Eq(24) agrees with the experimental results. But when C becomes thiner, Eq(24) gets out of the experimental result, In Fig.13, the inclination of the concentration curve of discharged washing water($\triangle \log C/\triangle Q$) is proprotional to $-1/QDH$.

Let's the discrepancy from this inclination be K, and the concentration inclination during washing be 1/(K QDH) and caluculate from the result. In the case of ϕ 7 mm ×2, as QDH is 0.028 m^3;

$1/0.028K = 7.9$

therefore, $K = 4.5$

In the case of ϕ 4 mm ×2, as QDH is 0.011 m^3,

$1/0.011K = 22$

therefore $K = 4.1$

It is considered that washing efficiency decreases as the K incresses. Between ϕ 7 mm and ϕ 4 mm, there is little difference in washing efficency. Although there is much effect with QDH, at the later period of low concentration, the gradient $\frac{\triangle \log C}{\triangle Q}$ of the curve Q−C of the experimental result of ϕ 4 mm is as 2.8 times large as one of ϕ 7 mm. Necessary quantity of washwater decreases with decreasing diameter of washing nozzle. However if the washwater in the same pipe line is used for both the washing and the power to move washing machine, it is difficult to move nozzle smoothly in the case of small diameter nozzle. Because it is insufficiency of the momentum. According to the different viscosety of liquids which adhere to tank surface, from Fig, 14, in the case of glycerin of high viscosity;

$C = 0.12\exp(-18.5Q)$

is given and in the cases of low and middle viscosity,

$C = 0.064\exp(-28.5Q)$

$C = 0.022\exp(-22Q)$

are given respectively. In the case of high viscosity, the efficiency of washing decreases. From the results described above, it is tried to estimate the quantity of necessary water to wash tank. If it is assumed that the water is homogeneously mixed in the tank during tank washing, the concentration in the effluent C is given by the expression.

$C = Qres0/(Q+Qres0)$

When $Q>QDH-Qres0$;Eq.(24) is used.

$$C = \frac{Qres0}{QDH} \cdot \exp\left(-\frac{Q-QDH+Qres0}{QDH}\right) \quad \cdots\cdots\cdots(24)$$

On the other hand, fron the experimental result, in the region almost steady region $C<10^{-2}$, the relation between the concentration and the amount of used water is expressed as

$$C = a2 \cdot \exp(-b2 \cdot Q) \quad \cdots\cdots\cdots(25)$$

then a2 and b2 obtained by the experiment, in the case of ϕ 7 mm washing machine.

$a2 = 0.011$, $b2 = 7.9$

are given.

Substitution of $QDH = 0.028$ m^3 and $Qres0 = 0.0021$ m^3 of the data of expetiment into Eq.(24) gives

$C = 0.19\exp(-36Q)$

Here, coefficients K0 and K1 are given by

$K0 = a2/(Qres0/QDH \cdot \exp((QDH-Qres0)/QDH)$

$K1 = b2/(1/QDH)$

In the case of ϕ 7 mm washing machine, K0 and K1 becomes

$K0 = 0.058$

$1/K1 = 1/4.6$

In Fig. 13, at the begining region, line Eq.(24)−7 represents the relation between C and Q by Eq.(24) about ϕ 7 mm nozzle washing machine. And for the later half, the relation can be represented by Eq.(25).

Eq.(25) may be modified by the follwing expression,

$$C = K0 \cdot Qres0/QDH \cdot \exp((QDH-Qres0)/QDH) \cdot \exp(-Q/K1 \cdot QDH) \quad \cdots\cdots\cdots(26)$$

The boundary between Eq.(24) and Eq.(26) is given as follows.

$C = Qres0/QDH \exp((QDH-Qres0/QDH) \exp(-K1 \cdot \ln K0/(1-K1))$

$Q = K1 \cdot QDH \cdot \ln K0/(1-K1)$

Then, the experimental results of the washing machine are considered. When QDH is $0.011\mathrm{m}^3$ and Qres0 is $0.0015\mathrm{m}^3$, Eq.(24) is plotted by Eq.(24)−4 in Fig.13. It deviates downwards little from the experimental result. From the experimental results,

at the begining region; $C = 0.30\exp(-66Q)$

at the latter region; $C = 0.022\exp(-22Q)$

are given. At the begining region,

$$C = Qres0/(K2 \cdot QDH) \cdot \exp(-(Q-K2 \cdot QDH+Qres0)/K2 \cdot QDH) \cdots\cdots\cdots(27)$$

K2 is the coeffiecient which express the effectiveness of the washing of begining region.

