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Selection of the fresh water supply system parameters for fish factory trawlers

SUMMARY

A new, original method of parameter selection of the fresh water production and supply systems for fish factory trawlers, i.e. selection of type, number and capacity of the desalination devices and storage tank capacities, is presented in the paper. The fresh water production and management system of a fish factory trawler is modelled as a mass service system. Such modelling is justified on the basis of the investigations carried out on 11 Polish fish factory trawlers in operation on fishing grounds.

INTRODUCTION

On most cargo ships the amount of heat carried away by the main engine (ME)cooling water is quite sufficient to fully cover heat demand for producing the fresh water by means of one-stage, boiling water evaporators.

The situation is different on the industrial fishing vessels whose the most characteristic representative is the fish factory trawler. The ships are specific due to their big and variable fresh water demand at limited ability of its production with the use of evaporators, most often one-staged, heated by the ME cooling water. In most cases the evaporators are not able to cover the entire fresh water demand due to not very high output of the main engines and their high load variability. The remaining, lacking amount of fresh water is obtained from other desalination devices, e.g. evaporators heated by the steam from auxiliary boilers, or reverse osmosis (RO) desalinators. However, some shipowners prefer to install the multi-stage evaporators.

The design methods which usually are applied in practice do not account for the real water production possibilities connected with the variable main engine loading and real water consumption, moreover the methods pass over the problem of selecting such tank capacity as to accommodate all the water that may be produced.

A new, original parameter selection method of the fresh water production and supply systems for fish factory trawlers, i.e. selection of type, number and capacity of the desalination devices and storage tank capacities, is presented in the paper.

PRESENTATION OF THE METHOD

The presented method concerns the operation time on the fishing ground which is the basic and longest exploitation state of the trawler (200 days per year on average) and during which the highest demand for fresh water appears simultaneously with lower outputs of the evaporators heated by the ME cooling water (due to lower average ME loading).

The operation conditions of the system in question are determined by the real course of water production and demand processes. Periodical storage of water surplus is necessary in result of random character of the processes. It led to the idea of using the mass service theory methods. The fresh water production and management system of a fish factory trawler is presented in Fig.1 [6] as a mass service system. Such modelling is justified under the following assumptions :

- the fresh water stream produced by the evaporators heated by the ME cooling water, and eventually by other desalinators, corresponds to the service request stream. Therefore the real capacity of the desalination devices (inflowing water amount) corresponds to the request intensity (rate)
- the fresh water supply installations covering the fresh water demand from the side of the consumers, correspond to the service rendering devices
- the fresh water demand covering process corresponds to the service process, and the demand value corresponds to the service intensity
- the fresh water amount produced by the desalination devices and stored in the storage tanks corresponds to the request queue.

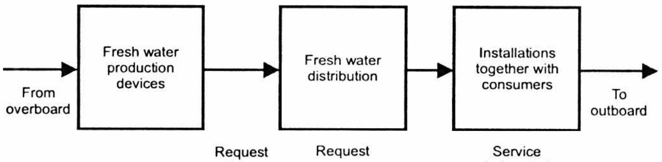

Fig.1. The fresh water production and management system of a fish factory trawler, modelled as a mass service system

Results of the investigations carried out on 11 Polish fish factory trawlers [6] allow :

- to consider the output of the evaporators supplied with the ME waste heat as random process realization, and the distribution of the water amount produced by the engines per day to be described by means of the Poisson distribution
- to consider the fresh water consumption as a random process, and the unit (1 t) water consumption periods to be described by means of the Erlang distribution.

The above mentioned statements formed the basis of modelling the fresh water production and management system for fish factory trawlers as the mass service system of the unlimited queue of $M/E_k/1$ type provided that any single request event amounts to 1 t of water.

The specified calculation procedures can be applied if values of the following parameters and particulars are known :

- the rated power N_{ME}^{nom} [kW] and type of ME
- the number of ship's crew Z [persons]
- the steaming rate of auxiliary boilers D_{AB} [kg/h]
- the mean catch rate of the fishing ground U^{m} [t/day]
- the trawler autonomous operation time on the fishing ground t [days]

The analyses begin with determination of the real, mean fresh water demand M_{fw}^{m} . Two possible situations can be distinguished :

1st : the demand concerns the sanitary and boiler supply water only. The situation occurs when the potable water is delivered, according to shipowner's specification, from the quay only and stored in separate tanks of the capacity $V_{pw} = t \cdot W_{pw}^{m}$

2nd : the demand concerns the potable, sanitary and boiler supply water. The potable water is obtained by appropriate treatment of the destilate.

