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THEORETICAL APPROACH TO MSF STAGES EFFICIENCY CALCULATION

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ABSTRACT

A general model of non equilibrium losses for MSF stages is developed.

The submergence loss calculation is treated independently from boiling point elevation calculation starting from the flashing rate analysis.

The correlation obtained is compared to the other semi-empirical models on the basis of experimental values from existing running plants.

INTRODUCTION

One of the major problems connected to the MSF units process design is the evaluation of the stage efficiency.

The solution of this problem was the objective of several studies and researches in the past years coming from the first experience of the Office of Saline Water.

The initial approach to the efficiency calculation was the endeavour to correlate the main parameters involved in the phenomena, so:

- stage length
- stage thermal level
- stage flashdown
- brine mass specific flowrate
- brine depth

through empiric formulas derived from laboratory experimental data.

In principle the main obstacle met with was the extension of the validity of the equations to the full range of running conditions for different plants.

This is a typical consequence of an empirical approach to a process problem.

The semiempirical model object of this study takes advantage respect to the others existing empirical ones for the capability

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to be applied to the whole field of MSF plants running conditions.

SYMBOLS

T_s = Brine temperature

T = Brine temperature deducted by boiling point elevation (°C)

T_r = Brine recycle temperature (°C)

T_o = Steam equilibrium temperature at stage pressure (°C)

Δ' = Boiling point elevation

h_o = brine height (m)

α = Kinetic constant rate ($kg/m^3 s °C$)

γ = $\frac{dT}{dP}$ = Temperature pressure gradient $\frac{°C}{kg/cm2}$

B = Stage width (m)

ΔH = Heat of evaporation ($\frac{kcal}{kg}$)

W_s = Brine flow (t/h)

C_{ps} = Specific heat of brine (kcal/°C kg)

r_s = flash rate (kg/sm^3 °C)

z = Horizontal coordinate (m)

y = Vertical coordinate (m)

L = Stage length (m)

SUFFIXES

i = Inlet

f = Outlet

THEORETICAL MODEL APPROACH

In fig. 1 a typical MSF stage temperatures profile is shown.

The vapour is in general partially released either from the surface or from the bulk of pool brine.

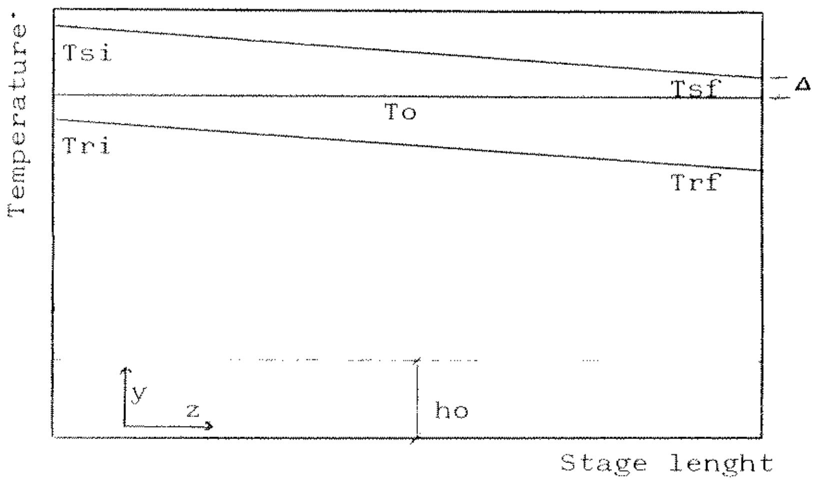

Fig. 1. Typical MSF stage temperatures profile.

It is possible to define

$$T^{*} = To + \gamma\, ho \qquad (1)$$

where γ is the gradient of temperature versus the pressure $\frac{dT}{dP}$

In fig. 2 γ versus temperature is reported, in fig. 3 T^{*} versus temperature is reported (for different brine height).

T^{*} can be defined as the vapour equilibrium temperature in the pool at stage bottom.

In general the local evaporation takes place only if the brine temperature deducted by boiling point elevation is greater than $To + \gamma\, y$

Three different behaviours can be distinguished:

1) $T^{*} < Tf$

2) $T^{*} > Ti$

3) $Tf < T^{*} < Ti$

1. In the first case the brine temperature in the bulk (deducted boiling point elevation) is greater than T^{*} in any point of the stage.

   The condition necessary so that the evaporation takes place is verified in the whole stage either in the length or in the depth of brine.

