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SALT WATER COOLING PONDS WITH PARTIAL TIDAL INTERCHANGE

by

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S U M M A R Y

The results of a preliminary investigation of the feasibility of using a salt water cooling pond with partial tidal interchange for the rejection of heat from the circulating water system of a thermal power station are presented. A computer simulation of the cooling pond system is described and the operating conditions of a cooling pond of sufficient size for a 1000 MW power station are discussed. The results for a completely closed pond and a partially open pond are compared.

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GLOSSARY OF TERMS

A Latitude of Site
B Declination of Sun
C Hour Angle of Sun
D Atmospheric Radiation Factor
H_r Relative Humidity
K Proportionality Constant
P Saturated Vapour Pressure
T Temperature
W Wind Speed

Subscripts

a Air conditions
w Water conditions

INTRODUCTION

The increases in the demand for electricity and the increases in the size of individual power stations, coupled with a growing concern for the possible effects of waste heat discharges on the aquatic environment, have made the problems of discharge and dispersal of heated water from the circulating water system of a power station extremely complex. Due to the large number of variables which must be considered, the prediction of the extent or location of areas of increased temperature is difficult. In addition, even if the actual hydrological and thermal effects of an intake and discharge could be specified, it is not possible to predict by either experiment or by observations at existing installations what the end effect on the aquatic environment will be at a proposed location. The present attitude towards this problem is to minimise or eliminate the quantities of natural water taken in or discharged or to locate the installation in a place where it can be shown that no extensive aquatic life exists.

One approach to the problem of waste heat rejection is the use of cooling ponds. The analysis of the operating conditions in an artificial pond is relatively easy and there is a considerable latitude in cooling pond design. The quantity of water which must be supplied to the pond system from external sources can be reduced to that amount needed to account for evaporation and the amount of water discharged to natural bodies of water can be reduced to zero.

The major disadvantage of cooling ponds is the large area which is required for the pond. The costs of dredging and bunding can also be a major factor, however, it may compare favourably with the costs of long underwater conduits and elaborate diffuser systems as are required to insure rapid dilution of a direct discharge. Also, in some locations, the establishment of a large area of enclosed, constant depth water could be used for experimentation in marine farming or for recreational facilities.

DESCRIPTION OF PROPOSED SYSTEM

The particular system discussed in this paper is a salt water pond situated in a coastal or estuarine location. The pond can be made of sufficient size to operate as a closed pond, but has provision for interchange of water in a portion of the pond over a part of the tidal cycle. This interchange would eliminate the problem of increasing salinity in the pond due to evaporation but, since only a portion of the pond is open to tidal interchange, there is control over the maximum temperature of any water discharged from the pond.

A simplified configuration of such a pond is shown in Fig. 1. The required area of the pond is dredged and bunded to form a constant depth pond with internal dividers to insure maximum residence time in the pond between the discharge and intake of the power station. At some predetermined point in the pond there is a dividing wall which separates the constant depth portion of the pond from the portion which is open to the tide. At some point in the bunding near the circulating water intakes to the power station there is an opening in the bunding which permits water flow into the pond during the latter part of the incoming tide and flow out of the pond during the early stages of the outgoing tide.

In order to estimate the operating characteristics of the pond, a computer programme was used to calculate the temperature distribution in the pond by considering the heat load from the power station and the heat losses from the pond surface to the atmosphere.

DESCRIPTION OF CALCULATIONAL PROCEDURE

The computer programme carries out a stepwise calculation through the pond from the discharge to the intake which includes the heat exchange with the atmosphere by radiation, convection and evaporation. For the preliminary investigations it was assumed that the pond was completely closed. It was assumed that the pond was a long, continuous rectangular channel of specified length, depth and width which is divided into a number of segments. An initial temperature distribution was assumed in order to reduce the amount of time required for convergence of the calculated temperature distribution. The computer calculates the residence time of the water in each segment based on the given flow rate of circulating water and the width and depth of the segment. It then calculates the surface heat loss per unit of time and surface area based on the average temperature in the segment and the atmospheric conditions. It then calculates an exit temperature from the segment based on the inlet temperature and the total heat loss as calculated from heat loss rates, surface area, total volume in the segment and residence time. This exit temperature is then used as the inlet temperature to the following segment and the process is repeated. When the last segment is reached, the exit temperature of that segment, the circulating water flow rate and the heat added by the power station are used to calculate a new inlet temperature for the first segment. The programme prints out a series of temperature distributions at time intervals corresponding to the residence time in a segment.

