacuum pump was stopped during the hot water injection as mentioned above, the effect of condensing heat exchanger should be clarified. So the pressure response experiments with hot water injection were conducted before the washing experiments. Shown in Fig.6 are the pressure response in the container with M6 bolts of 900 with or without the condensing heat exchanger when the hot water of 80℃ was injected at the flow rate of 0.22 kg/s. The pressure increased rapidly during approximately 10 s just after the injection and gradually increased after that. The pressure was enough below the saturation pressure corresponding to 80℃ and the flashing was taken place in the vessel.

The cooling water temperature flowed in the condensing heat exchanger was 26.5℃. It should be noted that the pressure increase was depressed with the heat exchanger only at the duration of gradual pressure increase.

Shown in Fig.7 is the effect of injected water temperature on transient pressure when the flow rate was approximately the same. The rapid increase of pressure was observed in the hot water injection of 80℃ due to the flashing. The pressure was enough below the saturation pressure corresponding to 80℃ and the flashing was taken place in the vessel. On the other hand, the rapid increase of pressure indicating the flashing was not observed in the hot water injection of 40℃ as the pressure was larger than the saturation pressure corresponding to 40℃. The increasing rate of pressure was approximately the same as that in the latter period of 80℃ injection.

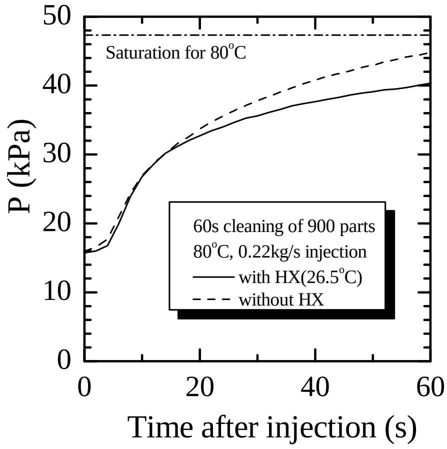

Fig.6 Effect of heat exchanger on transient pressure

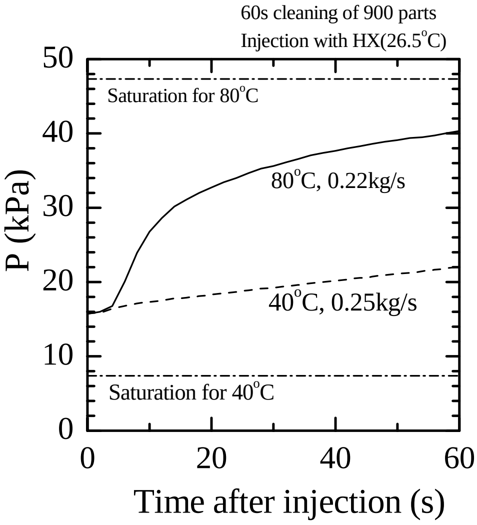

Fig.7 Effect of injected water temperature on transient pressure

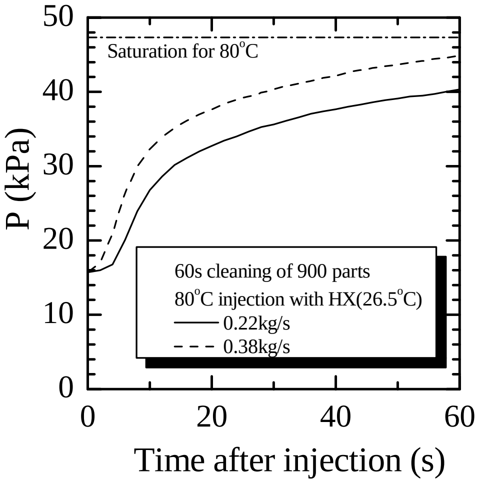

Fig.8 Effect of injected water flow rate on transient pressure

Table 2 De-oiling experimental condition

Injection duration (s)	30-120
Temp. of injected water (℃)	39.9-82.5
Injected mass flow rate (kg/s)	0.04-0.49
Average pressure P_m (kPa)	7.5-33.5

Shown in Fig.8 is the effect of injected water flow rate on the pressure response of container at the water temperature of 80℃. The larger pressure increases just after the injection could be observed at the larger injection flow rate. It should be noted that the pressure increasing rate at the latter duration was approximately the same in both experiments. The further increase of the flow rate will result as the depression of flashing because the pressure exceeds the saturation pressure of 80℃.

4.2 De-oiling experiment of M6 bolts

Shown in Table 2 is the de-oiling experimental condition in the present paper. The injected hot water temperature was between 39.9 and 82.5℃ and the injection duration was between 30 and 120 seconds.

