Predictive Cooling Tower Modeling Using PEPSE®

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ABSTRACT

Cooling tower tests are typically run as close to design ambient conditions as possible. This is done to allow a good comparison to design tower capability. The drawback to this approach is that design ambient conditions are achieved for only a small percentage of the year. This does not allow the use of the test information to directly determine the cold water temperature to the condenser under varied conditions. However, by using the as tested capability information and the vender performance curves, it is possible to predict the cold water temperature to the condenser for a wide range of ambient weather conditions. This paper presents a summary of the modeling methodology and the results of tests comparing predicted cold water temperature to actual cold water temperature under various conditions.

BACKGROUND

Craig Station Unit 1 is a nominal 447 Mw unit with a GE turbine, a B&W boiler and a 10 cell Marley crossflow cooling tower. The Unit is jointly owned and is routinely operated at five percent overpressure to obtain the maximum generation. During the summer season, the circulating water inlet temperature is often well above the 84°F design, causing condenser pressure to rise above the design point of 3.17 inches Hga. Since the condenser pressure vs. generation loss curve (Figure 1) is so steep above design condenser pressure, any increase in circulating water inlet temperature causes a significant decrease in generation. In the past, any increase in condenser pressure during the summer was attributed to poor cooling tower performance, but no easy method was available to determine which losses were due to the cooling tower, and which were due to other causes. The motivation behind this study was to be able to predict the generation loss due to the effects of weather conditions, and to determine how much effect cooling tower performance has on condenser and turbine performance.

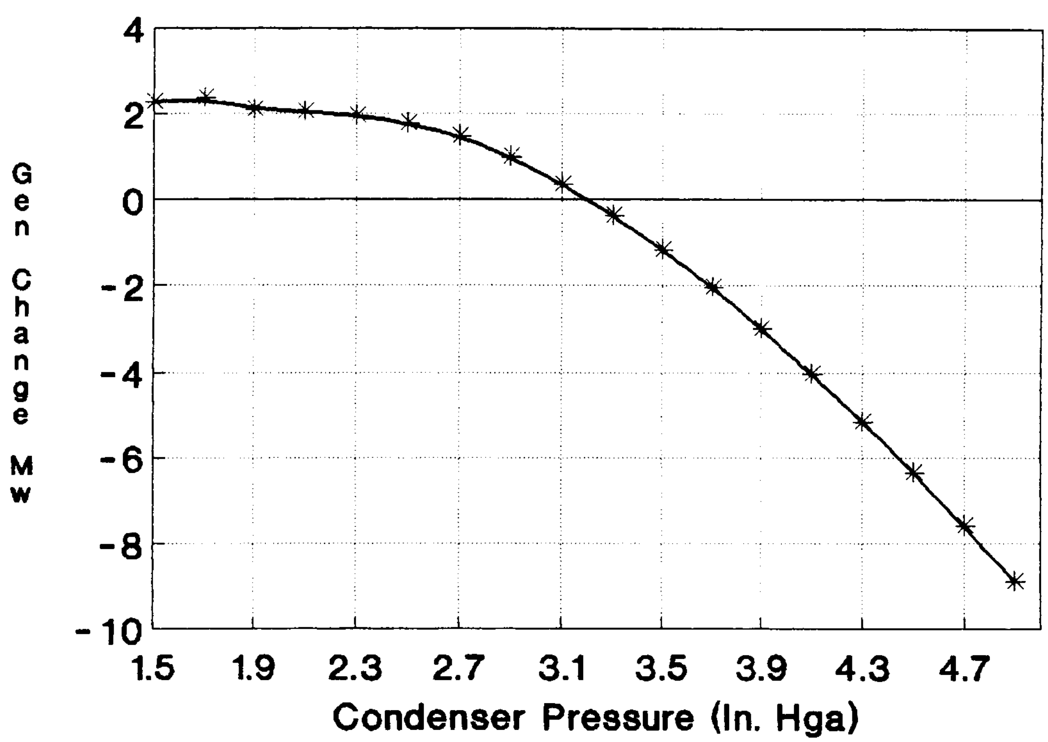


Figure 1 -- Generation Change vs. Condenser Pressure

MODELING APPROACH

Since Craig 1 has a predictive PEPSE turbine cycle model, we decided to try to utilize the PEPSE cooling tower model and HEI condenser model for predicting generation loss. This way, the cooling tower and condenser model could be used alone or in conjunction with the turbine cycle model. So the first step was to construct a cooling tower sub model.

