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MINIMIZING THE ENVIRONMENTAL IMPACTS OF THE THERMAL DISCHARGE AT POWER STATIONS USING DIFFUSERS

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ABSTRACT

This research proposed a new scheme (multi port diffusers) to help in minimizing the impacts of power plants' effluent. It was intended by introducing such a scheme to achieve an effective reduction to the outlet water temperature to comply with law 48/1982. An experimental investigation was carried out in the Hydraulics Research Institute (HRI) where a physical model was implemented. Several runs were executed to investigate the effect of the proposed scheme on the reduction of the water temperature and wave height. Measurements were undertaken in the vicinity of the proposed scheme. The measurements were analyzed and were subjected to a regression analysis, from which a formula was developed to predict the temperature reduction and the formed wave height. The formula was used to calculate the temperature and wave height. For comparison purposes, the measured and computed values were given. Their correlation line was 45 °.

تستخدم الدولة حاليا حوالى ٧ مليار متر مكعب من قنوات المياة العذبة و ٣ مليار متر مكعب من مياة البحار سنويا لاغراض التبريد لمحطات توليد الكهرباءحيث تستخدم المياة في تبريد المكثفات ثم يعاد صرفها الى تلك القنوات ولكن مع زيادة درجة حراراتها بحوالى عشر درجات سليزية عن درجة حرارة المياة العذبة، مما يؤدى الى اضرار بيئية واقتصادية عديدة منها تقليل نسبة الأكسجين الذائب الضروري للحياة في البيئة المائية وتغيير فى جودة المياة. والغرض من البحث هو دراسة كيفيه تقليل درجة حرارة داخل مخارج محطات القوي الكهربائيه قبل ان تصب تصرفها الساخن في القنوات المائية بحيث يقل الامتداد الحراري إلي اقل ما يمكن ويتم الوصول الى درجات الحرارة المسموح بها وذلك لتلبية التوسعات المتوقعة لمحطات الطاقة الكهربية وما يصاحبها من زيادة فى التصرفات الساخنة حيث حدد القانون ٤٨ لسنة ١٩٨٢ لوزارة الموارد المائية والرى درجات الحرارة المسموح بها فى المجارى المائية بحيث لا تزيد درجة حرارة المياة عن ٣٥ درجة سليزية، ولا ترتفع درجة الحرارة فى منطقة الخلط الحرارى على ٥ درجات سليزية عن حرارة مياة المجرى المائى. استخدم البحث اسلوب جديد لتبريد المياة الساخنة داخل قناة المخرج لتقليل التلوث الحرارى حيث تم اختبار وضع ماسورة متعددة الفتحات (diffusers) فى قاع المخرج تقوم باضافة تصرف مياة (بدرجة حرارة المجرى المائى) الى التصرف الساخن حتى يحدث اضافة منطقة خلط جديدة (قبل منطقة الخلط العادية داخل المجرى المائى) مما يقلل من درجة حرارة تصرف المياة الساخنة قبل ان تصب فى المجرى المائى. وقد تم تصميم النموذج الطبيعىالهيدروليكى وانشاء حوض للتجارب لدراسة العوامل المؤثرة حيث تم قياس كلا من ارتفاع درجة حرارة المياة (t) و ارتفاع الموجة الرئسية المتكونة (h) وقد تم دراسة الظاهرة الجديدة الغير معتادة والتى تعتمد على تحليل سبعة عوامل هيدروليكية مؤثرة على الظاهرة وايجاد معادلة عامة لحساب الخفض المتوقع لدرجة الحرارة وكذلك الموجة المتكونة لتبريد المياة الساخنة داخل قناة المخرج.

Keywords: environmental, thermal, power plants, cooling systems, physical model, diffusers

1. INTRODUCTION

Worldwide impacts from the effluent water of the cooling systems of electrical power plants were documented. Likewise it is the case in Egypt where many power plants suffer from similar problems i.e. Nubaria power plant and Eldabaa power plant [5].