Shown in Fig.9 is the relation of de-oiling efficiency and hot water flow rate at the different temperature of injected hot water. The hot water of 80, 60 and 40℃ was injected into the packed bet of 900 M6 bolts for 60 seconds. The de-oiling efficiency increased with the increase of injected hot water flow rate. The de-oiling efficiency of 80 and 60℃ was approximately same but that of 40℃ injection was relatively low indicating no flashing.

Shown in Fig.10 is the effect of nozzle configuration on de-oiling efficiency. The significant difference due to the nozzle configuration was not observed in the present experimental conditions.

Shown in Fig.11 is the relation of average pressure and injected water flow rate at the injection duration of 60s. The average pressure of 60℃ injection was lower than that of 80℃ injection. It is considered that the pressure difference made the same de-oiling efficiency of 60 and 80℃ injection as shown in Fig.9.

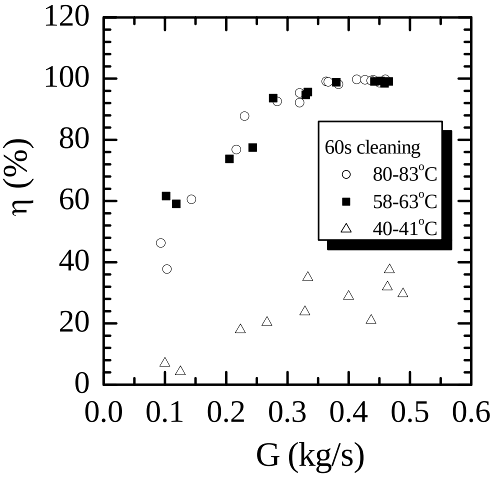

Fig.9 Relation of de-oiling efficiency and injected water flow rate

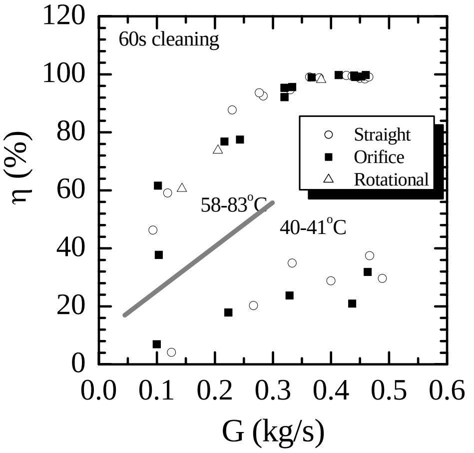

Fig.10 Effect of nozzle configuration on de-oiling efficiency

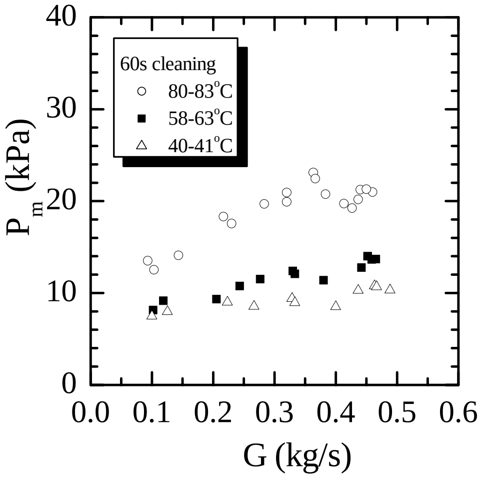

Fig.11 Relation of average pressure and injected water flow rate

The higher temperature of hot water is expected as the vigorous flashing behavior and the higher efficiency of de-oiling at the initial injection duration, but vise versa, it increases the container pressure at the latter injection duration and resulted as the degradation of the de-oiling efficiency. It should be noted that both the higher temperature of injected hot water and the lower average container pressure is necessary for the higher de-oiling efficiency.

For the indicator for the vigorous flashing, the average kinetic pressure of two-phase flashing flow in the injection duration is considered to be important. As the enthalpy of hot water before the injection and the two-phase flashing flow is considered to be the same [4],

$$h_{HW} = x h_G + (1-x) h_L \tag{2}$$

Where h_{HW}: enthalpy of hot water before the injection, x : two-phase quality, h_G: enthalpy of saturated steam in the flashing condition, h_L: enthalpy of saturated water in the flashing condition. When the average container pressure in the injection duration is given, the quality x can be calculated with Eq.(2) and steam table. When the homogeneous two-phase flow is assumed, the average density can be estimated by

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

The dynamic pressure at vacant container is

$$\rho_m u_m^2 = \frac{G^2}{A^2 \rho_m} \tag{4}$$

where G: mass flow rate, A: vacant flow area of container.

