ESTIMATION OF WATER TEMPERATURE INCREASES IN WHEELER RESERVOIR CAUSED BY THE DISCHARGE OF HEATED WATER FROM BROWNS FERRY NUCLEAR PLANT DURING OPEN CYCLE OPERATION

by

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INTRODUCTION

The facilities for disposing of wasted heat from the Browns Ferry Nuclear Plant have been planned and constructed to protect the waters of Wheeler Reservoir for the following uses: public water supply, swimming and other whole body water contact sports, fish and wildlife, and agricultural and industrial water supply. The Browns Ferry Plant and the flows in Wheeler Reservoir will be regulated by TVA in a manner which will prevent adverse thermal effects and which will meet the applicable temperature standards. This report presents a simple model which may be used during open cycle operation of the plant to predict the induced water temperature increases resulting from a proposed schedule of Browns Ferry and releases from Wheeler and Guntersville Dams. This technique has been developed as a part of a program in progress at the TVA Engineering Laboratory in Norris, Tennessee, since 1966 to study the heated discharge from Browns Ferry utilizing a variety of methodologies including field measurements, physical model studies, and analytical predictions.

The report first discusses the various factors which will influence the induced temperature increases in Wheeler Reservoir. Then specific models for each of these effects are presented. On the basis of comparisons with temperatures observed in a scale model of the Browns Ferry heated discharge, it is concluded that the estimation technique presented here will be useful in coordinating the regulation of flows in Wheeler Reservoir with the operation of Browns Ferry Nuclear Plant.

PROBLEM DEFINITION

The pattern of both the natural temperatures in Wheeler Reservoir and the temperature increases induced by the heated discharge from Browns Ferry Nuclear Plant are often complex and highly variable. Nevertheless, it is useful for purposes of plant operation and required for monitoring purposes that the effect of the discharge be characterized by a single downstream temperature measurement and a single upstream "ambient" temperature measurement. Model tests at the Engineering Laboratory have shown that downstream from the diffuser mixing region the induced temperature will be fairly constant over a large area. If the temperature of this region is called the mixed temperature, T_M, then it may be said that T_M is determined by the following set of relationships:

$$T_M - T_R = \Delta T_M = \text{function of } [H, Q_R] \qquad (1)$$

where T_R = "ambient" temperature of Wheeler Reservoir

ΔT_M = mixed temperature rise

H = rejected heat = function of $[P, T_R]$

Q_R = the river discharge in Wheeler Reservoir at the plant site = function of $[Q_G, Q_W]$

P = Browns Ferry power output

Q_G = Guntersville Dam release

Q_W = Wheeler Dam release

The following sections formulate the functional relationships expressed above so that the mixed temperature T_M (and the mixed temperature rise, ΔT_M), may be calculated for any given values of Q_G, Q_W, P and T_R.

THE TEMPERATURE - FLOW RELATIONSHIP

The mixed temperature, T_M, may be expressed in terms of a basic heat balance before and after diffuser jet mixing:

$$(T_M - T_R)Q_M = H/\rho c \qquad (2)$$

where Q_M is the mixed discharge at the mixed temperature, T_M and ρc is the specific heat per unit volume of water. Thus the problem of determining T_M can be expressed in terms of a determination of Q_M and H.

Model tests (ref.1) have shown that three distinct mixing flow regimes may exist depending upon the magnitude of the river flow, Q_R;

High Flow Regime: The multiport diffusers are capable of inducing a dilution flow, Q_D, which is predicted by a theoretical expression developed for diffusers in shallow water: (ref.2)

$$Q_D = 1/2Q_L + 1/2 \sqrt{Q_L{}^2 + 2(\frac{d}{a})Q_c{}^2} \qquad (3)$$

where Q_c = condenser flow

Q_L = the flow which would naturally pass over the diffuser

d = water depth

a = diffuser port area per foot of length

For Browns Ferry these values have been determined to be $Q_L = .22NQ_R$, d = 30 ft., and a = .283 ft^2/ft. where N = the number of units operating (1, 2 or 3). The high flow regime occurs whenever $Q_R > Q_D$ and results in $Q_M = Q_D$, i.e. there is more river flow than the diffusers can entrain so the mixing flow is controlled by the entrainment characteristic of the diffuser as given by equation (3).

Intermediate Flow Regime: When $Q_R < Q_D$ there is insufficient river flow to meet the diffuser demand and the mixing flow is then limited by the river flow, i.e. $Q_M = Q_R$. When this flow regime occurs, the entire river flow is entrained into the diffuser jets.