   In fact, if the evaporation takes place at the maximum

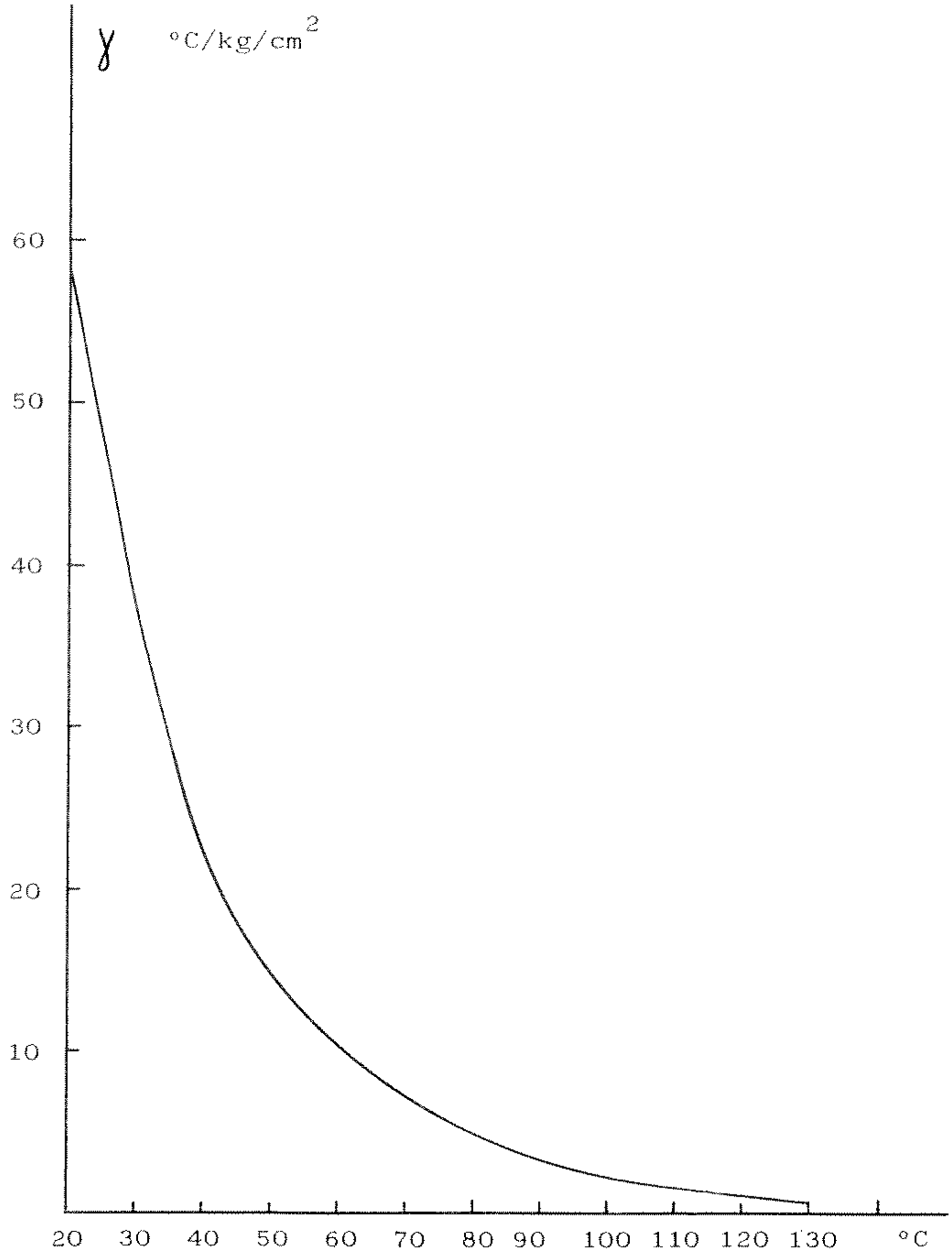

Fig. 2 - TEMPERATURE /PRESSURE GRADIENT

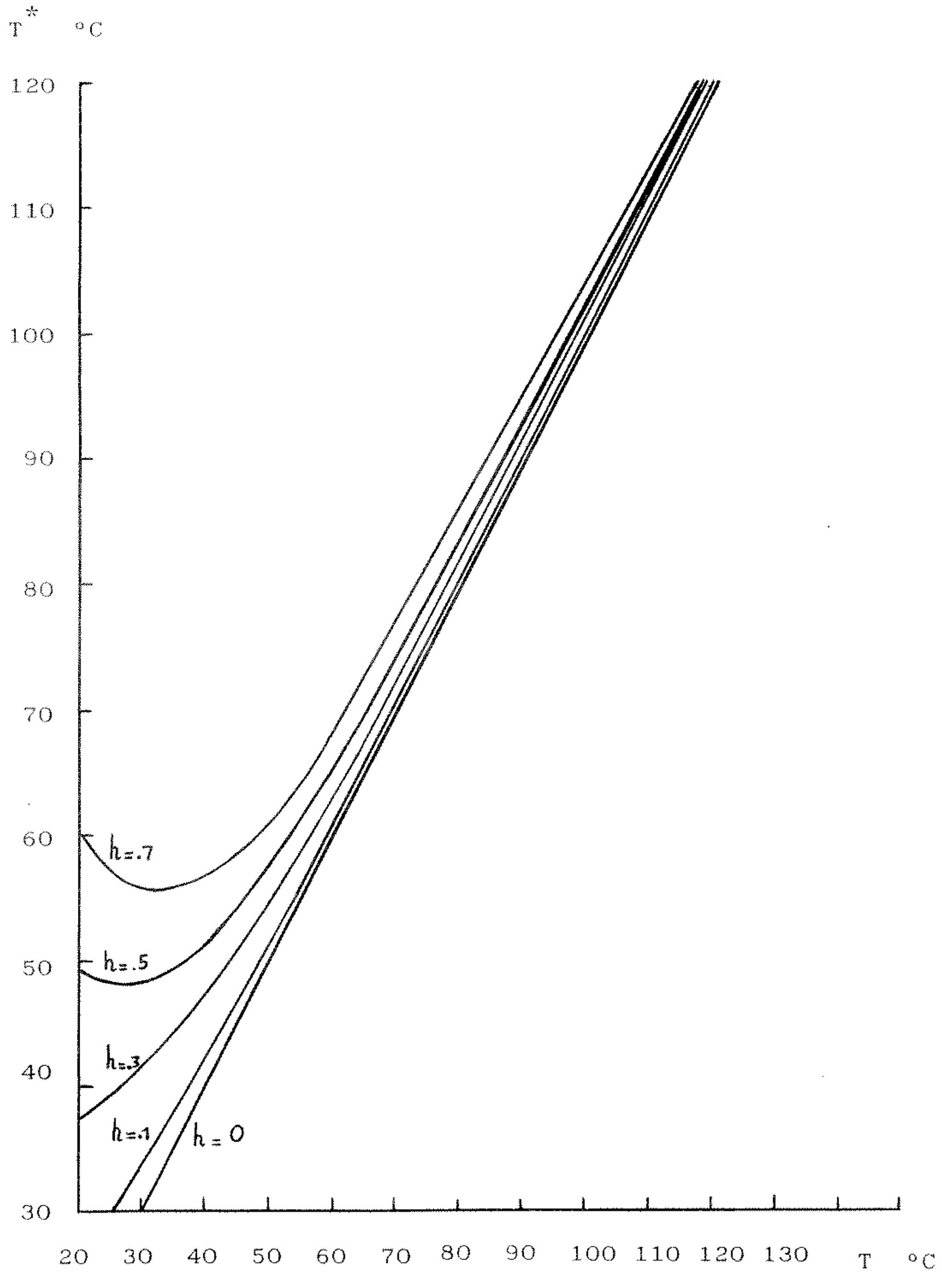

Fig. 3 - VAPOUR EQUILIBRIUM TEMPERATURE FOR DIFFERENT BRINE DEPTH

submergence even more so this occurs in any point up to the brine surface.

2. In the second case the brine temperature in the bulk (deducted boiling point elevation) is lower than T^* in any point of the stage bottom.
   The condition necessary to the evaporation can be verified only in a layer near to the brine surface where T is greater than $To + \gamma y$.

3. The evaporation phenomenon consists of two different mechanisms:
   - type 1) until T is greater than $To + \gamma ho$
   - type 2) when T is lower than $To + \gamma ho$

From the point of view of fluodynamic behaviour the model is valid both for supercritical either for subcritical flow.

FLASHING MODELS DESCRIPTION

Type 1) model

As first approach a semplified 1st order flashing rate can be supposed:

$$rs(y) = \alpha\,(T - To - \gamma y) \tag{2}$$

Integrating for each section on the y axis (depth) we obtain:

$$rs(z) = \alpha B ho\left(T - To - \gamma \frac{ho}{2}\right) \tag{3}$$

Considering the heat balance of the stage:

$$-Ws\ cps\ dTs = rs\,\Delta H dZ \tag{4}$$

and assuming dTs = dT we can obtain:

$$-Ws\ cp\ dTs = \alpha B ho \Delta H\left(T - To - \gamma \frac{ho}{2}\right) dz \tag{5}$$