Shown in Fig.12 is the relation of de-oiling efficiency and kinetic pressure of flashing two-phase flow at duration of 60 s. The kinetic pressure of 40°C injection was nearly 0 and the de-oiling efficiency was also low. The de-oiling efficiency of 60 and 80 °C injection were approximately the same due to the relatively low average pressure of 60°C injection as mentioned above.

The kinetic pressure of flashing two-phase flow is very important at a given constant duration of hot water injection. However, the de-oiling efficiency obtained at the different duration of hot water injection was shown in Fig.13. The de-oiling efficiency also depends on the injection duration. The lower efficiency was obtained at the shorter duration of hot water injection even at the same kinetic pressure.

Generally, the higher de-oiling efficiency can be obtained as the longer flashing duration and the smaller viscosity of attached oil. So the following non-dimensional flashing duration consisting of the kinetic pressure, the flashing duration and the oil viscosity was proposed to evaluate the de-oiling efficiency.

$$\left(\frac{\rho_m u_m{}^2 t}{\mu_{Oil}} \right)^{0.25} \tag{5}$$

where the oil viscosity was evaluated at the saturation temperature corresponding to the average vessel pressure. By using the non-dimensional flashing duration, the experimental result including the different flashing duration can be shown as Fig. 14.

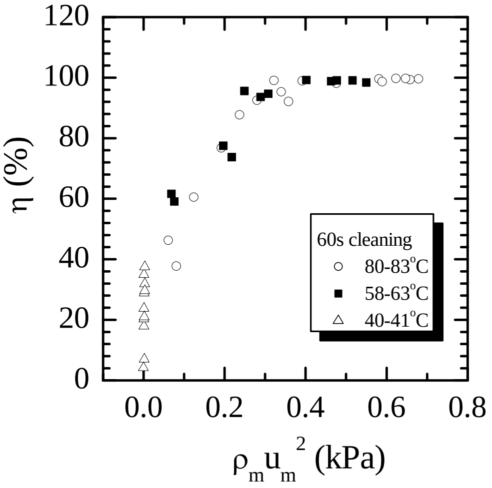

Fig.12 Relation of de-oiling efficiency and kinetic pressure of flashing two-phase flow at duration of 60s

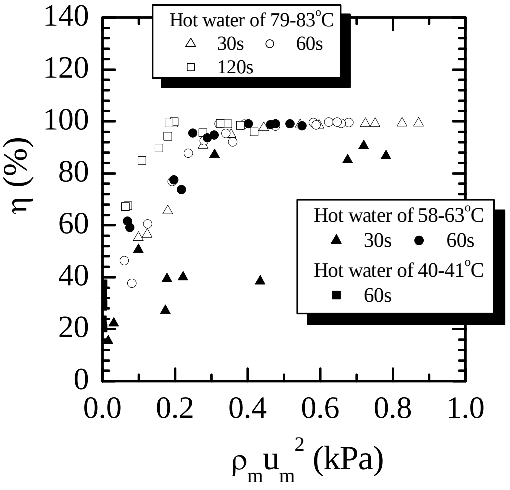

Fig.13 Relation of de-oiling efficiency and kinetic pressure of flashing two-phase flow at different duration

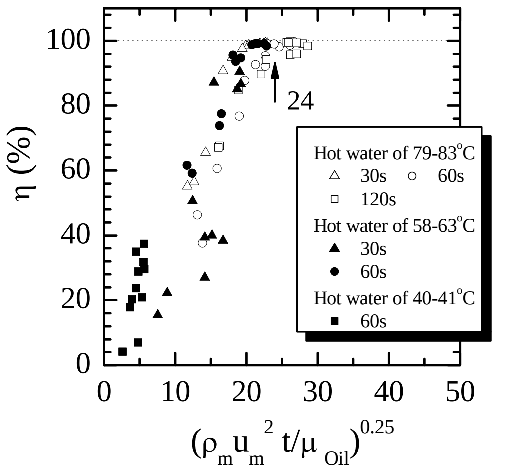

Fig.14 Relation of de-oiling efficiency and newly-defined non-dimensional parameter at different injection duration

The horizontal axis is the non-dimensional flashing duration and the vertical axis is the de-oiling efficiency. The scattering of data was relatively large at the smaller non-dimensional duration because the residual oil was measured for 100 pieces extracted from 900 pieces in total. When the de-oiling efficiency was relatively small, the distribution of residual oil amount on each piece was large and the extraction method resulted as the scattering of data. When the de-oiling efficiency was relatively large, the distribution of residual oil amount on each piece was small and the scattering of data could not be observed. The de-oiling efficiency of more than 95% could be obtained when the non-dimensional duration was larger than 24.