The mean potable water demand W_{pw}^{m} can be determined from the following relationship [4,5]:

$$W_{pw}^{m} = -0.04 + 0.01 \cdot Z \quad [t/day] \qquad (1)$$

and the mean total demand for both sanitary and boiler supply water W_{bw}^{m} from any of the formulas given in Tab.1.

***Tab.1.** The mean, total demand for sanitary and boiler supply water of the fish factory trawlers operating on a fishing ground*

1.	$W_{bw}^{m} = 0.129 \cdot Z + 0.141 \cdot U^{m} + 0.00023 \cdot (N_{ME}^{nom} + D_{AB})$
2.	$W_{bw}^{m} = 0.131 \cdot (Z + U^{m}) + 0.0003 \cdot (N_{ME}^{nom} + D_{AB})$
3.	$W_{bw}^{m} = 0.132 \cdot Z + 0.131 \cdot U^{m} + 0.00043 \cdot D_{AB}$

In the first case $M_{fw}^{m} = M_{bw}^{m}$, and in the other : $M_{fw}^{m} = M_{pw}^{m} + M_{bw}^{m}$.

The next step is :

☐ determining the real capacity of the sea water desalination devices within considered variants of the system and

☐ comparing the capacity with the mean demand.

The following selection variants of the desalination devices can be considered in practice as far as the fish factory trawlers are concerned :

a) exclusive application of the one-stage evaporators heated by ME cooling water

b) exclusive application of the one-stage evaporators heated by ME cooling water, reheated with the use of a part of the heat from cooling the charging air

c) exclusive application of the one-stage evaporators heated by ME cooling water, reheated with the use of the steam produced by auxiliary boilers

d) exclusive application of the multi-stage evaporators heated by ME cooling water

e) application of the one-stage evaporators (with the possible reheating of the cooling water) and additionally a desalination device of another type (a steam heated evaporator or RO desalination device).

In special cases other desalinator variants can also be taken into account.

In the actual analysis such variants of the desalination devices should be accounted for whose average capacities (but not their nominal capacities) are close to the average fresh water demand.

The capacity of evaporators D_{EV} supplied by ME waste heat can be determined from the following relationship :

$$D_{EV} = \frac{86.4\, Q_{EV}}{q_{EV}} \quad [t/day] \qquad (2)$$

where :

Q_{EV} [kW] - the heat flow which can be obtained from ME cooling water in an evaporator

q_{EV} kJ/kg - the unit heat flow required to produce 1 kg of fresh water.

The value of q_{EV} depends on evaporator's type and number of stages as well as its operation conditions (Tab.2).

***Tab.2.** Values of the unit heat flow q_{EV} [kJ/kg] applicable to evaporators*

Type of evaporator	Number of stages			
	1	2	3	4
Boiling	2 800	1 500	1 000	750
Expansion	3 250	1 800	1 350	1 000

The D_{EV} value calculated from the formula (2) for the Q_{EV} value which corresponds to the nominal ME output, determines the maximum available evaporator's capacity D_{EV}^{max} . The relative heat amount $\overline{Q}_{EV}$ depends on the relative ME loading $\overline{N}_{ME}$ and can be approximated by the following second-order polynomial :

$$\overline{Q}_{EV} = a_0 + a_1 \overline{N}_{ME} + a_2 \overline{N}_{ME}^2 \qquad (3)$$

where a_0, a_1, a_2 - constants.

The relationships $\overline{Q}_{EV} = f(\overline{N}_{ME})$ published by engine producers are exemplified in Tab.3.