The PEPSE cooling tower component, Type 75, is a performance mode component, and therefore is quite simple in input and calculation method. Two critical input values are variable APTOWI, the tower approach (Approach = Cold water temperature - Wet Bulb temperature), and TTUA, the temperature of the air exiting the tower. The problem is that the critical result of a predictive cooling tower model is the cold water outlet temperature, and the known parameter is the wet bulb temperature. If the approach remains constant, prediction of circulating water outlet temperature becomes a simple subtraction problem. The second difficulty is measuring the temperature of the air exiting the tower. An extensive temperature grid or a traverse would be required to get an accurate indication of air out temperature. We wanted to utilize a minimal input set of easily collected information, and we wanted the ability to employ the results of annual cooling tower tests. The Cooling Tower Institute Performance Curve method is used for capability calculation at Colorado Ute, and for consistency, we decided to employ the same basic method in PEPSE. Since so many changes to the cooling tower model were required, we opted to use PEPSE's special features to simulate cooling tower performance, instead of the Type 75 cooling tower model.

COOLING TOWER SUB MODEL

To simplify model debugging, we began with a simple HEI condenser sub model, shown in Figure 2. All component, stream and special feature numbers were made to be compatible with the Craig Unit 1 turbine cycle model for later ease of integration. The importance of the condenser model is that cooling tower performance is driven by cooling range and ambient weather conditions. The weather conditions are inputs, but the cooling range is defined by the heat load to the condenser and circulating water flow rate. The HEI condenser simulates actual condenser performance very well. A design mode condenser could also be used, however, the HEI model has a much smaller input data set while still providing a reasonable simulation of condenser performance. Our condenser model was benchmarked against Westinghouse design data (Appendix B), and matched very well.

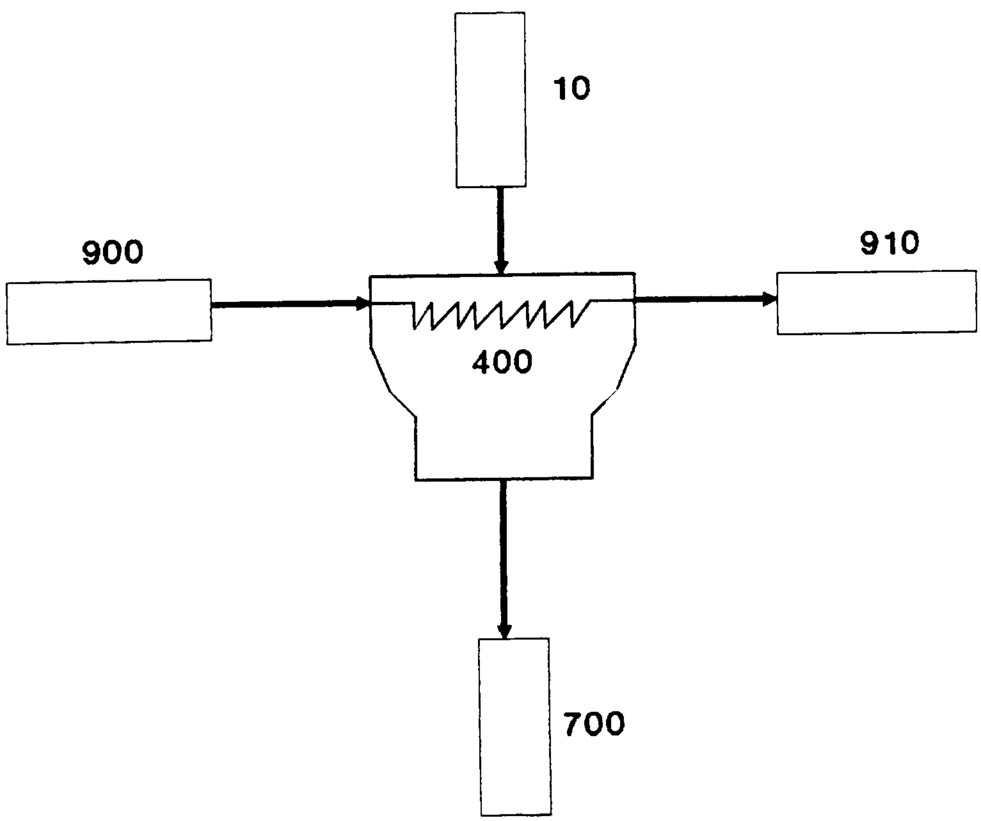


Figure 2 -- HEI Condenser Submodel

After the condenser model was complete, the Marley cooling tower performance curves (Appendix C) were input using PEPSE's Schedule feature. These curves present cold water temperature as a function of wet bulb temperature and cooling range. Three bivariate schedules were used, one each for 90, 100 and 110 percent design flow. These are schedules 1, 2 and 3. Since the schedules were constructed by picking points off of the original curves, a model was also set up to calculate tower capability based on test data. This way a consistent set of curves would be used to calculate the tower capability and to predict the cold water temperature.