Low Flow Regime: At low river flows the heated discharge tends to stratify and to form a heated surface layer. When this occurs, the river flow may not limit the dilution as cooler water may actually be drawn upstream as a lower layer flow beneath the heated surface layer. Stratified flow theory predicts that this may occur when the following condition holds

net heat

$H = Q_c \cdot \Delta T_c$

$$Q_M < Q_F$$

where
$$Q_F = [N^2L^2d^3\beta H]^{1/3} \tag{4}$$

$$\beta = -\frac{g}{\rho}\frac{\partial\rho}{\partial T}\Big|_{T=T_R} = .0000074\left[\frac{5}{9}(T_R - 32) - 4\right]$$

Because for Browns Ferry it is true that $Q_D > Q_F$, this low flow criteria becomes equivalent to $Q_R < Q_F$.

Although there is no theoretical expression for the complex stratified flow that occurs when the river flow is low, it is estimated that $Q_M = \frac{Q_F}{2}$ at the point when $Q_R = 0$. Thus the following relationship for Q_M is assumed for the range $0 < Q_R < Q_F$

$$Q_M = \frac{Q_F}{2-Q_R/Q_F} \tag{5}$$

A summary of the above flow temperature relationships is as follows:

$Q_M = Q_D$ when $Q_R > Q_D$ — Q_D by equation (3)

$Q_M = Q_R$ when $Q_F < Q_R < Q_D$

$Q_M = \frac{Q_F}{2-Q_R/Q_F}$ when $0 < Q_R < Q_F$ — Q_F by equation (4)

The above expressions for Q_M yield steady state values which are reached after a reasonably long time after a change in river flow occurs. To take account of this transient characteristic in calculating T_M, the mixing flow is calculated using a time weighted river flow value as follows:

$$Q_{RTRANS}(t) = r\,Q_R(t) + (1 - r)Q_{RTRANS}(t - \Delta t) \qquad (6)$$

where $Q_{RTRANS}(t)$ = the transient river flow used to calculate ΔT_M at time t

$Q_R(t)$ = the actual river flow at time t

$Q_{RTRANS}(t-1)$ = the transient river flow at time (t-1)

Δt = computation interval (usually 1 hour)

It should be noted the weighting coefficient, r, should be considered a function of the computation interval and should be reevaluated if a different Δt is utilized. This above formulation for simulating transient conditions also has the desirable property that changes in ΔT_M caused by load variations will occur without a time lag.

REJECTED HEAT

The rejected heat for each unit is a function of the electrical output of the plant, P, and the intake temperature which is assumed to be at the river temperature, T_R.

Although no exact method exists for calculating the rejected heat because of the complexity of the heat balances within the plant, an approximate method has been worked out (ref.3) which takes into account as many factors as possible. The basis for the calculation is as follows:

$$\text{Rejected heat} = H = OPL - P - R \qquad (7)$$

where OPL = reactor power production

P = electrical power generation

R = power loss to reactor recirculating pump = 5MW

The reactor power and electrical output are related empirically as follows:

$$OPL = \frac{1.831P}{F} + 275 \qquad (8)$$

where F is a function of OPL and T_R which accounts for the reduction in efficiency at high intake temperatures. Details of the calculation of F are given in Ref. (3). The final expression for the total heat rejection is:

$$H = \frac{P}{F}[2.831 - F] + 270 \qquad (9)$$

RIVER FLOW

The river flow at the Browns Ferry site is determined by the releases from Guntersville Dam, Q_G, and Wheeler Dam, Q_W. In general, the dependency is extremely complex and a detailed calculation is possible only by a complex computer program. On the other hand, the general behavior of the flow has been found to be approximately given by:

$$Q_R(t) = .46Q_W(t\text{-}1 \text{ hour}) + .54Q_G(t - 4 \text{ hours}) \qquad (10)$$

For the purposes of estimating T_M, the above formula adequately predicts relatively steady levels of Q_R and the timing of low flow occurrances although the magnitude of the low flows are not exactly reproduced.

REFERENCES

1. TVA Engineering Laboratory, Browns Ferry Nuclear Plant, Advanced Report No. 14.

2. Jirka, G. and D.R.F. Harleman, "The Mechanics of Submerged Multiport Diffusers for Buoyant Discharges in Shallow Water", R.M. Parsons Laboratory Technical Report No. 169, Dept. of Civil Engineering, M.I.T. 1973.

3. TVA Water Resource Management Staff, Report A-2.