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Agenda item 7

IMCO

PROCEDURES AND ARRANGEMENTS FOR THE DISCHARGE OF NOXIOUS LIQUID SUBSTANCES

Method for calculation of dilution capacity in the ship's wake

Submitted jointly by the Netherlands and Norway

1. The Government of the Kingdom of the Netherlands and the Government of the Kingdom of Norway have reviewed the results of discharge dilution experiments carried out in the two countries. The object of the experiments has been to determine the capability of a ship's wake to dilute water-soluble discharges from the ship.

2. The experiments in the Netherlands were carried out by the use of models in the Netherlands Ship Model Basin. A report of this work is submitted to the third session of MEPC (MEPC III/INF.4). In Norway full scale measurements were made on discharges from M/S "ESSO SLAGEN" of 18,000 t.dw. A report of this work is submitted to the third session of MEPC (MEPC III/INF.5). Previous experiments carried out in the United States, the Netherlands and Norway and reported upon at the IMCO 1973 Pollution Prevention Conference, were also considered in this context.

3. The present submission by the Netherlands and Norway contains a proposal for a method of calculation of the dilution capacity in the ship's wake and takes into account the available research data on this subject as mentioned under item 2 above. See list of references under item 14.

Conclusions

4. Based on tests carried out in the United States, the Netherlands and in Norway, comprising both model and full-scale tests for discharge of soluble substances into a ship's wake, the dilution capacity of the wake may be expressed by the following equation:

$$C_D Q_D = 0.003t^{0.4}L^{1.6}V^{1.4}C_p$$

in the case of a single point of discharge.
Symbols are defined in item number 9.

For multiple discharges located symmetrically about the ships centre line, the dilution capability is increased by 50%.

Considerations

5. The results from the experiments indicate that the dilution is effected in three different stages:

1. By turbulent mixing in the ship's boundary layer, duration of the order of seconds.
2. By turbulent mixing in the ship's wake, duration in the order of 20 minutes.
3. By subsequent diffusion into the surrounding sea.

Considering an exposure reaction threshold time of 300 sec., the dilution of interest will occur in the second stage when the concentration is declining very rapidly (half-life of the order of 200 sec.).

6. The volume of the wake may be related to the speed and the size of the ship. Thus, the dilution capacity may be expressed as a function of the non-dimensional expression $C_D Q_D / C_P V L^2$. The dilution capacity increases with the distance from the ship and may be related to the non-dimensional expression: Vt/L (MEPC II/10).

7. Plotting the experimental results in a diagram of $\log\left(C_D Q_D / C_P V L^2\right)$ against $\log(Vt/L)$ and drawing the lower envelope of these points (ref. fig.1) a curve is obtained. The left hand side of the curve relates to the model tests where measurements were taken immediately aft of the ship. In this region the curve rises most steeply, indicating that the mixing process is very strong. The center portion of the curve relates to the full scale measurements taken some 5 - 10 minutes aft of the ship. The levelling of the curve to the right is based on full scale measurements taken ½ to 1 hour aft of the ship. The curve thus shows the three stages of dilution discussed in the item 4 above.

(MEPC II/10)

8. Introducing $t = 300$ sec in the expression Vt/L and the lower speed limit for discharge of 7 knots (3,6 m/sec.), for a ship of 360 m length the expression $Vt/L = 3$. This may be considered the lower limit of the curve for practical applications also covering barges where the lower speed limit is 4 knots. On the other side, introducing $t = 300$ sec and a speed of 16 knots (8.2 m/sec.) for a ship of 62 m length the expression $Vt/L = 40$. This may be considered the upper limit of the curve for practical applications.

9. Introducing a straight line below the curve (safe side) in the region $3 < Vt/L < 40$, this line may be presented by the equation:

$$C_D Q_D = 0{,}003\ t^{0.4} L^{1.6} V^{1.4} C_p$$

where

C_D concentration of chemical in discharge

Q_D rate of discharge

C_p maximum concentration of pollutant in wake of vessel at time after ship's passage t.