$K2 = (1/QDH)/66 = 1.4$

The plofile calculated by Eq.(27) plotted with Eq.(27)−4 in Fig.13.

At the latter region,

$$C = K0s \cdot Qres0/QDH \cdot \exp((QDH-Qres0)/QDH) \exp(-Q/(K1s \cdot QDH)) \quad \cdots\cdots\cdots(28)$$

$K0s = 0.069$

$K1s = 4.1$

are given.

Next, the viscosity of clingage residue is considered here.

From Fig.14, considering the effect of the washing in the care of the different viscosity, there is little difference in it between the ethlene glycole (middle viscosity) and the water (low viscosity), but it becomes lower in the care of the glycerine (high viscosity). The washing about the clingage of different viscosity is considered similary in the care of the comparison of the diameter of the washing nozzle. From the result of washing test about high viscosity glycerin, at the begining washing time,

$C = 1.06\exp(-47.6Q)$

at the later washing time,

$C = 0.12\exp(-18.5Q)$

are given, and it is expressed by the equation, at the beginning region;

$$C = \frac{Qres0}{K3 \cdot QDH} \cdot \exp\left(-\frac{Q - K3 \cdot QDH + Qres0}{K3 \cdot QDH}\right)$$

$K3 = 2.0$

This is considered the product of the factor $K2 = 1.4$ reduced by making the nozzle diameter smaller and the factor 1.4 of the reduced washing efficiency by the viscosity.

At the later part,

$$C = K0sn \cdot \frac{Qres0}{QDH} \cdot \exp\left(\frac{QDH - Qres0}{QDH}\right) \cdot \exp\left(\frac{-Q}{K1sn \cdot QDH}\right)$$

$K0sn = 0.11 \quad K1sn = 5.2$

are given.

In the case of the tank washing by the prevailing washing machine, until about 0.5% residual concentration, the relation between concentration and washwater agrees with the ideal mixing model. But after that, in the case of the concentration less than about 0.5%, the washing efficiency decreases.

Then the recirculation washing is recomended at the later washing.

Here the case of $QDH = 0.085\ m^3$ and $Qres0 = 0.074m^3$ is considered. At first, tank is washed continiously and washwater is discharged until the concentration becomes down to 0.5% After that, recirculation washing is done. In Fig.32, line ABC is for the washing by continiously pumping out slops.

In the case of the tank washing by recirculation, it is more effective if the washwater is stripped in the middle of the washing. If to do so, the C−Q curve becomes CEG. The more time the washwater is stripped completely, the cleaner comes the tank. If the washing is done at the begining as curve ABH shown in Fig.32, it is not so effective compared with the washing by continiously pumping by continiously pumping out slops shown as line ABC.

4.2 Copmarison and Discussion of Results of Clingage Residues.

From Fig.30 the formulas to calculate the clingage residues are obtained concerning the different viscosity. In the cases of 1.5 mPa.s of water for low viscosity, 22 mPas of ethlene glycol for middle viscosity and 1300 mPa.s of glycerin for high viscosity, the amount of clingage residue on tank surfaces are estimated. The amount of clingage residue to each tank surface is obtained as follows.

$Q_d = Q_T - (Q_W + Q_b)$

$Q_W = (Q_W + Q_b) - Q_b$

$Q_b = Q_b$

Q_T:amount of clingage residue to all surface

Q_d:amount of clingage residue to horizontal area facing downwards

Q_W:amount of clingage residue to vertical area of tank

Q_b:amount of clingage residue to area of tank bottom.

Q_T, (Q_W+Q_b) and Q_b are measured.

The formulas corresponding to Eqs.(12),(13),(14) are obtained from the result of the model tank test as follows. In the case of the 90 minutes later after sprinkling;

At 1.5mPa.s;