About 10 °C (Celsius degrees) above ambient water temperature was recorded and reported by the different existing plants in Egypt. This problem becomes critical in seas, lakes, and gulfs where the current of the ambient water is small and lower mixing is evident. This problem also appears on a larger scale in narrow channels where thermal discharge reaches to the other side bank and spreads a long distance, i.e. Nubaria power plant [7].

Moreover, in summer months, the average water temperature in the Nile River and the canals is 28 °C. That means, at the disposal of hot water, the temperature will reach 38 °C or more [4].

On the other hand, power plants are of significant importance to Egypt to assist in the development projects.

To enhance the economy of Egypt and to raise the living standards of the increasing population, more and more power plants are to be implemented in the near future [6].

In the moment, about 7 milliards m^3 of water and 3.7 milliards m^3 from the seas are yearly needed for cooling purposes to the existing power plants along the Nile River reaches and its branches. This amount is expected to increase in the coming years after introducing new power plants in operation. Consequently, more and more problems will be created with negative environmental impacts with a larger scale [1].

It was thus thought of implementing diffusers to reduce the temperature rise to reach the permissible standards as dictated by the requirements of the environmental law No 48/1982. It specified that the maximum allowable temperature rise, above ambient water, is 5 °C with a maximum discharge temperature of 35 °C [2].

The HRI, thus initiated this study as a contribution to the development plan of the Ministry of Water Resources and Irrigation (MWRI). The objective of the study was to introduce a new technique (multi port diffusers) to reduce the temperature of thermal water before discharging it into rivers, Figure (1) and (2).

In this paper the following will be presented:

- The theoretical background
- The constructed model
- The formulae that described the physical phenomena

2. THE THEORETICAL BACKGROUND

The following section introduces the basic equations that described the physical phenomena.

It is well known that the relative thermal concentration $\frac{t}{T}$ is a function of the following parameters:

$$\frac{t}{T}, \frac{h}{H} = f(Q, V, H, B, q, U, D, L, N) \qquad (1)$$

Where:

$\frac{t}{T}$ = thermal concentration [-]
$\frac{h}{H}$ = wave height [-]
Q = discharge of outlet [m3/S]
V = water velocity of outlet [m/S]
H = water depth of outlet [m]
h = height of the formed wave [m]
B = breadth of outlet [m]
q = discharge of diffusers [m^3/S]
U = water velocity of diffuser [m/S]
D = diameter of diffusers [m]
L = length of diffusers [m]
N = number of diffusers [-]

From the literature, the relative thermal concentration $\frac{t}{T}$ at any section downstream the outlet was defined as follows [9]:

$$\frac{t}{T} = \frac{Ts - Tr}{To - Tr} \qquad (2)$$

Ts = temperature at the measured section [°C]
Tr = temperature at river [°C]
To = temperature at the outlet [°C]

Also, from the literature, a dimensionless thermal concentration was given by a formula that was reported by Miller, Brighouse, (1984) [7] that is given as follows:

$$\frac{t}{T} = f(N, \frac{H}{B}, \frac{L}{B}, \frac{D}{B}, \frac{V}{U}, F) \qquad (3)$$

Where:

F = densimetric Froude number [-]

These were the main formulae upon which the present research was based.

3. PHYSICAL MODEL AND MEASURING DEVICES

This section displays the constructed Physical model together with the measuring devices [3].

Regarding the physical model, different multi port diffusers configurations were proposed and were physically modelled together with the connected channel part. The efficiency of these configurations was investigated in a fixed bed flume, in the Hydraulics Research institute (HRI). The flume is 10 m long, 0.5 m wide and 0.7 m deep. The power plant condenser was represented using an electric boiler to heat up the water. Photo (1) shows the construction phase of the model while photos (2) and (3) show the model layout. The power plant condenser was represented using an electric boiler to heat up the water, photo (4).

