CHAPTER 2

HYDROTHERMAL MODELLING AND SCALING CRITERIA

2.1 Introduction.

The heat carried by cooling water discharge may disperse in the receiving body of water by several different mechanisms. The main phenomena are jet diffusion, bouyant plume, convective spread, mass transport by ambient currents, ambient turbulence and surface cooling. It is not possible to simulate simultaneously all these processes in a hydrothermal model as the scaling requirements for these phenomena are not totally compatible. However, correct scaling of the predominant processes and proper precautionary compromises with the remaining ones will assure meaningful results from the model tests. The scaling parameters assosiated with the six mechanisms mentioned above are evaluated in connection with the Thermal Hydraulic Model to be described in the following sections.

2.2 Similarity parameters.

2.2.1 Geometric similarity.

To properly simulate the effluent plume shape and the effects of outfall and sea geometry, undistorted geometric similarity is required. This has been satisfied by using the same scale for the horizontal and vertical dimensions.

That is,

$$\frac{L_{hm}}{L_{hp}} = \frac{L_{vm}}{L_{vp}} = L_{hr} = L_{vr} = L_r \qquad (2.1)$$

where:

L = length

h = subscript denoting a horizontal component of length

v = subscript denoting a vertical component of length

m = subscript denoting model

p = subscript denoting prototype

r = subscript denoting ratio of model to prototype

A value of 1/100 for L_r has been chosen to achieve reasonable model size.

2.2.2 Densimetric Froude Number.

For water flow with a free surface, the controlling parameter is the gravity and not the viscosity of the fluid. Therefore, the value of Densimetric Froude Number of the model may be taken to be equal to that of the prototype.

$$F_m = \left(\frac{U}{\sqrt{\frac{\Delta\rho}{\rho_a} g L}}\right)_m$$

$$F_p = \left(\frac{U}{\sqrt{\frac{\Delta\rho}{\rho_a} g L}}\right)_p$$

For similar flow $F_m = F_p$

$$\left(\frac{U}{\sqrt{\frac{\Delta\rho}{\rho_a} g L}}\right)_m = \left(\frac{U}{\sqrt{\frac{\Delta\rho}{\rho_a} g L}}\right)_p$$

$$\frac{U_m}{U_p} = \frac{\left(\sqrt{\frac{\Delta\rho}{\rho_a} gL}\right)_m}{\left(\sqrt{\frac{\Delta\rho}{\rho_a} gL}\right)_p}$$

$$U_r = \left(\sqrt{\frac{\Delta\rho}{\rho_a} gL}\right)_r \qquad (2.2)$$

where:

F = Densimetric Froude Number

U = discharge velocity

g = acceleration of gravity

$\Delta\rho$ = density difference between the ambient and the hot water

ρ_a = density of the ambient water

Because of the density difference, the fluids in the prototype and the model are not exactly the same. However, as the difference is small, it can simply be assumed that the two fluids are identical in density.

Thus $$(\rho_a)_m = (\rho_a)_p$$

then $$\left(\sqrt{\frac{\Delta\rho}{\rho_a}}\right)_m = \left(\sqrt{\frac{\Delta\rho}{\rho_a}}\right)_p$$

and equation (2.2) may be reduced to

$$U_r = \sqrt{L_r}$$

For $L_r = 1/100$, U_r, according to the hydrothermal model, will be equal to 1/10 . This ensures correct simulation of mass transport by ambient currents and jet diffusion.

2.2.3 Reynolds similarity.

Simulation of viscosity effects in fluid motion requires that the following relationships hold:

$$Re = UL/\nu$$

where $$Re_m = U_m L_m/\nu_m$$

$$Re_p = U_p L_p/\nu_p$$

and $$Re_r = U_r L_r/\nu_r$$

For similar flow $$Re_r = 1.0$$

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so that $$U_r = 1.0 \times \nu_r/L_r \qquad (2.3)$$

where ν_r = ratio of kinetic viscosity in the model to that in the prototype

Since $\nu_r = 1.0$ when the temperature of the water is the same in both model and prototype. It is apparent that equation (2.3) contradicts the requirement of equation (2.2). However, in open channel flow, the viscosity effect is negligible if the Reynolds Number is above a certain critical value. Analysis by Sharp (10) shows an critical value of 5,000 whereas Ackers (8) quotes a lower limit of 2,500 for jet. For the ambient current flow, a critical value of 600 is stated by Ackers (8).