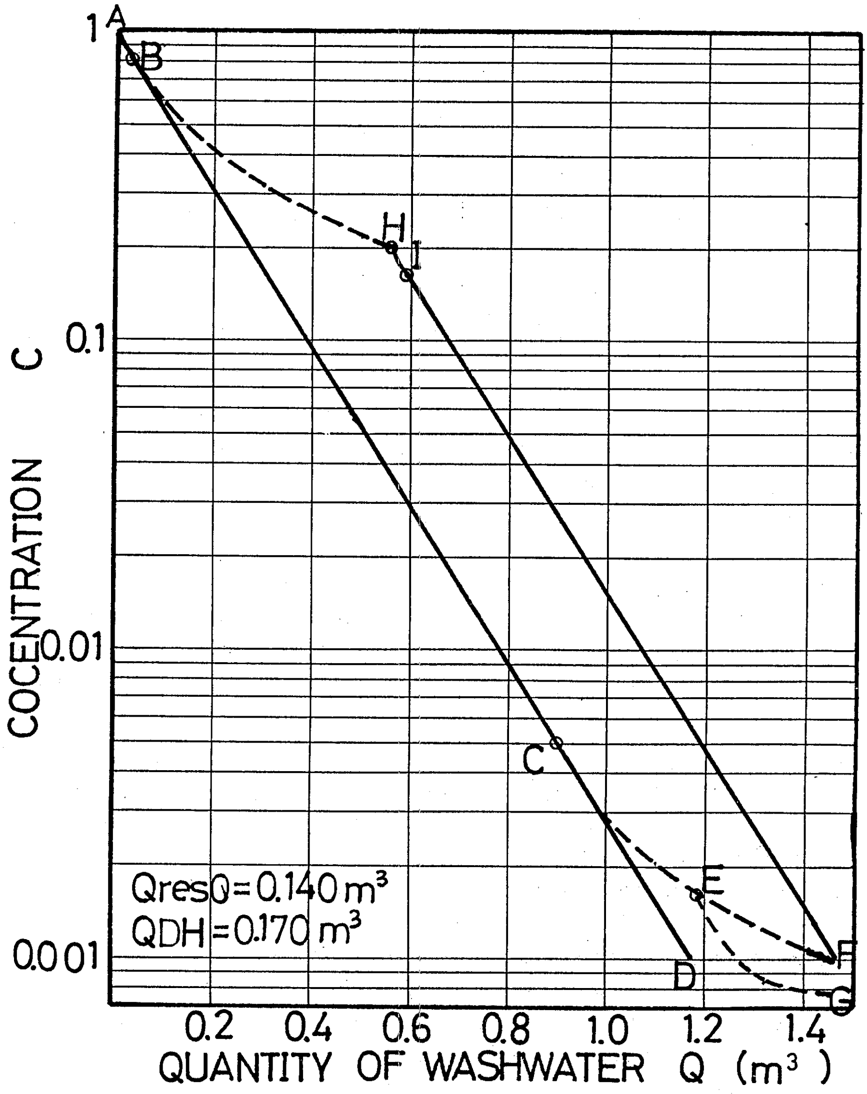

Fig.32 Comparison between continious washing and recirculating washing

$$Q_{res(surf)} = 2.5\times10^{-5}\ A_d + 2.1\times10^{-5}\ A_w + 1.9\times10^{-5}\ L^{1/2}\ A_b \quad \cdots\cdots\cdots(12')$$

At 22 mPa.s;

$$Q_{res(surf)} = 1.1\times10^{-4}\ A_d + 2.9\times10^{-5}\ A_w + 3.1\times10^{-4}\ L^{1/2}\ A_b \quad \cdots\cdots\cdots(13')$$

At 1300 mPa.s;

$$Q_{res(surf)} = 8.5\times10^{-4}\ A_d + 1.1\times10^{-4}\ A_w + 2.3\times10^{-4}\ L^{1/2}\ A_b \quad \cdots\cdots\cdots(14')$$

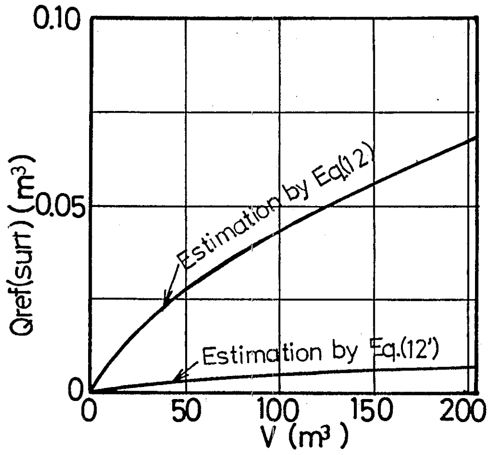

Fig.33 V—Qres(surf)

These equations give smaller Qres(surf) than Eqs. (12), (13), (14).

Fig.33 represents the difference in Qres(surf) between by Eq.(12) and by Eq.(12'). This is estimated using Table 1. V is tank volume. It is necessary to confirm these equations by the board test. However, as the efforts have been made to minimize the residual cargo on board, amount of clingage residues seemes to become less now.

Next, the relation between the temperature of the test liquid and amount of clingage residues was considered. The liquid temperature changed from 6℃ to 38℃ through the year. From Fig.30, the viscosity and the amount of clingage residue per unit area corresponding to these temperatrres are shown in the table 4. Concerning the water of low viscosity and ethylene glycole, the change of the amount of clingage residue by the season is small but concerning the glycerin of high viscosity, the change by season is large.