As for the measuring devices, temperature sensing probes (thermometer) were used to measure the water temperature distribution in the flume, photo (5). On the other hand, the multi port diffusers and boiler (outlet) discharges were measured by two electromagnetic flow meters, photo (6). The velocities were measured using an electromagnetic current meter, photo (7).

4. EXPERIMENTAL WORK AND RESULTS

Several runs were carried out and measurements were undertaken to record the temperature and wave heights at different locations for the various diffusers configurations using: shallow condition $\frac{H}{B}=0.2$ and deep condition $\frac{H}{B}=0.5$

The measurements were analyzed and the results are given here as follows:

The diameter ratio of the ports $(\frac{D}{B})$ is inversely proportional to the thermal reduction ratio $\frac{t}{T}$ and wave height ratio $\frac{h}{H}$. This was noticed during testing deep and shallow conditions. Also, the thermal reduction was 17% to 20% and 10 % to 12%at shallow and deep conditions, respectively. It should be also further noted that the formed wave height was 1% to 3% at the shallow conditions and no wave was detected at the deep conditions. The effect of the port diameter $(\frac{D}{B})$ on $\frac{t}{T}$ are given on Figure (3), while Figure (4) relate the $\frac{D}{B}$ to $\frac{h}{H}$ at (N=6, $\frac{L}{B}=2.5$, $\frac{q}{Q}=0.25$).

The number of ports (N) is inversely proportional to the thermal reduction and wav height ratio $(\frac{h}{H})$ in shallow and deep conditions. The thermal reduction was 18% to 23% and 10% to 13% at shallow and deep conditions, respectively. It is also to be noted that the formed wave height was 2% to 5% at the shallow condition but no wave was formed during testing the deep condition. The effect of the number of ports (N) on $\frac{t}{T}$ is represented on Figure (5) while Figure (6) presents the effect of N to $\frac{h}{H}$ at (N=6, $\frac{L}{B}=2.5$, $\frac{q}{Q}=0.25$).

The distance between the ports ratio $(\frac{L}{B})$ is directly proportional to the thermal and inversely proportional to the wave height both in shallow H and deep conditions. The thermal reduction was 20% to 23%.and 11% to 13% during testing both the shallow and deep conditions, respectively. The formed wave height was 2% to 4% at the shallow condition and no wave was formed at the deep condition. The effect of the distance between the ports ratio $(\frac{L}{B})$ on $\frac{t}{T}$ is given on Figure (7) while the effect of $\frac{L}{B}$ on $\frac{h}{H}$ at (N=6, $\frac{D}{B}=0.02$, $\frac{q}{Q}=0.25$) is given on Figure (8).

The densimetric Froude number (F) is directly proportional to thermal reduction and the wave height both in shallow and deep conditions. The thermal reduction was 17% to 22%.and 10% to 13%.at shallow and deep conditions. The formed wave height was 1% to 3%.at shallow condition and no wave was formed at the deep condition. The effect of the densimetric Froude number (F) on $\frac{t}{T}$ is given on Figure (9) while Figure (10) presents the effect of F on $\frac{h}{H}$ at $\frac{q}{Q}=0.25$.

The ambient diffuser velocity ratio $(\frac{V}{U})$ is inversely proportional to the thermal reduction and wave height in shallow and deep conditions. The thermal reduction was 17% to 22%.and 10% to 13%.at shallow and deep conditions, respectively. The formed wave height was 1% to 2%.at shallow condition and no wave was formed at the deep condition. The effect of the ambient-diffuser velocity ratio $(\frac{V}{U})$ on $\frac{t}{T}$ is given on Figure (11) while present the effect of $\frac{V}{U}$ on $\frac{h}{H}$ at $\frac{q}{Q}=0.25$ is given on Figure (12).

As for the Vertical mix, it was noticed that the thermal mixing depended on the formed wave height. The dimensionless terms depended on the vertical mix are $\frac{D}{B}$, N, F and $\frac{V}{U}$.