L ship length

V ship speed

t time after ship's passage = 300 sec.

For ships operating significantly outside this range of Vt/L, special considerations may be made (ref. fig.4).

10. In addition to discharges through a single discharge location at approximately 1/4 L aft of midship, between the water line and the bilge keel, model tests have been made in the Netherlands with multiple discharge points, symmetric to the ship's centre line. The dilution with two or more discharge points increases about 50% in relation to a single discharge point. The dilution equation representing such discharges is thus:

$$C_D Q_D = 0.0045\ t^{0.4} L^{1.6} V^{1.4} C_p.$$

The principle of distribution improvement is illustrated in figure 3.

11. Discharge behind the ship's propeller in the wake of the ship under the water surface should be permitted in view of the chemical properties of some residues.
The Netherlands model study shows that the dilution for such a discharge location achieved 300 seconds after the ship's passage is comparable with that obtained using single discharge location ahead of the engine room.

Proposal

12. Maximum allowable rate of discharge of noxious liquids in the wake of the ship should be determined by the following formula:

$$C_D Q_D = C_1 C_p t^{0.4} V^{1.4} L^{1.6}$$

C_D = concentration of chemical in discharge

Q_D = rate of discharge

C_p = maximum concentration of pollutant in wake of vessel at time after ship's passage (t) (10^{-6} for Category B products and 10^{-5} for Category C products).

t = 300 seconds

L = ship length

V = ship speed, where $3 < \frac{Vt}{L} < 40$

C_1 = 0,0030 for single discharge

C_1 = 0,0045 for multiple discharge, located symmetrically with respect to centre line of the ship and forward of 0,2L from the rudder stock.

Note: The formula permits the use of any consistent measurement system e.g. the international system.

13. The maximum allowable discharge rate can be determined from figure 4.

References to research

14. a) Final Report on Pollution caused by the Discharge of Noxious Liquid Substances other than Oil through normal Operational Procedure of Ships engaged in Bulk Transport. (IMCO, 1973).

b) M.C.Meijer and A. Goeman; " Model test on discharge of fluid with neutral density in the boundary layer of a light ship". (Delft Shipbuilding Laboratory, Report Nr. 392, September 1973).

c) J.A. Mercier, R.I. Hires and M. Wu; " Model study of the dilution of soluble liquids discharged from tankers" (Stevens Institute of Technology, Report Nr. CG - D - 12 - 74, September 1973).

d) J.B. Dahl et. al.; " Dilution in the Ship's wake of Tank Washings Released from M/T Esso Slagen". (Institute of Atomenergy, Kjeller, 1973).

e) A.J.M. Overgaag; " Dilution of liquids discharged from a ship. Model study on the influence of various ship parameters" (Delft Hydraulics Laboratory, Report Nr. M 1312, April 1975).

f) J.B. Dahl et. al.; " Measurement of the dilution of tank washings in the wake of M/T Esso Slagen on the 4th and 5th February 1975 ". (Institute of Atomenergy, Kjeller, March 1975).