Table 4 Comparison with the amount of liquid adhering to the tank surfaces between 6℃ and 38 ℃ (Trim=List=2°)

Liquid	Adhering surfaces	6°C	38°C
Water	(Viscosity)	(1.7 mPa S)	(1.1 mPa S)
	Underdeck	0.041 kg/m^2	※ 0.031 kg/m^2
	Wall	0.018 〃	※ 0.019 〃
	Bottom	0.041 〃	※ 0.038 〃
Ethylene glycol	(Viscosity)	(44 mPa S)	(9.2 mPa S)
	Underdeck	0.061 kg/m^2	0.050 kg/m^2
	Wall	0.048 〃	0.028 〃
	Bottom	0.094 〃	0.041 〃
Glycerin	(Viscosity)	(3000 mPa S)	(280 mPa S)
	Underdeck	※ 0.55 kg/m^2	0.075 kg/m^2
	Wall	※ 0.25 〃	0.075 〃
	Bottom	※ 1.2 〃	0.175 〃

(※ is gained by extrapolation)

4.3 Comparison between Estimation and Experimental Result about Washings Quantity Remaining in Tank during Washing

QDH may be estimated by calculation. In the case of the model tank test, QDH is obtained as follows.

Model Tank: Length;4 m, Breadth;2 m, Depth;2 m
Washing Machine: Capacity $Q = 0.001 m^3/sec$, two$-\phi$ 7 mm nozzles

$QDH = Q1+Q2+Qs$ ………(30)

$Q1$ = Water Quantity on the Vertical Surface(m^3)
$Q2$ = Water Quantity on the Bottom(m^3)
$Qs2$ = Water Quantity in the vicinity of the well (m^3)

$Q1 = \delta_1 \times b \times D/2 \times 2$ ………(30)

$Q2 = \delta_2 \times B \times L$ ………(32)

(1) Estimation of Q1
Velocity $U = (1/2 \cdot Q)/(\pi/4 \cdot d^2) = 13.0 (m/s)$
Using Eq.(19);
$r = rN \times 0.58(R \cdot F)^{0.22}$ ………(19)
Here,
$R = U \cdot rn/\nu = 4.55 \times 10^4$, $(\nu = 1.0 \times 10^{-6} m^2/s)$
$F = U^2/(g \cdot rN) = 4930$
By substituting R and F into Eq.(19);
$r = 0.139 (m)$
Substituting r into Eq.(18);
$b = 4.3r = 0.60 (m)$
Flow rate per Unit Width $ql = q/2b = 8.3 \times 10^{-4} (m^2/s)$
Viscosity $\mu = 1.0 \times 10^{-4} (kg.s/m^2)$
Water specific gravity $\gamma = 998 (kg/m^3)$
Then, water Film Thickness along the vertical surface;
$\delta_1 = ((3ql \cdot \mu)/(\gamma \cdot \sin\phi 1))^{1/3} = 0.63 \times 10^{-3} (m)$
Therefore, from Eq.(17), Q1 is obtained:
$Q1 = 0.77 \times 10^{-3} (m^3)$

(2) Estimation of Q2
$\phi 2 = 2^\circ$ By using Eq.(22),
Water Film Thickness on the Bottom $\delta_2 = ((3q \cdot \mu)/(B \cdot \gamma \cdot \sin \phi 2))^{1/3} = 1.6 \times 10^{-3} (m)$.
Substituting δ_2 into Eq.(20);
$Q2 = 1.6 \times 10^{-3} \times 2 \times 4 = 1.28 \times 10^{-3} (m^3)$

(3) Qs2 is obtained by the washing test with water in this model tank.
$Qs2 = 2.28 \times 10^{-3} (m^3)$

(4) QDH = Q1+Q2+Qs = 15.9×10^{-3} (m^3)

By the experimental result of the model tank test, the average of QDH is 18.4×10^{-3} (m^3).

So the estimation by the calculation is not so much deviate from the experiment.

Let Q1+Q2 = Q12. The relation between Q12 and the tank volume V can be estimated statistically in Fig.34.

The tank shapes are considered as rectangular parallelepiped and the dimensions are shown in Table 1.

In Fig.34, Q12 of the prevailing washing machine is compared with Q12 of the one with two ϕ 4 mm nozzles and Q12 of the one with two ϕ 2.5 mm nozzles.

In the cases of ϕ 4 mm nozzle and ϕ 2.5 mm washing machine, the water pressure is 200kPa. Using the washing machine with small diameter nozzle, Q12 can be decreased.