From the experiments, three types of mixing processes were distinguished. These were:

Type (1), the jet height is less than the water level and the entrainment of thermal water to ambient water along the jet height forms a thick layer, Figure (13).

Type (2), the jet height is equal to the water level and the entrainment of thermal water to ambient water along the jet height, forms a thick layer, Figure (14).

Type (3), the jet height is greater than the water level and the entrainment of the thermal water to ambient water along the jet height forms a thin layer, Figure (15).

As for the longitudinal mix, it was noticed that the turbulence in the thermal water was the important mixing mechanism after the vertical mix. The strength of the ambient turbulence mechanism depends on a number of factors that are related to the geometry of the ambient (L), Figure (16). The dimensionless term depended on the longitudinal mix is $\frac{L}{B}$. Also, it was noticed that:

- The effect of $(\frac{D}{B})$, (N) and $(\frac{V}{U})$ are inversely proportional to $\frac{t}{T}$ and the effect of $(\frac{L}{B})$ and (F) are directly proportional to $\frac{t}{T}$

  The dimensionless terms depended on the vertical mix are $\frac{D}{B}$, N, F and $\frac{V}{U}$, the dimensionless term depended on the longitudinal mix $\frac{L}{B}$
- Shallow water is more effective than deep water in the thermal mixing process
- *The effect of* $(\frac{D}{B})$, *(N),* $(\frac{L}{B})$ *and* $(\frac{V}{U})$ *are inversely* proportional to $\frac{h}{H}$. The effect of (F) is directly proportional to $\frac{h}{H}$. The results indicated that the formed wave height presented the mechanism of mixing as it is strong enough to make a complete vertical mix at shallow condition but not strong enough to make a complete vertical mix at the deep condition which means that the effect of $\frac{D}{B}$, N, F and $\frac{V}{U}$ increase at the shallow conditions than the deep conditions

5. DEVELOPMENT OF THE EMPIRICAL FORMULAE

The measured quantities in this study were subjected to a regression analysis to obtain empirical formulae that can be used for predicting the reduction of temperature and wave height. The dimensionless terms

$$\frac{t}{T},\frac{h}{H}=F(N,\frac{q}{Q},\frac{H}{B},\frac{L}{B},\frac{D}{B},\frac{V}{U},F) \qquad (5)$$

Where:

$\frac{t}{T}$ = thermal concentration [-]

$\frac{h}{H}$ = wave height [-]

Q = discharge of outlet [m^3/S]

V = water velocity of outlet [m/S]

H = water depth of outlet [m]

h = height of the formed wave [m]

B = breadth of outlet [m]

q = discharge of diffusers [m^3/S]

U = water velocity of diffuser [m/S]

D = diameter of diffusers [m]

L = length of diffusers [m]

N = number of diffusers [-]

DATA FIT which is statistical software packages from Oakdale engineering was used to develop the formula. The formulae developed for $\frac{t}{T}$ and $\frac{h}{H}$ at

$\frac{q}{Q}$=0.25

The formulae for predicting heat reduction is:

$$\frac{t}{T}=+0.002692\left(\frac{L}{B}\right)+0.417\left(\frac{q}{Q}\right)+0.0000212(F)-0.00069(N)-0.324\left(\frac{D}{B}\right)-0.1045\left(\frac{V}{U}\right)-.163\left(\frac{H}{B}\right)+0.133 \qquad (6)$$

Where the correlation factor between measured and predicted values is above 90% (R^2>0.9).

The obtained formulae for predicting wave height is:

$$\frac{h}{H}=Exp\,(-0.204\,(N)-70.86\left(\frac{D}{B}\right)-6.88\left(\frac{H}{B}\right)-0.0177\left(\frac{L}{B}\right)-0.000247(F)+2.2929\left(\frac{q}{Q}\right)-17.9929\left(\frac{V}{U}\right)+1.7765) \qquad (7)$$

Where the correlation factor between measured and predicted values is above 90% (R^2>0.9). The differences between measured and predicted values plotted against others in figures (17) and (18) the line of equality drowns for each.