4.3 De-oiling experiment of bolts and nuts in different size

Shown in Fig.15 is the de-oiling efficiency of different size bolts. The number of bolts stored in the container was 4000 for M4, 900 for M6 and 200 for M12. The hot water of 79-83℃ was injected during 60 s. The more than 95 % of de-oiling efficiency was obtained in spite of the bolts size at around the non-dimensional flashing duration of 24.

Shown in Fig.16 is the de-oiling efficiency of different size nuts compared with the M6 bolts. The number of nuts stored in the container was 11500 for M4 and 550 for M12. The hot water of 79-83℃ was injected during 60 s. The more than 95 % of de-oiling efficiency was obtained in spite of the nuts size at around the non-dimensional flashing duration of 24 as well as the M6 bolts.

5. CONCLUSION

The prototype flashing water cleaner was designed and its de-oiling ability was experimentally investigated with the different sizes of bolts and nuts. The followings were obtained as the major results.

(1) The pressure increased rapidly during approximately 10 s just after the injection and gradually increased after that. The pressure increase was mitigated with the heat exchanger only at the duration of gradual pressure increase.

(2) The significant difference due to the nozzle configuration was not observed in the present experimental conditions.

(3) For the indicator for the vigorous flashing, the average kinetic pressure of two-phase flashing flow in the injection duration is considered to be important. The de-oiling ability was strongly affected with the newly-defined non-dimensional parameter consisting of the injection duration, the average kinetic pressure of flashing two-phase flow defined at vacant container flow area and the viscosity of oil. The de-oiling efficiency more than 95 % was successfully achieved at the parameter larger than 24.

(4) Even in the different size of bolts and nuts, the de-oiling efficiency more than 95 % was successfully achieved at around the non-dimensional flashing duration of 24.

6. REFERENCES

1. Osakabe M., Cleaning method and equipment for machine parts, Japanese patent 3234204, (2001).
2. Horiki S. and Osakabe M., Cleaning and De-oiling of Machine Parts with Low-pressure Flashing Flow, Proc. of the 2001 IJPGC (New Orleans), CD-ROM, (2001).
3. Horiki S. and Osakabe M., Cleaning and de-oiling of machine parts with low-pressure flashing flow, Proc. of ISME (Tokyo), (2000), pp. 97-100.
4. Osakabe M. et al., Characteristics of steam flow in non-spherical particles bed, J. of Japan Institute of Marine Engineering, 33(4), (1998), pp.294-299.

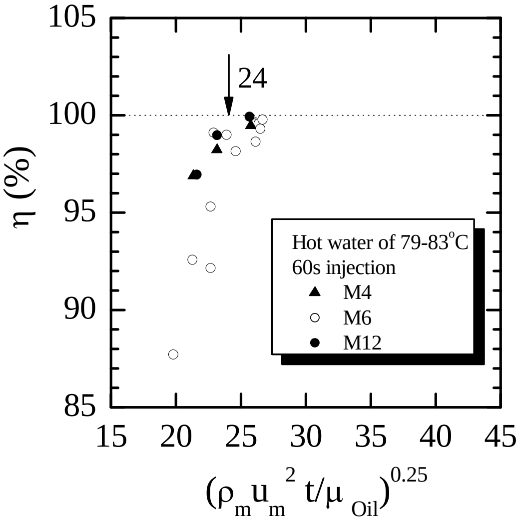

Fig.15 Effect of bolts size

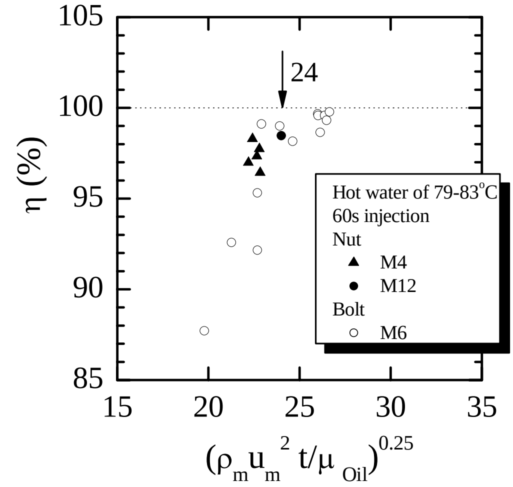

Fig.16 Effect of nuts size