Dividing the variables and integrating between Ti (Z = o) and Tf (Z = L)

we obtain

$$Tf - To = \left(Ti - To - \gamma \frac{ho}{2}\right) e^{-ND} + \gamma \frac{ho}{2} \tag{6}$$

where ND is a dimensionless number $ND = \frac{\alpha B ho L \Delta H}{Wscps}$ (7)

Then it is possible to write:

$$Tf-To = \Delta TNE = (Ti-To-\gamma\frac{ho}{2})\ e^{-ND} + \gamma\frac{ho}{2} \qquad (8)$$

or

$$Tf-To = \Delta TNE = (Ti-Tf)\frac{e^{-ND}}{1-e^{-ND}} + \gamma\frac{ho}{2} \qquad (9)$$

Type 2) model

In this case the depth limit up to the evaporation takes place is h(z) where $T(z) = To + \gamma h(z)$

Then:

$$h(z) = \frac{T(z)-To}{\gamma} \qquad (10)$$

Considering the (2) equation integrated between y=0 and y=h(z) and the equation (4) integrated between Ti(z=0) and Tf(z=L) the non equilibrium value is

$$Tf-To = \Delta TNE = \frac{\sqrt{(Ti-Tf)\left((Ti-Tf) - \frac{8\gamma ho}{ND}\right)} - (Ti-Tf)}{2} \qquad (11)$$

Type 3) model

If L^* is the coordinate z up to $T > To + \gamma ho$, it is possible to distinguish two different fields:

1) the evaporation takes place as per model 1 between z = 0 and $z = L^*$

2) The evaporation takes place as per model 2 between $z = L^*$ and z = L

Integrating the equation (5) in this field we can obtain:

$$L^* = \frac{Wscps}{\alpha B\ \ ho \Delta H}\ \ln \frac{Ti-To-\gamma\frac{ho}{2}}{\gamma\frac{ho}{2}} \qquad (12)$$

The integration of (2) and (4) equations in the field $z = L^*$, z = L, taking into account the equation (12), gives the following results:

$$T_f - T_o = \Delta TNE = \frac{2\gamma h_o}{2 + ND - \ln \dfrac{(T_i - T_f) + (T_f - T_o) - \gamma \frac{h_o}{2}}{\gamma \frac{h_o}{2}}} \qquad (13)$$

The effective value of ΔTNE is obtainable by iterative convergence procedure.

The kinetic rate constant in the different fields can be calculated by experimental values collected on running existing plants.

EMPIRICAL FORMULAS ANALYSIS

The first studies relevant to non equilibrium allowance calculation start in the early sixties mainly from Office of Saline Water.

In Table 1 a short list of the most significative empirical equations is reported.

The equations give correlation between the terminal temperature difference (No. 4 excepted) and the parameters listed in the introduction

1) stage length
2) stage thermal level
3) stage flashdown
4) brine mass specific flowrate
5) brine depth

In general, all the equations do not take into consideration the influence that the boiling point elevation has on the non equilibrium value. So considering that the terminal temperature difference (or non equilibrium allowance) consists of submergence losses and boiling point elevation it is easy to obtain in the high temperature range non equilibrium allowance less than the boiling point elevation alone.

In fig. 4 a plot of different equations versus the temperature is shown.

The parameters assumed are typical of a MSF cross flow unit of 5-6 MIGD

Formula	Source	Year
1) $\Delta = 12.3\ e^{-0.0356Te}\ e^{0.07L}\ e^{0.476W}$	AMF for OSW	1967
2) $\Delta = \dfrac{L^{0.86}\ VG^{0.71}\ W^{4.55}}{374\ \ T^{0.5}}$	AMF for OSW	1970
3) $\Delta = L\ \dfrac{^{0.86}\ VG^{0.71}\ W^{1.7}}{449\ \ T^{0.5}}\ M^{0.19}\ Ls^{0.19}$	AMF for OSW	1970
4) $\Delta = (0.5x\ T + SUBA)\ \left(\dfrac{SUBA}{0.5x\ T + SUBA}\right)^{\left(\frac{Ls}{10}\right)}$	ORNL for OSW	1971

Table 1 - Non equilibrium allowance empirical formulas.