6. CONCLUSIONS

From the above, the following conclusions were obtained:

1- The new technique is considered to identify a new phenomenon of mixing that needs to find the sensitivity of the temperature reduction and wave height.

2- The developed formula could to predict the temperature reduction and the formed wave height depending on seven dimensionless parameters.

3- The new technique can be used at different sites of power plants to comply with law 48/1982 and minimize the ecological, hydraulically impacts and water quality change.

7. RECOMMENDATIONS

1- The formulae need to be verified to satisfy the actual field condition.

2- Some another factors of multi port diffusers need to be studied such as the angle of the ports and its effect.

3- Another types of multi port diffusers such as staged and alternating diffusers should be studied.

8. REFERENCES

[1] Edward, A. laws, John Wiley. (1993) "Aquatic pollution" USA.

[2] El-alfy, K. S. , Sobeh M. F., Khattab A. F., Saad M. B and Shawky Y.M (2002) " Study of Near Field Performance of Multi-ports Diffuser in Relatively Deep River"

[3] Chow, V. T (1959) "Open-Channel Hydraulics" University of Illinois

[4] Hydraulics Research Institute. (2003) "Cairo North Power Plant, Cooling System, Module I & II", Delta Barrage.

[5] Hydraulics Research Institute. (2003) "New Nubaria Power Plant I & II Cooling System", Delta Barrage.

[6] Hydraulics Research Institute. (2006) "Tebben Power Plant Model Study", Delta Barrage.

[7] Hydraulics Research Institute. (2001) "Nubaria Power Plant-Final report", Delta Barrage

[8] Miller, D. S, Brighouse, B, A. (1984) "Thermal Discharge"

[9] Sobeh M. F, El-alfy, K. S.,., Khattab A. F., Saad M. B and Shawky Y.M (2001)" Thermal Discharge from multi-port Diffuser into Shallow Water Rivers"

9. NOTATION

Q = discharge of outlet [m^3/S]
V = water velocity of outlet [m/S]
H = water depth of outlet [m]
h = height of the formed wave [m]
B = breadth of outlet [m]
q = discharge of diffusers [m^3/S]
U = water velocity of diffuser [m/S]
D = diameter of diffusers [m]
L = length of diffusers [m]
N = number of diffusers [-]
F = densimetric Froude number[-]
Tr = temperature at river [°C]
To = temperature at the outlet [°C]
Ts = temperature at the measured section [°C]
S. c = shallow condition where $\frac{H}{B}$ =0.2
D. c = deep condition where $\frac{H}{B}$ = 0.5

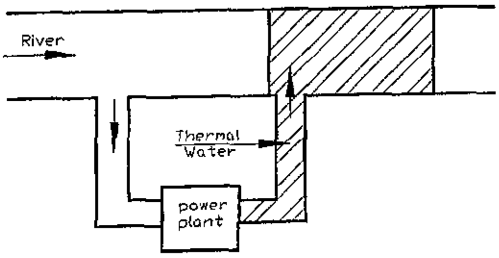

Fig (1) Thermal water discharge to ambient water of river directly (ordinary outlet)

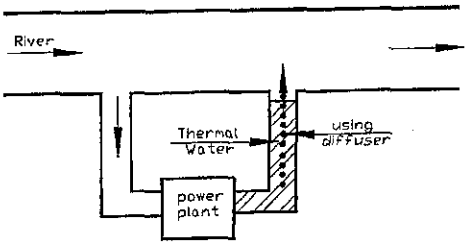

Fig (2) Thermal water mix with ambient water at the outlet channel with diffusers