Essentially, predicting cold water temperature from test results is little different from calculating capability. First, cold water temperature for each design flow is calculated based on wet bulb temperature and cooling range. The wet bulb is determined from a plant relative humidity instrument or psychrometer, and the range is calculated by the HEI condenser model. Adjustment must be made to the circulating water flow for off design fan horsepower, yielding adjusted test flow. Next, the predicted flow is back calculated from the adjusted test flow and the test capability. These are operations 56 through 61, in Appendix A.

Using a binary if operation (BIF), the predicted flow is located in relation to design flow. If less than design flow, predicted cold water temperature is calculated by linear interpolation between cold water temperatures at 90 and 100 percent design flow. If predicted predicted flow is greater than design, the 100 and 110 percent flow values for cold water temperature are used.

To integrate the cold water temperature into the HEI condenser model, the cooling range must be calculated from the condenser model and then transferred to the cooling tower model. This is done in operation 65. Then the cold water temperature from the cooling tower model is transferred to the HEI condenser via operation 170. In this way the cooling tower model is integrated into the iteration scheme.

ANALYSIS RESULTS

Before integrating the Condenser/Cooling Tower model into the full turbine cycle model, several sets of historical cooling tower data were used for verification. All produced results consistent with the actual test results.

Model integration was as simple as removing source component 10 and sink component 700 from the condenser/cooling tower sub model. Since the sub model was numbered consistent with the turbine cycle model, all of the geometry, components and special features ran with no problems.

Figure 3 presents the results of a sensitivity study performed with the new cooling tower model, and presents maximum generating capability of Craig Unit 1 as a function of wet bulb temperature, for two different capabilities. This analysis is based on cooling tower test data from a June 1990 cooling tower performance test.