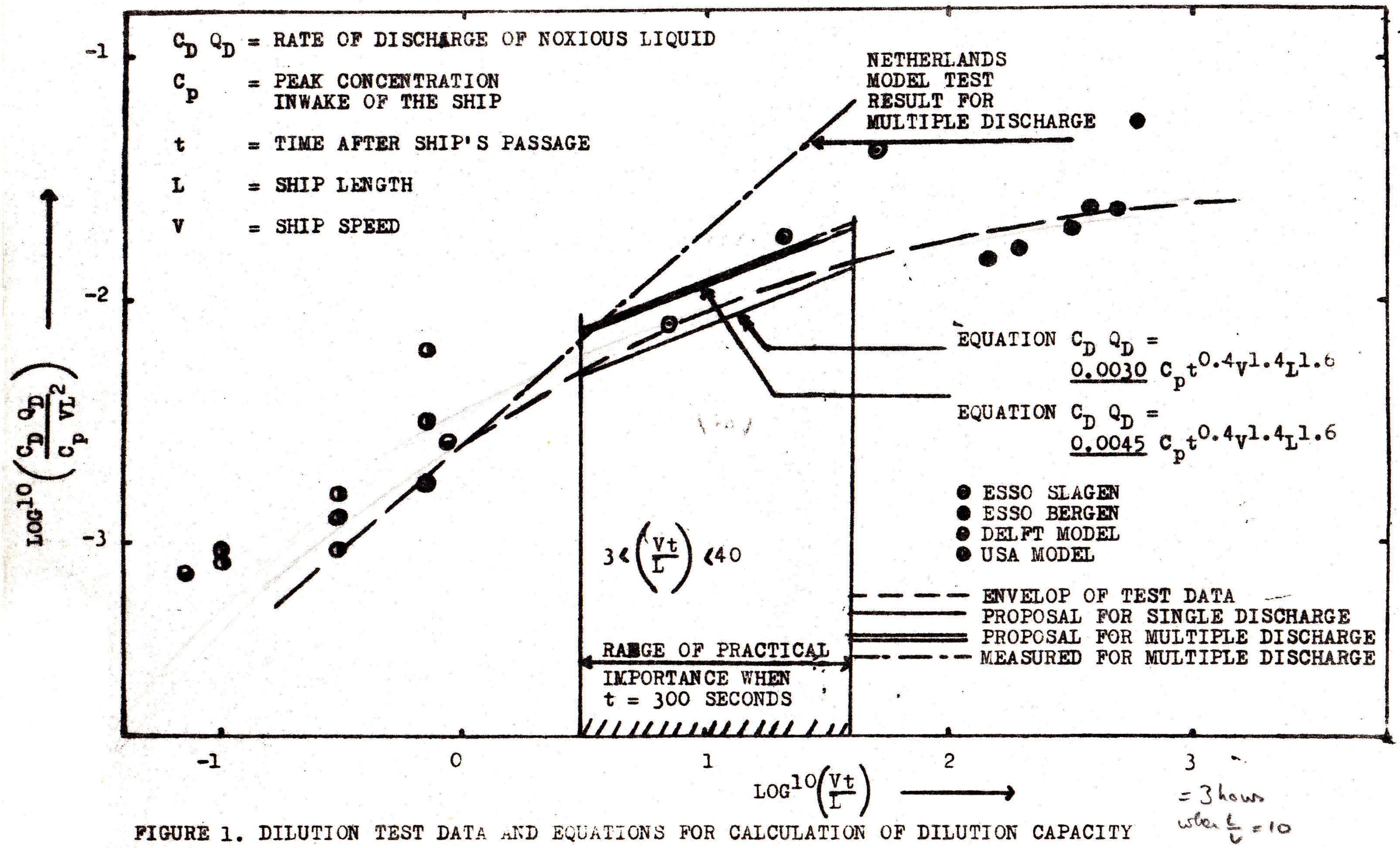

FIGURE 1. DILUTION TEST DATA AND EQUATIONS FOR CALCULATION OF DILUTION CAPACITY