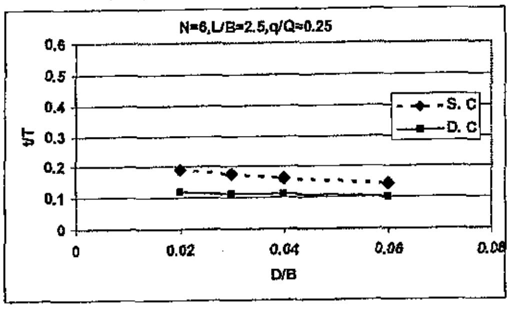

Fig (3) Effect of $(\frac{D}{B})$ on $(\frac{t}{T})$

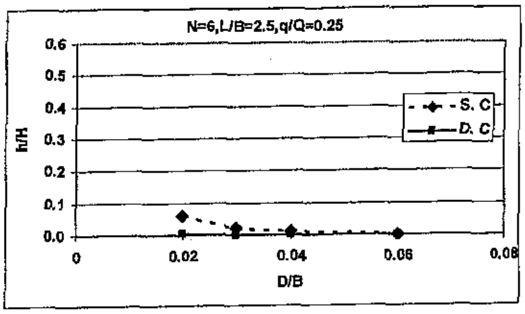

Fig (4) Effect of $(\frac{D}{B})$ on $(\frac{h}{H})$

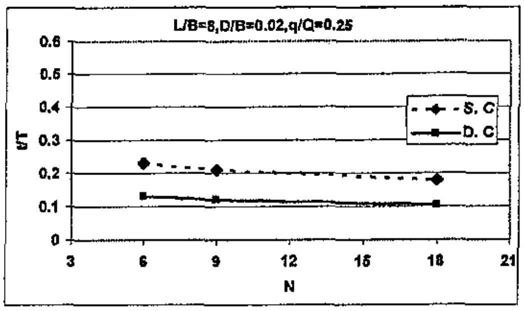

Fig (5) Effect of (N) on ($\frac{t}{T}$)

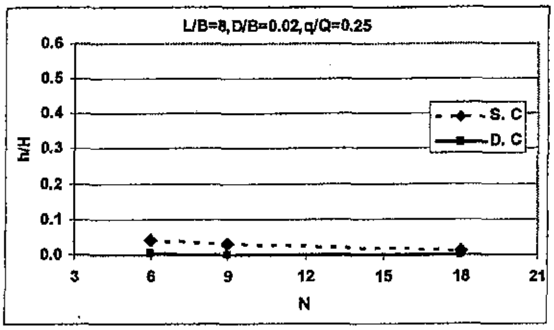

Fig (6) Effect of (N) on ($\frac{h}{H}$)

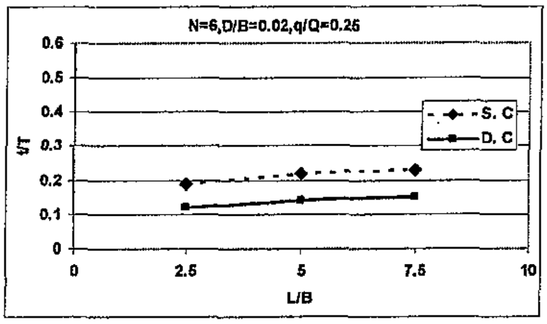

Fig (7) Effect of ($\frac{L}{B}$)on ($\frac{t}{T}$)

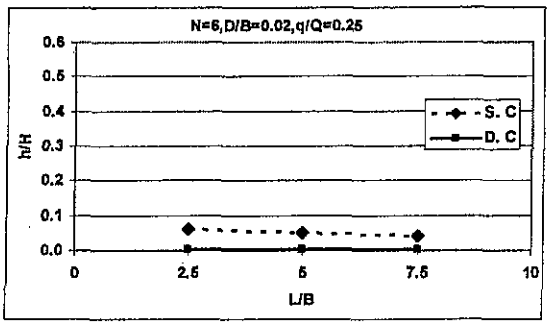

Fig (8) Effect of ($\frac{L}{B}$)on ($\frac{h}{H}$)