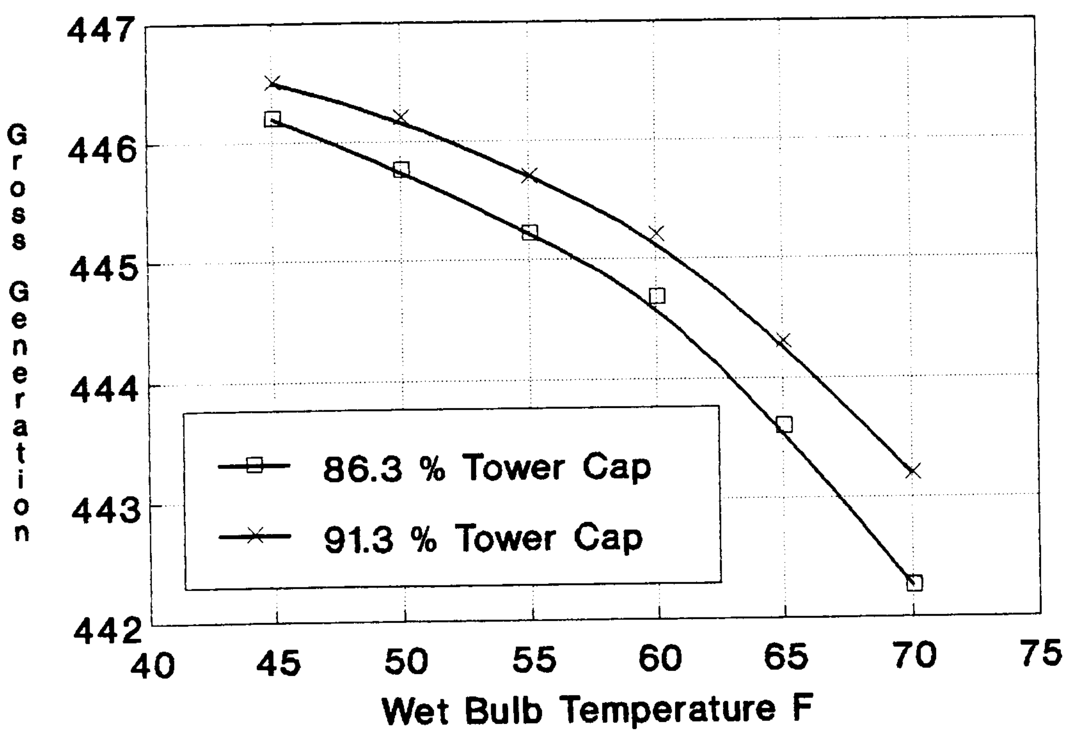


Figure 3 -- Gross Generation vs. Wet Bulb Temperature

CONCLUSION

The cooling tower model, combined with the PEPSE turbine cycle model provides a convenient method of predicting generation losses during the summer months, in addition to quantifying the portion of generation losses that can truly be attributed to the cooling tower. The method is relatively simple to implement if performance curves are available from the tower vendor, and also provides a consistent method for cooling tower test data analysis.

We have not yet had an opportunity to benchmark the cooling tower predictive model against current test data. We plan to complete cooling tower testing on Craig 1 during July 1991, and then compare the actual predictive abilities of the model to plant data throughout the summer and fall.

REFERENCES

(1) PEPSE Computer Code, NUS Corporation, PO Box 50736, Idaho Falls, ID., Version 55I, 1990.

(2) PEPSE Manual: Volume I, User Input Description, NUS Corporation, PO Box 50736, Idaho Falls, ID., Revision 15, 1990.

(3) PEPSE Manual: Volume II, Engineering Model Description, NUS Corporation, PO Box 50736, Idaho Falls, ID., Revision 15, 1990.

(4) ASME PTC 23, Atmospheric Water Cooling Equipment, United Engineering Center, 345 East 47th Street, NY, NY, 1986.

(5) ATC 105, Acceptance Test Code for Water-Cooling Towers, Cooling Tower Institute, 19627 IH-45 North, Houston, TX, June 1982.