The length scale, $L_r = 1/100$, has been chosen so that the value of Reynolds Number in the model are greater than these critical values. Consequently, the viscous effects are considered unimportant relative to the other factors of heat dispersion process.

2.3 Boundary roughness.

For steady flow in open channel, the effect of boundary roughness can be represented by Manning's equation as follows:

$$V = \frac{1}{n} R^{2/3} S^{1/2} \qquad (2.4)$$

where:

V = average flow velocity, m/sec

R = hydraulic radius, m

S = slope of the bottom of the channel

n = Manning's Roughness coefficient

If the open channel is excessive in width, the value of hydraulic radius is almost identical to the value of depth.

Then,
$$V = \frac{1}{n} D^{2/3} S^{1/2}$$

where V and D are known quantities and the slope S is generally almost similar to slope of the bed of the sea. If the model and the prototype are of perfect similarity, the value of S for the model equals to that of the prototype. The remaining difficulty is how to specify 'n_{model}' as the value of '$n_{prototype}$' is unmeasureable. Therefore, tests were carried out to choose the materials which would make the bed realize the depth and velocity required (for details, see Appendix. D).

2.4 Model design.

2.4.1 Basin.

Simulation may be obtained by making Froude Number of the model equal to that of the prototype. Table 2.1 shows dimensions of the test basin and quantities involving the discharge and tidal flow.

2.4.2 Cooling water system.

To reduce the parameters under investigation, the following conditions are formulated:

1. Temperature in the model must be equal to that in the prototype.

2. Scales being used in the cooling water system model must be identical to of those in the basin model.

3. Ratio of the discharge velocity to the current speed of the sea (U/V) in the model must be the same as that of the prototype.

From these three criteria, the size of the nozzle, the corresponding discharge velocity, mass flow rate of cooling water, Reynolds Number and heat consumption in the model could be obtained. Table 2.2 illustrates the results of the hydrothermal modelling of the problem under investigation. (for details, see Appendix. B).

TABLE 2.1

DIMENSIONS AND QUANTITIES OF TIDAL AREA
FOR MODEL 1 : 100

Item	Unit	Ratio	Prototype	Model
Length	m	L_r	400	4
Width	m	L_r	200	2
Area	m^2	L_r^2	80,000	8
Avg. Depth	m	L_r	8	0.08
Avg. Tide Velocity	m/sec	$L_r^{1/2}$	1	0.10
Avg. Tide Discharge	m^3/sec	$L_r^{5/2}$	1,600	0.016

Note Average Tide Discharge was evaluated from the product of cross section area and average tide velocity,

$$Q = A \times V$$

TABLE 2.2

Variation in Pipe Diameter, Flow Velocity, Reynolds Number and Rate of Heating Required for Model 1 : 100

	d - m	U - m/sec	Re x 10^{-4}	$\frac{U}{V}$				
				$V_p = 0.6$ m/sec	$V_p = 0.8$ m/sec	$V_p = 0.9$ m/sec	$V_p = 1.0$ m/sec	$V_p = 1.2$ m/sec
Prototype								
	3	4.93	1885	8.21	6.16	5.48	4.93	4.11
	4	2.78	1420	4.63	3.48	3.09	2.78	2.32
	5	1.78	1130	2.97	2.23	1.98	1.78	1.48
Model 1 : 100	0.03	0.49	2.24	8.21	6.16	5.48	4.93	4.11
$\dot{m} = 0.349$ Kg/sec	0.04	0.28	1.68	4.63	3.48	3.09	2.78	2.32
$\dot{P}_m = 14.6$ kw.	0.05	0.18	1.35	2.97	2.23	1.98	1.78	1.48