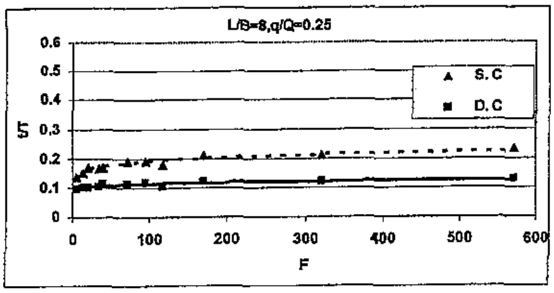

Fig (9) Effect of (F) on ($\frac{t}{T}$)

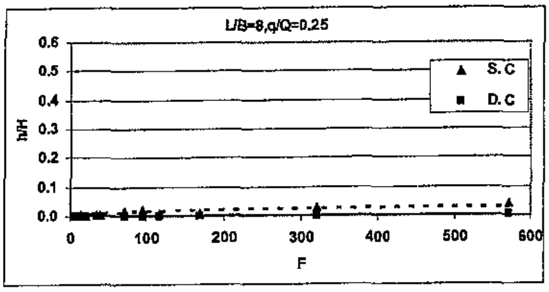

Fig (10) Effect of (F) on ($\frac{h}{H}$)

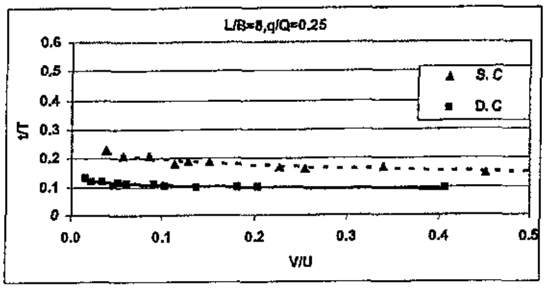

Fig (11) Effect of ($\frac{V}{U}$) on ($\frac{t}{T}$)

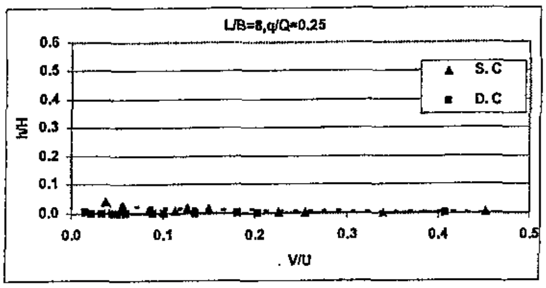

Fig (12) Effect of ($\frac{V}{U}$)on ($\frac{h}{H}$)