SUBA = $2.674\ e^{(-0.01222\ Te\ +\ 0.07L\ +\ 0.476W)}$

Te = Brine Temperature °F

L = Brine level inches

W = Brine specific flowrate lb/hrft/10^6

VG = Specific volume of steam Cuft/lb

ΔT = Stage flashdown °F

M = Temperature difference between inlet flash brine and outlet recovery bundle °F

Ls = Stage length ft

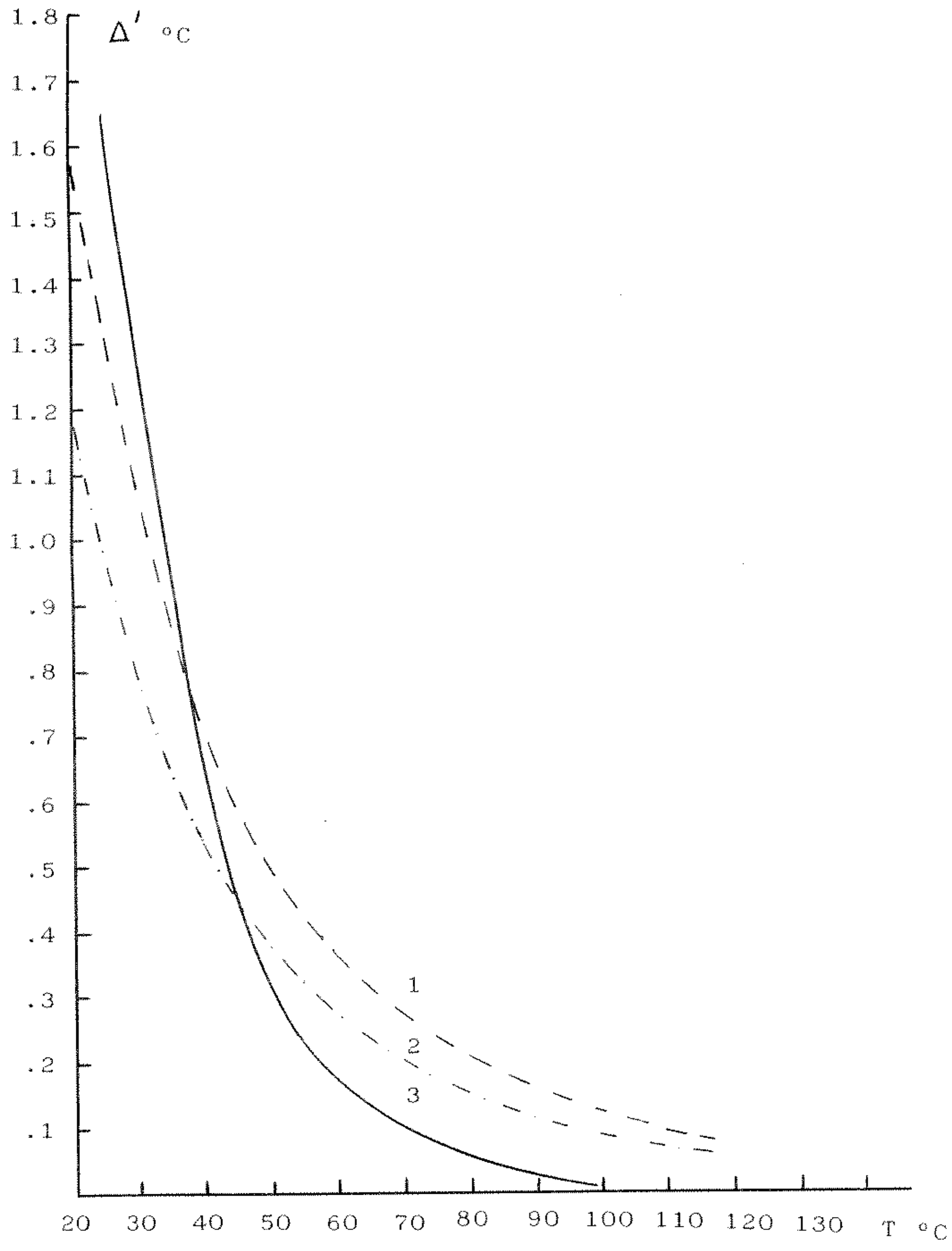

Fig. 4 -Δ EMPIRICAL EQUATIONS TYPICAL CURVES

W = 800 t/h m

T = 30-110°C

L = brine level 400 mm

ΔT = 4°C

Fig. No. 4 shows that, considering the field of salinity and the relevant boiling point elevation typical for the concentrated sea water (0.5-1°C) the empirical formulas considered are applicable only for the low temperatures range.

No comparison is possible between the equations of this category (that include the boiling point elevation) and the equations relevant to the submergence losses calculation only.

The only equation relevant to the submergence loss calculation (independently from B.P.E.) is No. 4 deriving from ORNL.

THEORETICAL MODEL ANALYSIS AND COMPARISON WITH EXPERIMENTAL VALUES

In fig. 5), 6) the profiles of ΔTNE for the type 1), 2), and 3) models and for different values of kinetic constant are shown.