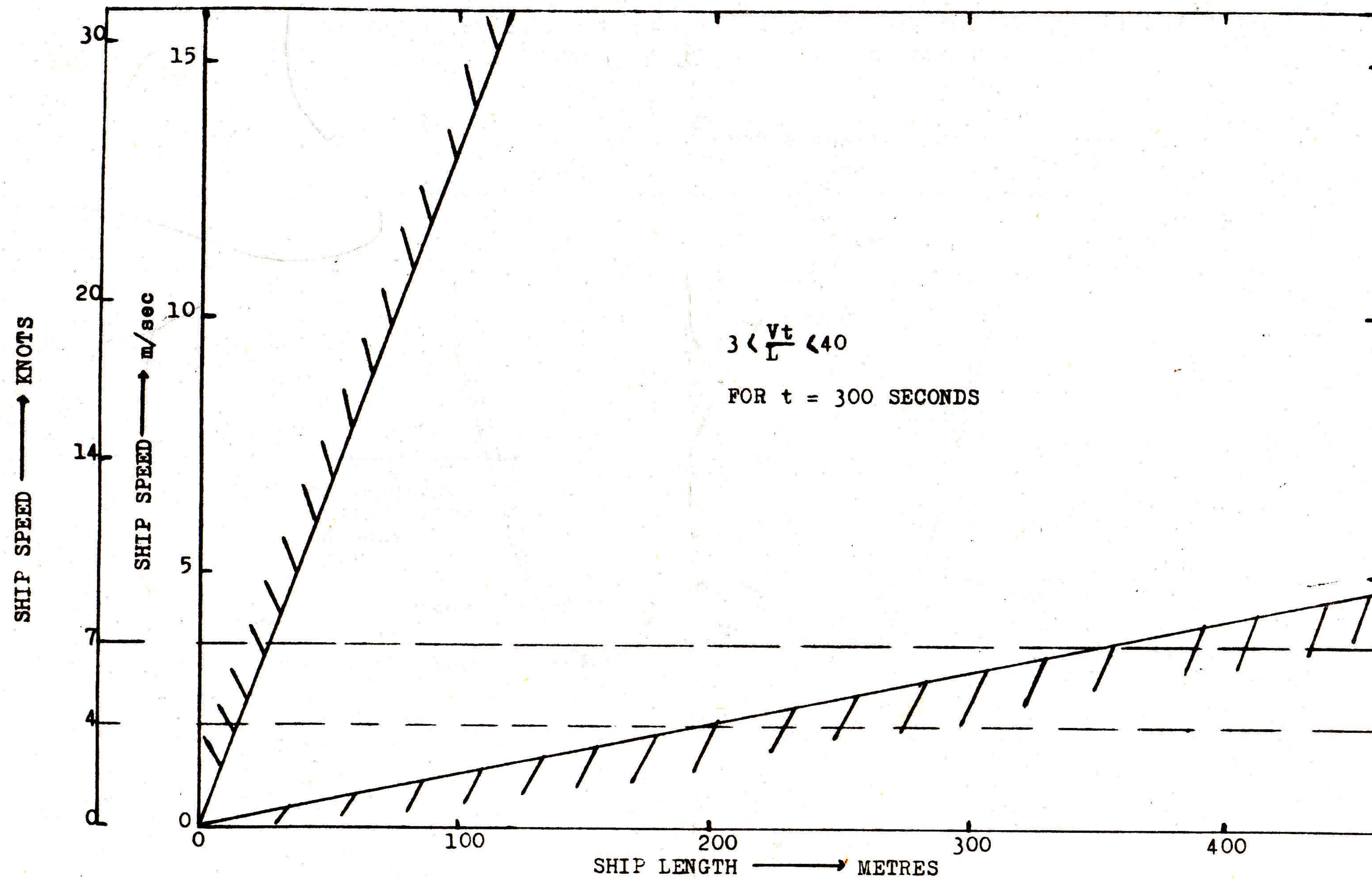

FIGURE 2. RANGE OF APPLICATION OF FORMULA FOR DILUTION CAPACITY