Further investigations of a partially open pond were made by a modification to the program in which the tidal height at each time interval was compared to a specified minimum value and when the tidal height was above that value the water temperature into the power station was taken as the natural water temperature outside of the pond rather than the calculated temperature of the last segment.

The equations used for atmospheric heat interchange were taken from Reference (1) and are shown in general form in Table 1. The variations in atmospheric conditions such as air temperature, wind speed and relative humidity were assumed to be periodic functions of time. These functions and the functions used for natural water temperature, tidal height and power station output are also listed in Table 1.

RESULTS OF CALCULATIONS

All of the preliminary calculations were based on a pond with an effective length of 13 700 m with a 400 m width and a 2.5 m depth. The pond was divided into 50 segments. The heat rejection rate from the power station was 1275 Mw and the circulating water flow rate was 38 m^3/sec. This results in a residence time, and therefore a time interval, of 2 hours per segment.

The initial calculations of a closed pond were used to verify the calculational procedure and to obtain an indication of the portion of the pond which could be left open to tidal interchange without the outflow exceeding a temperature difference of 3 C above the natural water temperature. The results, which are shown in Fig. 2, compare favourably with similar results from References (2) and (3). There is a daily variation in pond temperatures resulting from the change in atmospheric conditions.

If it is assumed that the variable depth portion of the pond is allowed to fluctuate between a depth of 1.25 m and 1.87 m, the water in the variable depth portion of the pond would be diluted with about one half as much natural water on the incoming tide. A partition in the pond separating the constant and variable depth portions could then be placed at any point in the pond below the region where the pond temperature was 4.5 C above natural temperature and the outflow would be 3 C or less above natural temperature. From Fig. 2, this would permit inflow and outflow from between 30% and 40% of the ponded area. If a greater tidal height were assumed this percentage could be increased because of greater dilution.

A further series of calculations was made on the same pond with similar operating conditions except that it was assumed that during the 6.25 hours when tidal height exceeds 1.25 m the cooling water taken into the circulating water system was at natural water temperature rather than at the temperature of the last segment of the pond. This would correspond to a configuration where only a small portion of the pond near the power station intake was open to tidal flow and mixing between natural water and pond water was minimal. The results of this case are shown in Fig. 3. Temperatures throughout the pond are generally lower but exhibit a wider variation, particularly in the discharge end of the pond. The temperatures in the last 20% to 30% of the pond are relatively constant which indicates that the pond could be reduced in area by at least 20% without affecting temperature levels elsewhere in the pond.

The variations in temperature in the first and last segments of the pond and the assumed variation in natural water temperature with time are shown in Fig. 4. The variation in temperature in the first segment is quite wide due to the mathematical discontinuities which are incorporated in the program. If some mixing of natural flow and pond flow is assumed, these fluctuations should be more gradual. The variations in temperature in the last segment are considerably less, and when compared to natural temperatures, they vary between 1.9 C and 3.1 C above the natural temperature.

The evaporation from the pond varies daily from 0.8 to 1.6 m^3/sec. The minimum pond area which must be open to the tide with a tidal range as assumed in the calculations is one segment or 109 600 m^2. Any additional inflow will result in a discharge from the pond.

CONCLUSIONS

The use of cooling ponds in environmentally sensitive coastal or estuarial locations can reduce or eliminate the possible effects of the marine environment by reducing the quantities of water which need to be drawn from or discharged to the natural waters. Although it would be necessary to impound a relatively large area for the pond, it can be assumed that the effects outside of the impounded area are minimal. In many of the large, shallow harbours of New Zealand the percentage of intertidal area needed would be small.