***Tab.3.** The relationships $\overline{Q}_{EV} = f(\overline{N}_{ME})$ for some main engines used on the fish factory trawlers*

Type of the engine	Relationship
ZA40	$\overline{Q}_{EV} = 0.454 - 0.574 \cdot \overline{N}_{ME} + 1.12 \cdot \overline{N}_{ME}^2$ *
AT25	$\overline{Q}_{EV} = 0.46 + 0.49 \cdot \overline{N}_{ME} + 0.05 \cdot \overline{N}_{ME}^2$ *
L35MC	$\overline{Q}_{EV} = 0.25 + 0.75 \cdot \overline{N}_{ME}$ ** $\overline{Q}_{EV} = 0.19 + 0.81 \cdot \overline{N}_{ME}$ *

*) *The engine operating according to the load characteristics*

**) *The engine operating according to the propeller characteristics*

In the case of application of the two-stage charging air coolers it is possible to increase the heat flow which can be utilized in the evaporator, by the heat flow output from the first stage of the charging air cooler. The corresponding relationship $\overline{Q}_{EV} = f(\overline{N}_{ME})$ is of the following form :

$$\overline{Q}_{EV} = \frac{a_{01}+a_{02}}{2} + \frac{a_{11}+a_{12}}{2}\,\overline{N}_{ME} + \frac{a_{21}+a_{22}}{2}\,\overline{N}^2_{ME} \tag{4}$$

where:

a_{01}, a_{11}, a_{21} - the constants of the equation $\overline{Q}_{cw} = f(\overline{N}_{ME})$ which describes the relationship between the relative heat amount contained in the ME cooling water and the ME relative loading

a_{02}, a_{12}, a_{22} - the constants of the equation $\overline{Q}_{ca} = f(\overline{N}_{ME})$ which describes the relationship between the relative heat amount exchanged in the first stage of the charging air cooler and the ME relative loading.

The average ME loading distribution should be known to determine the evaporator capacity D^m_{EV}. A distribution histogram of the mean diurnal ME loading of the fish factory trawlers operating on the fishing ground is shown in Fig.2 [1, 2, 3].

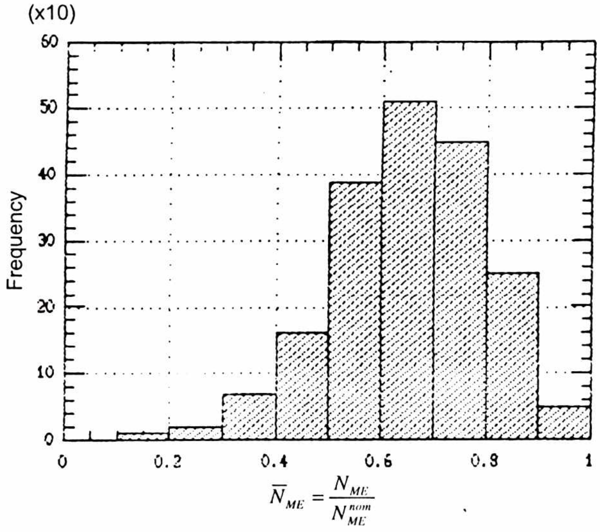

Fig.2. The distribution histogram of the summary, relative, mean diurnal ME loading of the fish factory trawlers operating on the fishing ground

It is possible to determine the relative distribution and, in consequence, relative capacity of a considered evaporator if the ME loading distribution and the function $\overline{Q}_{EV} = f(\overline{N}_{ME})$ is known. The scheme presented in Fig.3 highlights the way of preparation of the histogram.

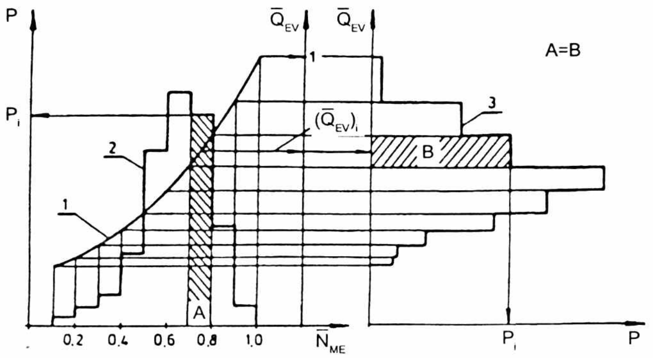

Fig.3. The preparation scheme of the histogram of the relative heat flow delivered to the evaporator :
1- the relationship of the relative heat flow $\overline{Q}_{EV}$ versus ME relative loading $\overline{N}_{ME}$,
2- the histogram of the ME relative load distribution (see Fig.2),
3- the histogram of distribution of the relative heat flow delivered to the evaporator, contained in the cooling water (i.e. of the relative evaporator capacity)