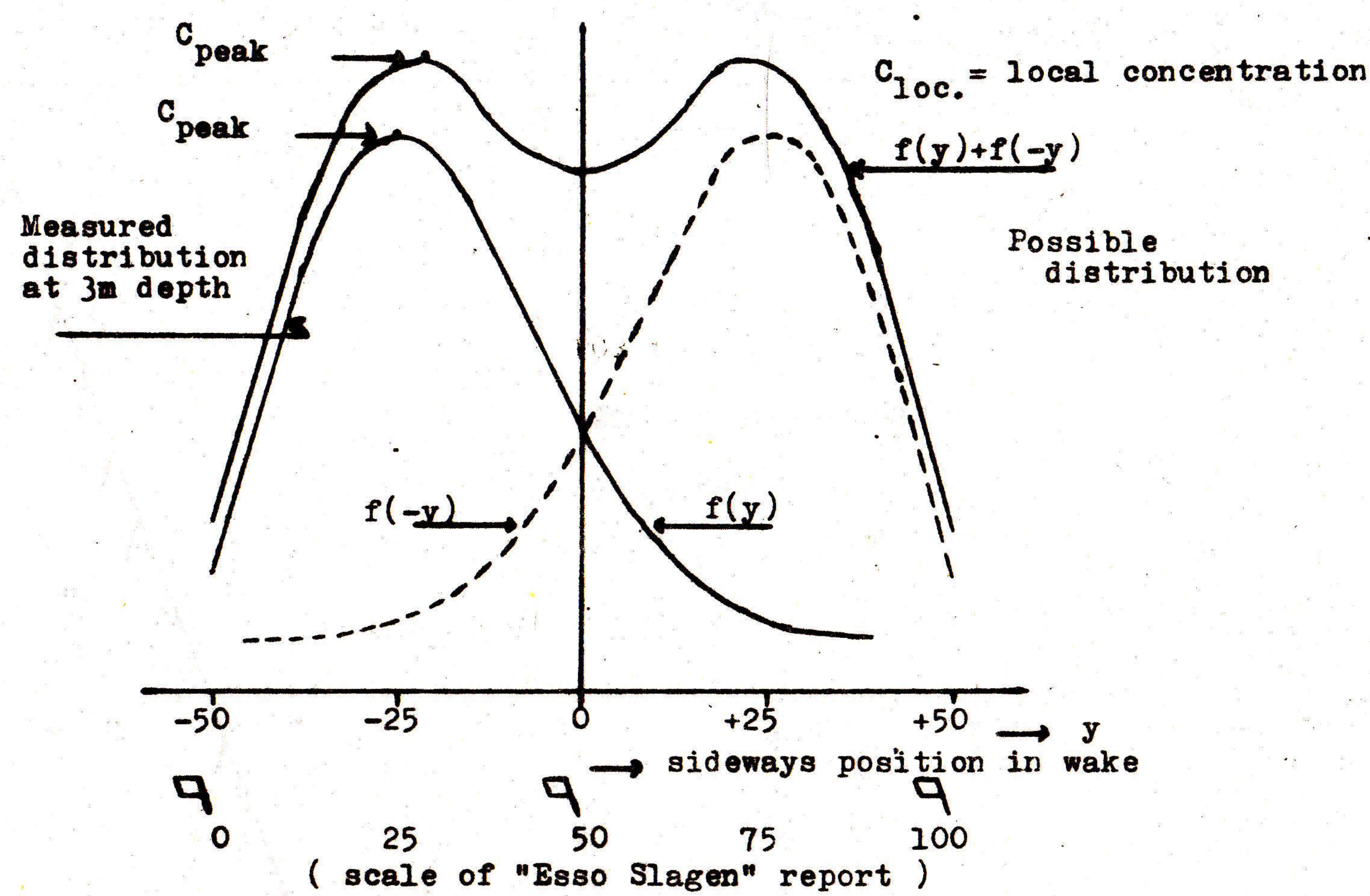

FIGURE 3. PRINCIPLE OF DISTRIBUTION IMPROVEMENT BY DISCHARGE THROUGH BOTH SIDES OF THE SHIP