There is a considerable latitude in the design of cooling ponds which enable studies of power station requirements and limitations on water use in an area to be considered to produce a satisfactory compromise. Calculational procedures are relatively simple and can predict cooling pond operating conditions to a reasonable degree of confidence.

ACKNOWLEDGEMENT

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TABLE 1

EQUATIONS AND FUNCTIONS USED IN HEAT LOSS CALCULATIONS

Components of Atmospheric Heat Interchange Equations

1. Solar Radiation Heat Gain

$$Q_{sr} = K_1 \text{ (cosAcosBcosC + sinAsinB)}$$

2. Radiation Heat Loss

$$Q_{rl} = K_2(Ta^4 \times D - Tw^4)$$

3. Convection Heat Loss

$$Q_c = K_3(1.0 + 0.602W)(T_a - T_w)$$

4. Evaporation Heat Loss

$$Q_{ev} = K_4(1.0 + 0.0602W)(H_r P_a - P_w)$$

Periodic Functions Included in Computer Programme

Function	Mean	Range	Time of Day of Maximum
Air Temperature, deg. C	19.0	4.0	1500
Relative Humidity, %	80.0	10.0	0300
Wind Speed, m/sec	7.0	4.0	1500
Water Temperature, deg. C	20.7	0.4	1500
Heat Rejection, Mw	1275	0	-
Tidal Height, m	1.25	0.62	*