The mean relative value of the heat flow delivered to the evaporator, $\overline{Q}^m_{EV}$ or the mean relative capacity of a given evaporator, $\overline{D}^m_{EV}$, can be determined by using the histogram 3 of Fig.3 :

$$\overline{Q}^m_{EV} = \sum_{i=1}^{z} (\overline{Q}_{EV})_i\, p^*_i$$

$$\overline{D}^m_{EV} = \sum_{i=1}^{z} (\overline{D}_{EV})_i\, p^*_i \tag{5}$$

where :

$(\overline{Q}_{EV})_i$ - the relative heat flow delivered to the evaporator at the ME load value which corresponds to the middle of i-th interval of the ME load histogram

$(\overline{D}_{EV})_i$ - the relative evaporator capacity at the ME load value which corresponds to the middle of i-th interval of the ME load histogram

p^*_i - the corrected interval frequency of the distribution histogram of the relative heat flow values delivered to the evaporator (of the relative evaporator capacity), determined by using p_i values

p_i - the interval ME load frequency (see Fig.3).

$$D^m_{EV} = D^{\max}_{EV}\,\overline{D}^m_{EV} = \frac{86.4}{q_{EV}}\,Q^{\max}_{EV}\,\overline{D}^m_{EV} \quad [t/day] \tag{6}$$

where : $D^{\max}_{EV}$ [t/day] - the maximum evaporator capacity.

Knowledge of the ME load distribution is required to determine the mean evaporator capacity D^m_{EV}. The summary mean value of the desalinator capacity with regard to the system variants c) and e), should be determined as the sum of the mean capacity of a given, ME-cooling-water-heated evaporator and the mean water production capacity of an additional device (a steam reheater, seperate steam heated evaporator, RO desalinator). The mean, additional desalinator capacity can be obtained from the following relationship :

$$D^m_{DP} = \delta_{DP} \cdot D^{nom}_{DP} \quad [t/day] \tag{7}$$

where :

δ_{DP} - the coefficient which determines the share of desalinator operation time in ship's operation time on a fishing ground

D^{nom}_{DP} - the nominal desalinator capacity.

The assumed δ_{DP} value equal 1 denotes continuous operation of an additional device at its nominal capacity during whole exploitation period.

The W^m_{fw} and D^m_{EV} values so determined make it possible to calculate the values $\rho = D^m_{EV} / W^m_{fw}$ which indicate probability of water presence in the spare tanks. Therefore the value (1-ρ) determines probability of fresh water shortage. It is recommended, if selection of the desalination devices is made on the basis of their ρ values, to take into account only those with $\rho \geq 0.95$. Acceptance of a set of the desalinators of $\rho \ll 0.95$ would mean that the permanent keeping of an additional, large amount of spare water on shipboard is necessary to cover water demand in the case if the water in the spare tanks is lacking.

The selected mass service model makes it possible to determine the minimum capacity of fresh water spare tanks. The following notation is assumed :

$$\lambda = D^m_{EV}$$

$$\mu = W^m_{fw} \tag{8}$$

$$\rho = \frac{\lambda}{\mu} = \frac{D^m_{EV}}{W^m_{fw}}$$

The basic characteristics of the mass service system of M/E$_k$/1 type are defined by the following relationships [7, 8, 9] :

★ the mean amount of water stored in the spare tanks, V^m_{fw}, which corresponds to the mean number of requests in the queue, L :

$$V_{fw}^{m} = L = \frac{(k+1)\rho^2}{2k(1-\rho)} \quad [t] \tag{9}$$

★ the largest amount of fresh water which can be stored in the tanks, $V_{fw}^{\max}$, corresponding to the maximum queue length (with 0.95 probability level), $L^{\max}$:

$$V_{fw}^{\max} = L^{\max} = V_{fw}^{m} + 2\sigma_V \quad [\mathrm{t}] \tag{10}$$

where : σ_V - the standard deviation of the distribution of water amount awaiting in the queue for servicing, determined in compliance with [9] as follows :

$$\sigma_V = \sqrt{\frac{\lambda^3 n_3}{3(1-\rho)} + \frac{\lambda^2 n_2}{3} + L\left(1 + \frac{\lambda^2 n_2}{(1-\rho)}\right) - L^2} \tag{11}$$

where : $n_2 = \dfrac{k+1}{\mu^2}$ and $n_3 = \dfrac{k+2}{\mu^3}$

The so calculated water amount $V_{fw}^{\max}$ determines capacity of the spare tanks. Assumption of the ρ parameter value equal to 0.95 is recommended even if the value of ρ for the entire selected system of fresh water producing devices is greater than 0.95. The value of k parameter of Erlang distribution, which characterizes variability of the fresh water consumption, is recommended to be contained between 2 and 4.