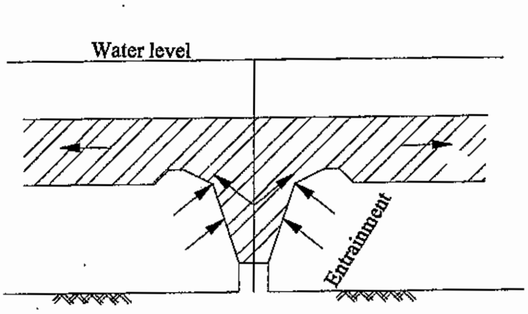

Fig (13) Type 1 of mixing

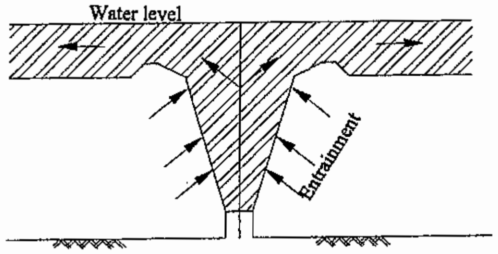

Fig (14) Type 2 of mixing

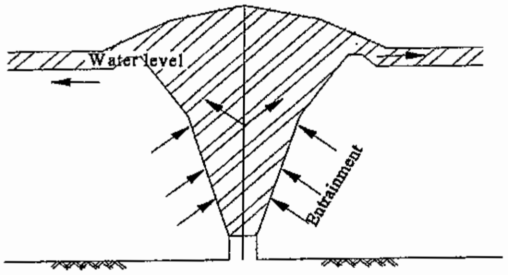

Fig (15) Type 3 of mixing

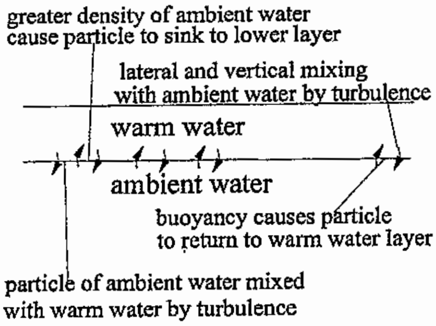

Fig (16) Longitudinal mix

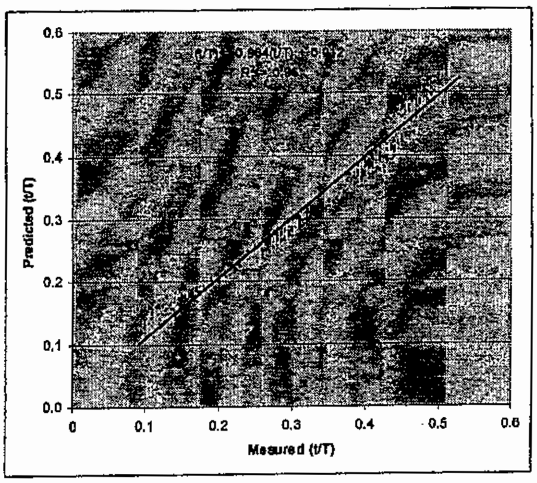

Fig (17) Measured and calculated values of $(\frac{t}{T})$

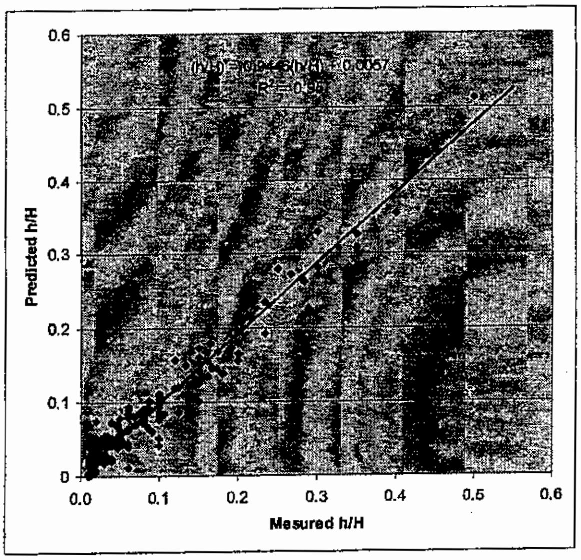

Fig (18) Measured and calculated values of $(\frac{h}{H})$

Photo (1) Model construction

Photo (2) Model layout from upstream

Photo (5) Thermometer

Photo (3) Model layout from downstream

Photo (6) Electromagnetic flow-meter

Photo (4) Boiler

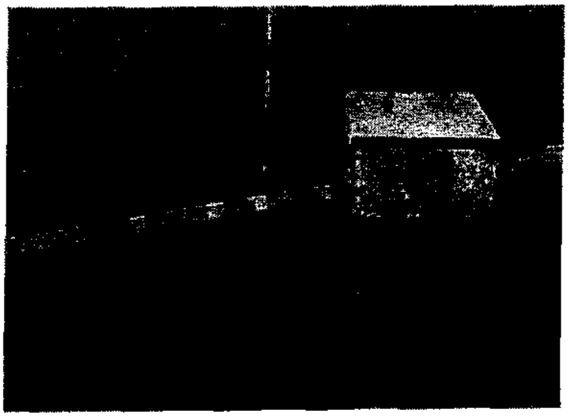

Photo (7) Electromagnetic current-meter