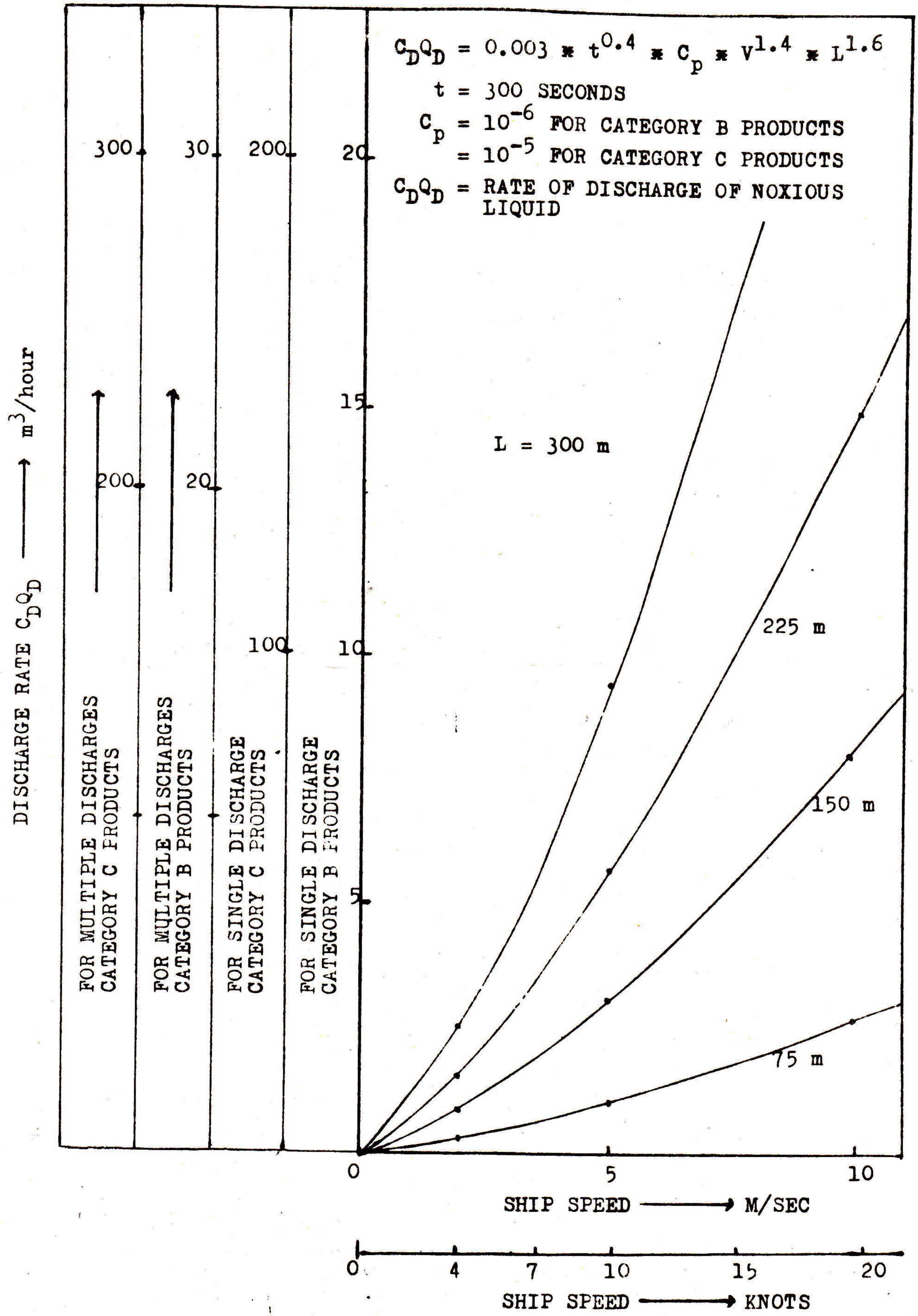

FIGURE 4. GRAPHS FOR DETERMINATION OF MAXIMUM ALLOWABLE DISCHARGE RATE