However, lower values of k are more justified for ships of a higher water consumption. Even assumption of the value k = 1 can be justified in the case of the ship of a specially high water consumption, and also in order to ascertain full consumption of the water amount produced onboard.

A block diagram of the presented method is shown in Fig.4.

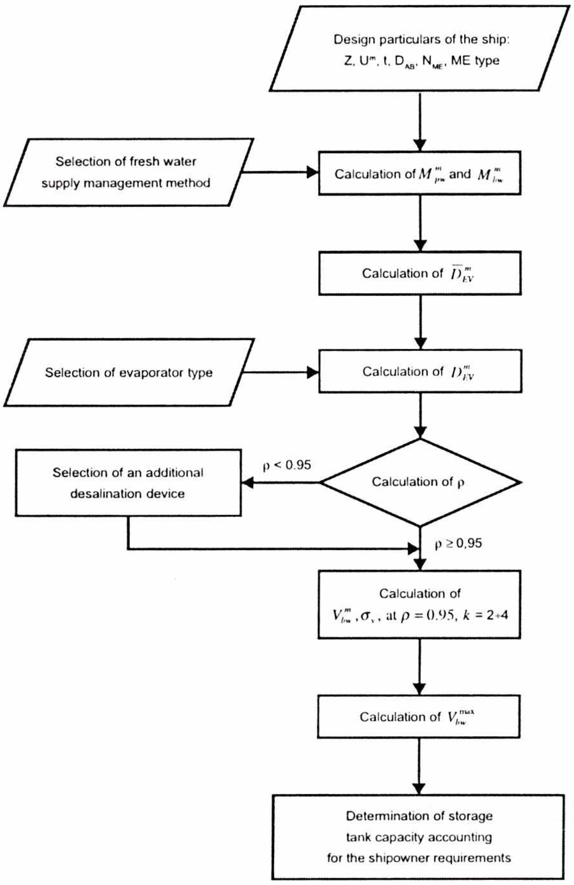

Fig.4. Block diagram of the presented method

FINAL REMARKS

The calculated water amount $V_{bw}^{\max}$ relates to the most unfavourable situation in service, i.e. commencing the operation on fishing ground without any spare fresh-water amount. It may be assummed that the probability of fresh water shortage would be then close to zero because of a limited (and not infinite) time of autonomous ship operation on fishing ground, in spite of assuming the recommended value ρ = 0.95.

The real exploitation situation is more favourable as the trawler usually commences operating on the fishing ground with some (often quite large) spare water amount. The amount can be obtained from a mother ship (or supply vessel), port or produced during the arrival voyage onto fishing ground, when possibilities of producing the fresh water by means of the evaporators are greater and water consumption lower.

The above presented considerations deal only with the technical parameters of the fresh water production and management systems but not with economic questions. However they are somehow accounted for by assumming that the whole water produced by the evaporators of the lowest operation cost, i.e. by those supplied by ME waste heat, is consumed.

NOMENCLATURE

a - constants of the equations $\overline{Q} = f(\overline{N}_{ME})$
D - capacity
$\overline{D}$ - relative capacity
E - Erlang distribution
k - constant of Erlang distribution
M - exponential distribution
n - moment of a variable
N - power output
$\overline{N}$ - relative power output
p - probability
q - unit heat flow
Q - heat flow
$\overline{Q}$ - relative heat flow
t - operation time on fishing ground
U - catch rate of fishing ground
V - capacity of tanks
W - water consumption (demand)
z - maximum number of histogram intervals
Z - number of ship's crew
λ - mean fresh water amount inflowing to a system
μ - mean intensity of fresh water consumption
ρ - system's utilization coefficient (= occupancy probability of servicing devices)
δ - coefficient of the share of device's operation time in ship's operation time on a fishing ground
σ_V - standard deviation of the distribution of fresh water amount in tanks

Indices

bw - of sanitary and boiler water
ca - of charging air
cw - of ME cooling water
fw - of fresh water
pw - of potable water
AB - of auxiliary boiler
DP - of desalinating plant (device)
EV - of evaporator
ME - of main engine
i - of i-th histogram interval
m - mean value
max - maximum value
nom - nominal value
* - corrected value

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