Type 1) model ($Tf > T^*$) is generally not applicable to the running conditions of MSF plants designed following the process parameters above mentioned.

In fact the model is valid for very low brine level (20- 30 mm) and kinetic constant value very low.

Type 2) and 3) models have profiles practically coincident showing that the evaporative phenomenon, with very high probability, follows type 2) model. Moreover, the analysis of model 2) and 3) with reference to the existing running plants shows that the values of kinetic constant are included within 3 and 10 $\frac{kg}{m^3 s °C}$

In fig. 7) the profile of ΔTNE according to model 2) for different values of the kinetic constant compared with ORNL equation No. 4 is reported.

In fig. 8) the same profiles of ΔTNE compared with experimental points coming from MSF crossflow of 7.0 MIGD capacity de-

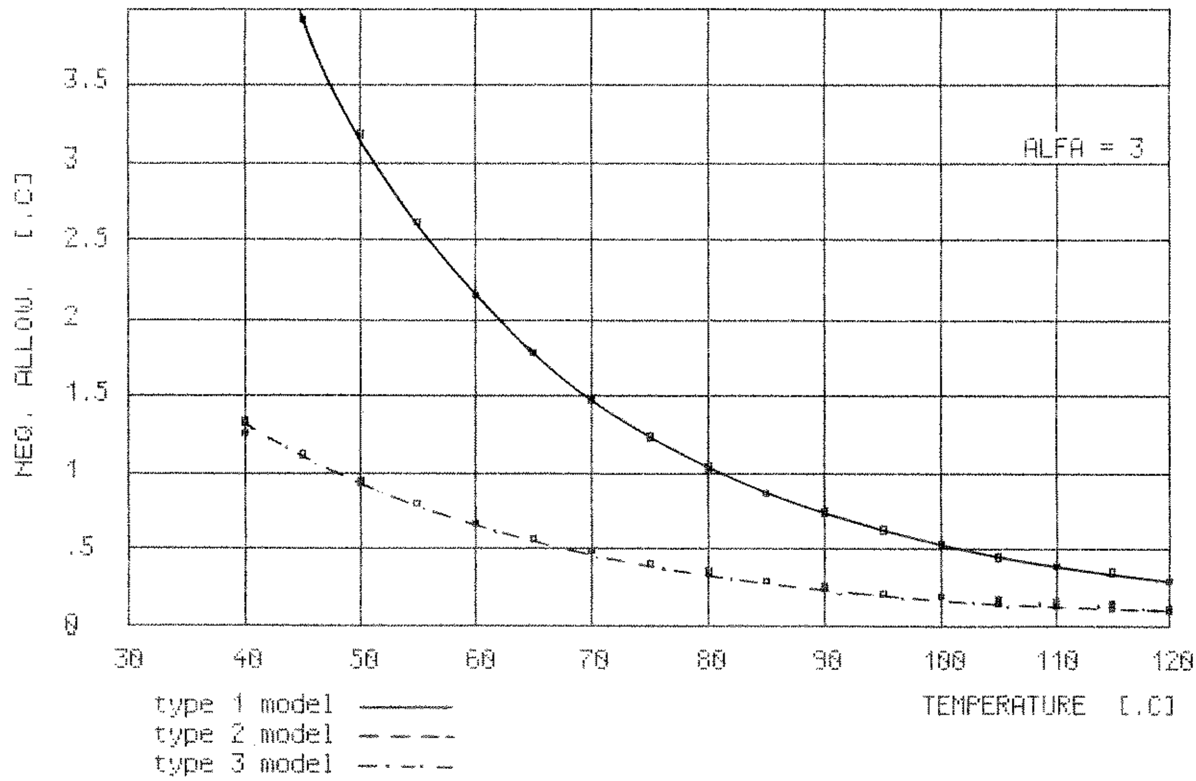

Fig. 5 - PROPOSED MODEL ΔTNE TYPICAL PROFILES

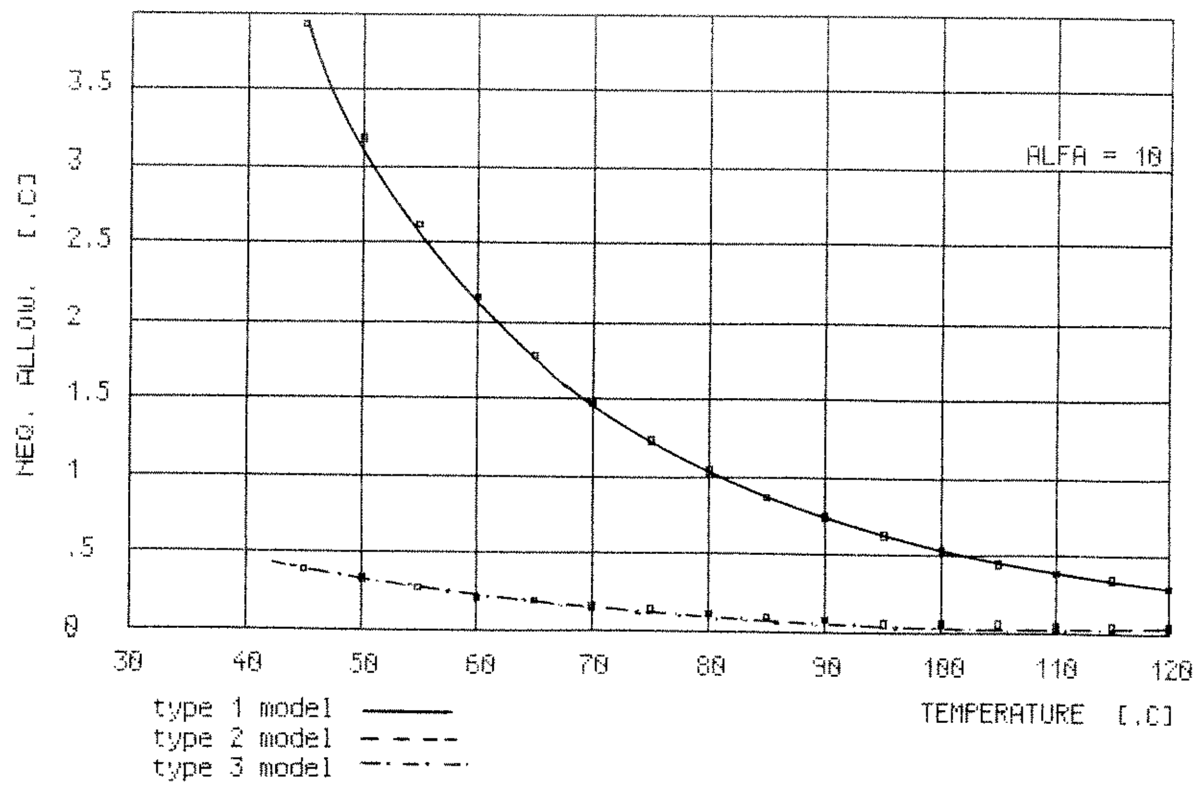

Fig. 6 - PROPOSED MODEL ΔTNE TYPICAL PROFILES

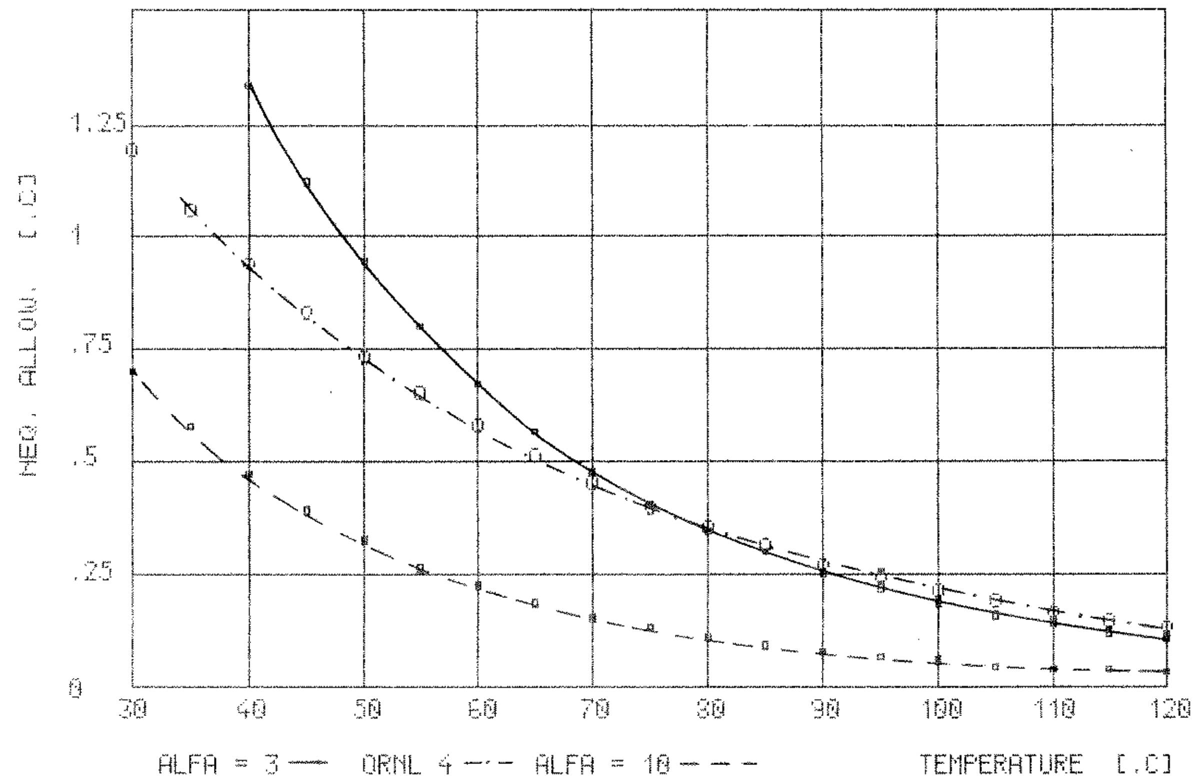

Fig. 7 - COMPARISON BETWEEN MODEL 2 TYPE AND ORNL EQUATION

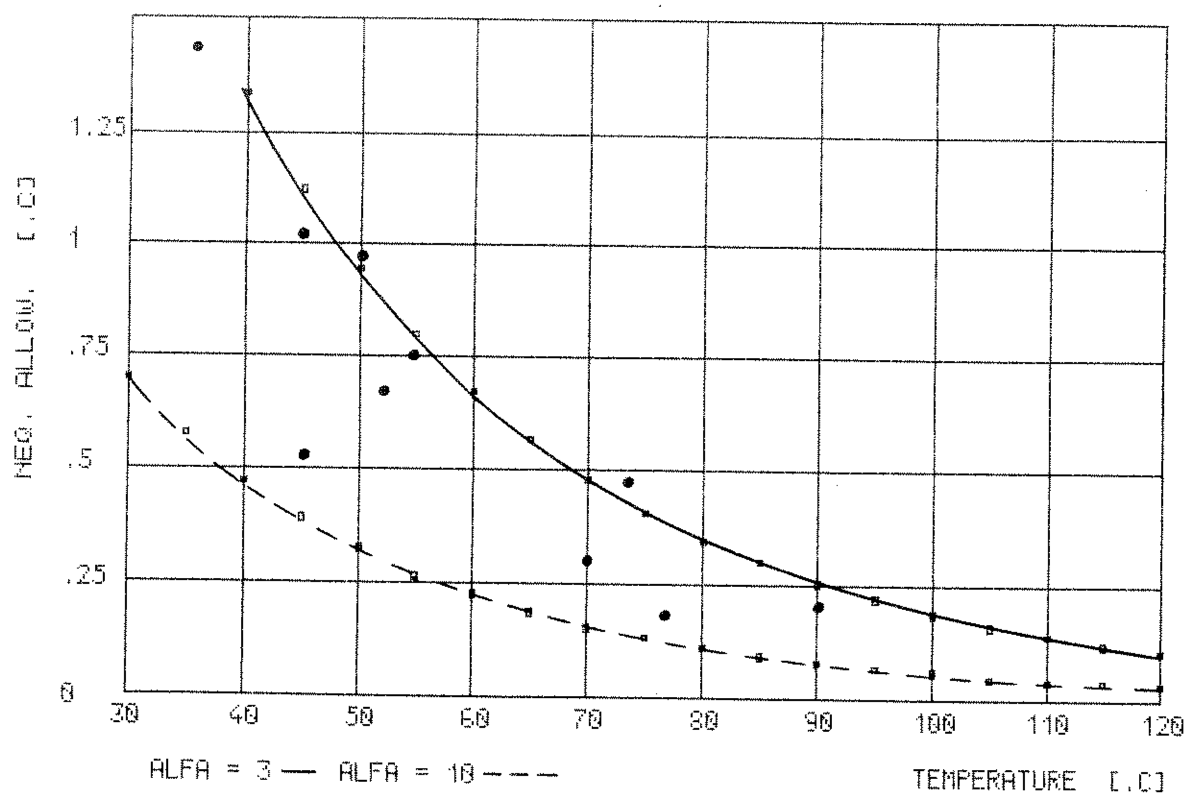

Fig. 8 - COMPARISON BETWEEN MODEL 2 TYPE AND EXPERIMENTAL POINTS

salination plant are reported.

CONCLUSIONS

The theoretical general model for TNE has been described.

- The examination of the existing common models shows that those are not applicable in general for high salinity and high temperature.
- The analysis of the different types of flash mechanism shows that for MSF desalination unit designed according to usual process parameters models 2) and 3) are applicable.
- The range of kinetic constant values with reference to existing running plants is identified.

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