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Subject: Analysis of MSRE Cooling Water Temperature Control System

System Description

A block diagram of the system is shown in Fig. 1. The purpose of the controller is to maintain the water leaving the cooling tower pump (line 851) at a constant temperature by regulating the flowrate that by-passes the cooling tower. A second objective might be to maintain the treated water leaving the heat exchanger at a constant temperature. Whether or not this is required depends on the performance of the cell leak detector, which may be sensitive to changes in cell air temperature resulting from variations in the water temperature in the space coolers. Tower cooling water is also to be used to cool the charcoal beds. A separate controller (TCV-893A) will be used for finer control of the beds' cooling water temperature; however, good control of the tower water temperature will reduce the demands placed on this controller.

The proposed control system consists of a gas-filled temperature bulb in a well, and a field-mounted pneumatic indicator-controller with adjustable proportional and reset. The characteristics of the control valve TCV-858, the cooling tower, and the treated water heat exchanger are given in Table 1.

Control System Analysis

For the analysis, the following assumptions were made:

a. The frequency response of the gas filled thermal bulb in a well corresponds to Taylor Instrument Companies test data on a system with a 3/8 in. O.D. gas bulb in a well with a "Thermospeed" sleeve in water at 130°F with a velocity of 1.15 ft/sec. (The water velocity for MSRE conditions is 6 ft/sec.)

b. The time constants of the valve operator and controller responses are 5 and 2 seconds, respectively.

c. The transport lag time between mixing of the water and the sensing element is 2 seconds.

The analysis consisted of constructing a Bode plot of the open loop system without a controller, and then incorporating controller characteristics to obtain satisfactory closed loop response results, as determined from a Black-Nichols chart. The analysis showed that a closed-loop d-c gain (exclusive of
the controller reset gain) of 1.4 would give satisfactory results. The system d-c gain is a function of the operating conditions for two reasons:

1. The amount by which valve manipulation can change the controlled temperature is equal to the difference between the temperatures of the tower return water and the water in the tower basin; thus the control system gain is proportional to this difference.

2. The valve was bought with equal percentage trim (unfortunately), so for this case, where the pressure drop across the valve will be about constant (equal to the head required to move the water to the top of the tower), the Δ flow/Δ stem position, or "gain" of the valve in the loop will vary, and it will be higher for larger differences in tower return and basin temperatures.

The maximum difference between the tower return and basin water temperatures would be about 60°F, (i.e. 95° - 35°). The maximum "gain" of valve with equal percentage trim and constant pressure drop, i.e. % Δflow/% Δ stem position, is about 3.0*. Assuming the controller has a 50°F span, the controller gain would be:

\[ 1.4 = \frac{(\text{Controller gain})(3.0)(60°F)}{50°F} \]

Controller gain = 0.4 (proportional band = 250%)

Using a reset time setting of 1.0 min., the analysis indicates that for maximum gain condition (full heat load on a cold day), the system would recover from load changes in about a minute. For low heat loads on hot days, however, it may take 10 to 15 minutes to recover from a load change. If this were undesirable, one might use a higher "summer gain", or put linear trim in the valve.

Since the cooling capacity of the tower depends on the states of its two manually-controlled fans, an alarm on high cooling water temperature (on the data logger) would indicate that a fan should be turned on. There is no automatic means in the present design that would indicate that a fan could be turned off.

**Treated Water Operating Temperatures**

The overall U of the treated water heat exchanger was calculated as 232 BTU/hr. ft² °F.** The cooling efficiency of the exchanger was calculated to be

\[ \varepsilon = \frac{\Delta T_{\text{Hot}}}{T_{\text{Hot(in)}} - T_{\text{Cold(in)}}} = 0.693 \]

The maximum load change in the treated water system would be due to variations in the reactor thermal shield load, estimated to be 120 KW (by

H. C. Claiborne). 120 KW would increase $\Delta T_{\text{Hot}}$ by 2.7°F, so for $T_{\text{Cold}}$ controlled constant, $T_{\text{Hot(in)}}$ would go up to 3.9°F, so the temperature of the treated water leaving the cooler would go up 1.2°F.

The maximum load on the treated water system was estimated at 450 KW, giving $\Delta T_{\text{Hot(Max)}} = 10^\circ F$. Thus the maximum temperature of the treated water leaving the cooler would be 90°F for a tower water temperature of 85°F.

Recommendations

1. Move the controller sensing element TE-858 to a point downstream of the tee at the tower pumps' discharge. In its presently-shown location (D-AA-B-40509-C), it would not measure the mixed temperature.

2. Change the control valve TCV-858 from a "fail-open" to a "fail-closed", as shown on D-AA-B-40509-C.

3. Use a gas-filled thermal bulb in a well and a field-mounted pneumatic indicator-controller with proportional and reset control, and a range of 50-100°F. A spare Taylor Fulscope controller (less bulb and proper range Bourdon tube) is available.

4. Provide an alarm on the data logger for high tower water temperature (TE-851-1) to indicate that a tower fan should be turned on.

5. It should be noted that since the gain of the system is very dependent on operating conditions, field adjustments of controller settings for tight control on a hot day may give oscillatory control when it turns cold.

Encls:

SJB: vcc
Table 1. Characteristics of Control Valve TCV-858, Cooling Tower, and Treated-Water Heat Exchanger

TCV-858 (Spec. MSRE-48)

Line size = 6"  
Max. Flow = 565 gpm  
Cv = 360  
Trim = Equal Percentage  
Fails: open (should be "fail-closed")  
ΔP at 550 gpm = 2.34 psi  
(Cooling tower head is 2.8 psi, so valve can by-pass all water)  
Assumed operator response time constant = 5 sec.

Cooling Tower

Type: Marley Double Flow Aqua Tower No. 8320  
No. of fans = 2  
Flow: 550 gpm  
Design outlet temperature for 95°F inlet and 79°F wet bulb temperature = 85°F  
Design load = 800 KW

Treated Water Heat Exchanger

Type: 4 tube pass, 1 shell pass  
Tower water flow (in shell) = 260 gpm  
Treated water flow (in tubes) = 310 gpm  
Overall U = 232 BTU/hr. ft² °F  
Heat transfer area = 1885 ft²  
Cooling efficiency = .693  
Shell holdup time = 102 sec.  
Tube holdup time = 46 sec.  
Design temperatures:

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FIG. 1 MSRE COOLING WATER TEMPERATURE CONTROLLER