* Tidal period is 12.5 hours. Time of first high tide is 0.0 hours

FIGURE 1

SCHEMATIC DIAGRAM OF COOLING POND

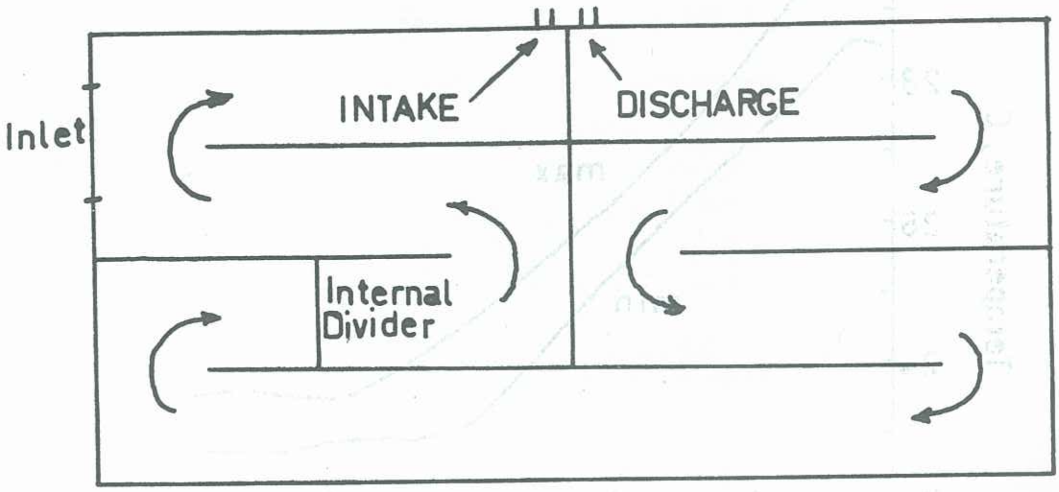

FIGURE 2
TEMPERATURE DISTRIBUTION IN CLOSED POND

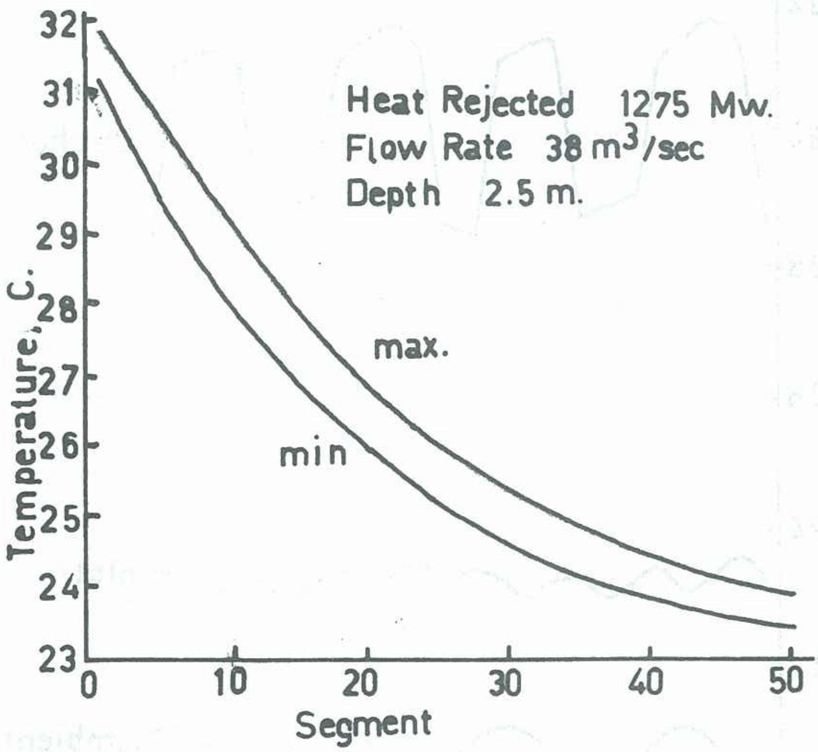

FIGURE 3
TEMPERATURE DISTRIBUTION SEMI-CLOSED POND

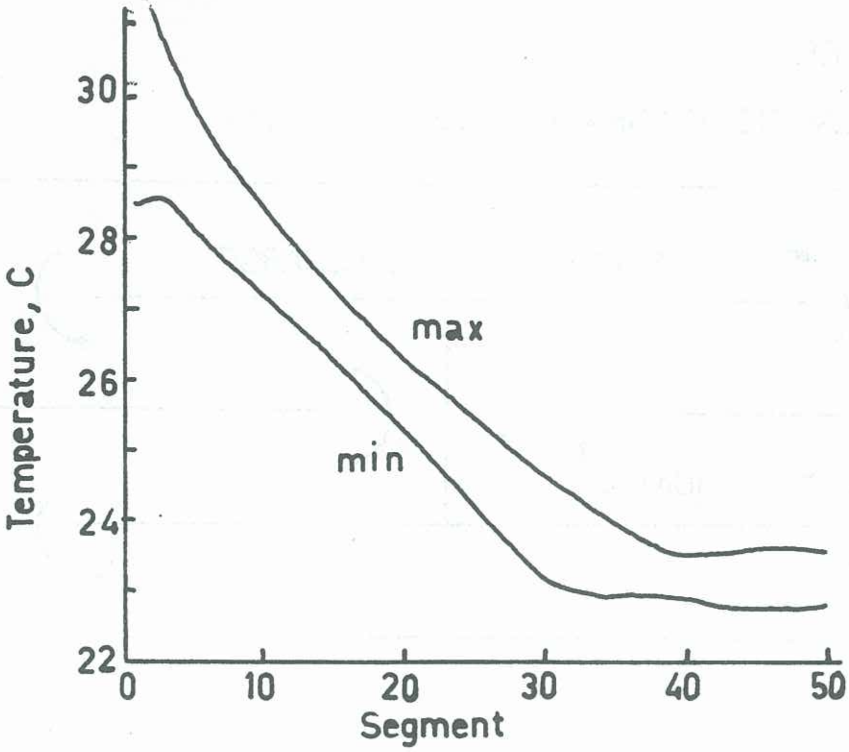

FIGURE 4
TEMPERATURE VARIATION WITH TIME