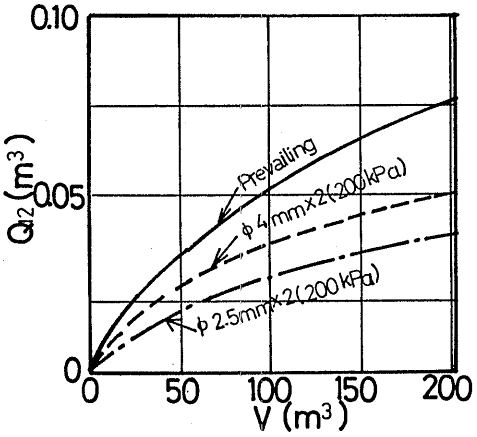

Fig.34 V−Q12

5. CONCLUSION

From the result of the model tank test, the relation between the concentration in discharged water and the water quantity was gained as follows;

(a) At the early washing stage of prevailing washing machine (nozzle diameter is 7 mm) in the case of the model tank, the relation between the concentration of discharged water and the water quantity is given as the following.

$C = Qres0/QDH \cdot \exp(-(Q-QDH+Qres0)/QDH)$

C:concentration, QDH:remaining water in the tank during washing, Qres0:Amount of residue in tank.

(b) At the later washing stage of prevailing washing machine in the case of the model tank, the relation between the concentration and the washing water quantity is given as follow.

$C = K0 \cdot Qres0/QDH \cdot \exp(((QDH-Qres0)/QDH) \cdot \exp(-Q/K1 \cdot QDH)$

K0, K1 are coeficients and k0 = 0.058, K1 = 4.6 respectively.

(c) At the early washing stage of the washing machine with small diameter nozzles (nozzle diameter = 4 mm), the relation between the concentration of discharged water and water quantity for washing is estimated by the following equation.

$C = \mathrm{Qres0/K2 \cdot QDH \cdot exp(-(Q-K2 \cdot QDH+Qres0)/K2 \cdot QDH)}$

K2 is coefficient, $K2 = 1.4$

(d) At the later washing stage of the small diameter washing machine, the relation between the concentration of discharged water and washing water quantity is estimated by the equation.

$C = \mathrm{K0s \cdot Qres0/QDH \cdot exp((QDH-Qres0)/QDH) \cdot exp(-Q/K1s \cdot QDH)}$

K0s and K1s are coefficients, $K0s = 0.069$, $K1s = 4.1$

(e) At the early washing stage of high viscosity residue by the small diameter washing machine, the relation between the concentration of discharged water and washing water quantity is estimated by the expression.

$C = \mathrm{Qres0/K3 \cdot QDH \cdot exp(-(Q-K3 \cdot QDH-Qres0)/K3 \cdot QDH)}$

K3 is coefficient, $K3 = 2.0$

(f) At the later washing stage of high viscosity by the small diameter washing machine, the relation between the concentration of discharged water and washing water quantity is estimated by the following equation.

$C = \mathrm{K0sn \cdot Qres0/QDH \cdot exp((QDH-Qres0)/QDH) \cdot exp(-Q/K1sn \cdot QDH)}$

K0sn and K1sn are coefficients, $K0sn = 0.11$ and $K1sn = 5.2$.

These coefficients are obtained only by the model tank experimnt, it is necessary that the coefficients shall be confirmed by the board test.

At the begining time of the tank washing, the estimation of the washwater quantity by the ideal mixing agrees with the experimental result. But at the end of the tank washing, the estimation by the ideal mixing, deviates from the line by the experimental result. At the end of the washing, the residue become hard to remove from the tank surfaces. Therefore, at the begining the tank should be continiously washed and washings should be discharged until the concentration becomes about 0.5%.

After that, the washing should be done by recycling of washing medium.

Residual quantity of the tank surfaces is approximatelly estimated by Eqs.(12'),(13'),(14').

Remaining tank washings quantity in the tank during washing is approximately estimated by Eq.(23) or Fig.34.

Fig.35 represents the comparison of the tank washing by different diameter nozzle. From this, by using small diameter nozzle and reestimation of clingage residue, the necessary water seemes to be decreased.

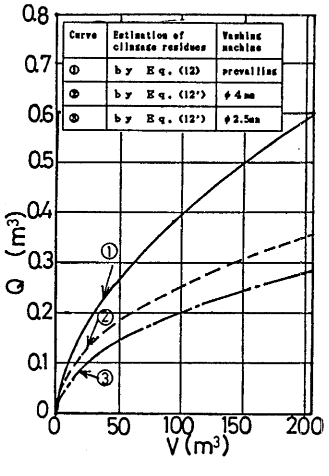

Fig.35 Necessary washwater quantity to wash until the concentration of 1%(estimated by ideal mixing model)

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