APPENDIX A

```
*
*
*         PEPSE USER : ADMIN
*               DATE : 06/01/91
*               TIME : 16:45
*      MODEL FILE ID : C2COOL
*        JOB FILE ID : \EASEPLUS\DEMO\C2cool.JOB
*    RESULTS FILE ID : \EASEPLUS\DEMO\C2cool.OUT
*
= Craig 1 HEI Condenser/Cooling Tower Sub Model
*
*
*
*************************************************************
*       GENERIC INPUT DATA
*************************************************************
*
*  CYCLE FLAGS
010200     0     0     0     0     0     0     0.    0.
*
*  CYCLE CONVERGENCE DATA
012000    50     0.    0.    0.    0.    0.    0     0.
*
*  PEPSE OUTPUT SUPPRESSION CARDS
*
*
*
*************************************************************
*         GEOMETRY CARDS
*************************************************************
*
500100     10        U   400      S
504000    400        T   910      I
504020    400        D   700      I
509000    900        U   400      T
509900    990        U   400      D
*
*
*************************************************************
*       COMPONENT DATA
*************************************************************
*
*************** CONDENSERS AND FEEDWATER HEATERS
*
*  Main Condenser - HEI Model
704000    10     1     5     0.  3.17
704005     1   0.902     1.  456.  21916.    2   -0.85
*
*************** SOURCES, SINKS, AND VALVES
*
*  Input Component for Condenser Sub Model
700100    33     0.  1.556   1954043.    0.  1044.916016
```

```
*  Circ Water Inlet From Cooling Tower
709000   31    84.   30.  -141843.    0.    0.
*  Condenser Drain Inlet Flow
709900   31     0.   30.  2600.     0.  719.900024
*  Output Component - Condensate to Heaters
707000  32
*  Hot Water To Cooling Tower - Sink
709100  30
*
*
***************************************************************
*      SPECIAL FEATURES
***************************************************************
*
*************** SCHEDULES
*
*
800100   '90% Design Flow'
*            X VALUES
810100    45.    50.   55.   60.   65.
*            Z AND Y VALUES
810110    19.   69.000000   71.500000   74.000000   76.750000   79.500000
810120    23.   72.000000   74.000000   76.300003   78.800003   81.500000
810130    27.   74.250000   76.300003   78.500000   80.750000   83.250000
810140    31.   76.650002   78.300003   80.500000   82.500000   84.750000
*
800200   '100% Design Flow'
*            X VALUES
810200    45.    50.   55.   60.   65.
*            Z AND Y VALUES
810210    19.   71.000000   73.500000   75.750000   78.400002   81.250000
810220    23.   74.000000   76.199997   78.500000   80.750000   83.250000
810230    27.   76.500000   78.000000   80.599998   82.750000   85.000000
810240    31.   77.800003   80.599998   82.500000   84.500000   86.750000
*
800300   '110% Design Flow'
*            X VALUES
810300    45.    50.   55.   60.   65.
*            Z AND Y VALUES
810310    19.   73.500000   75.750000   78.000000   80.500000   83.000000
810320    23.   76.599998   78.500000   80.750000   83.000000   85.500000
810330    27.   79.250000   81.000000   83.199997   85.000000   87.500000
810340    31.   81.500000   83.300003   85.250000   87.000000   89.000000
*
*************** SCHEDULE VARIABLES
*
*
*  90% Design Flow Cold Water Temp
830100      1  OPVB  100   OPVB   52   OPVB   53
*
*  100% Design Flow Cold Water Temp
830200      2  OPVB  101   OPVB   52   OPVB   53
```

```
*
*  110% Design Flow Cold Water Temp
830300      3  OPVB  102    OPVB   52   OPVB   53
* .
*************** OPERATIONAL VARIABLES
*
* OPVB(2) = -1.0
870020    -1.
* Set OPVB(40) = 0.333
870400   0.333
* Set OPVB(41) = 100.0
870410   100.
* Design Circ Water Flow
870420   153000.
* 90% Design Flow
870430   137700.
* 110% Design Flow
870440   168000.
* Design Fan Horsepower
870500   170.
* As Tested Tower Capability
870510   100.
* Test Wet Bulb Temperature
870520    63.
* Cooling Range - For Debug
870530   26.799999
* Test Flow
870540   153000.
* Test Fan Horsepower
870550   170.
*
*************** OPERATIONS
*
* Des HP/Test HP
880560    OPVB        50        DIV        OPVB       55        OPVB        56
* OPVB(56)^1/3
880570    OPVB        56        TO         OPVB       40        OPVB        57
* OPVB(57)*TEST FLOW
880580    OPVB        57        MUL        OPVB       54        OPVB        58
* Calculate Predicted Flow
880600    OPVB        58        MUL        OPVB       41        OPVB        60
* Finish Predicted Flow Calculation
880610    OPVB        60        DIV        OPVB       51        OPVB        61
* Calculate Cooling Range
880650    TT         402        SUB        TT        900        OPVB        53
* Test Flow > Design = 0:Test Flow < Design = 1
881100    OPVB        61        BIF        OPVB       42        OPVB       110
* Test Flow < Design = 0:Test Flow > Design = 1
881110    OPVB        42        BIF        OPVB       61        OPVB       111
* Calculate Slope Between 90% and 100% Design Flow
881200    OPVB       101        SUB        OPVB      100        OPVB       120
* Denominator
```

```
881210    OPVB     42     SUB    OPVB     43    OPVB    121
* Calculate Slope
881220    OPVB    120     DIV    OPVB    121    OPVB    122
* Multiply Result * Bound (111)
881230    OPVB    122     MUL    OPVB    111    OPVB    123
* Calculate Slope Between 100% and 110% Design Flow
881250    OPVB    102     SUB    OPVB    101    OPVB    125
* Denominator
881260    OPVB     44     SUB    OPVB     42    OPVB    126
* Calculate Slope
881270    OPVB    125     DIV    OPVB    126    OPVB    127
* Multiply Result * Bound (110)
881280    OPVB    127     MUL    OPVB    110    OPVB    128
* Add Resultant Slopes to Yield One Slope
881300    OPVB    128     ADD    OPVB    123    OPVB    130
* Calculate Intercept Based on Know Flow and CWT
881400    OPVB    130     MUL    OPVB     42    OPVB    140
* CWT - MX = INTERCEPT
881410    OPVB    101     SUB    OPVB    140    OPVB    141
* Calc Predicted CWT -- Slope * Predicted Test Flow
881500    OPVB    130     MUL    OPVB     61    OPVB    150
* Add Intercept to Yield Cold Water Temp
881600    OPVB    150     ADD    OPVB    141    OPVB    160
* Input CWT to Circ Water Source
881700    OPVB    160     EQL    TTVSC   900
* Input Test Flow to Circ Water Inlet Source
881710    OPVB     54     MUL    OPVB      2    WWVSC   900
*
*************** SPECIAL INPUT/OUTPUT
*
891000     'Cold Water Temp to Condenser'
891001     OPVB       160
891009     F5.1
*
*
.
```

APPENDIX B

SPECIAL DATA

MAIN SURFACE CONDENSER

Size sq. ft.	218000
Number of Water Passes	2
Steam Condensed lbs/hr	1954043
Cooling Water g.p.m.	141843
Cooling Water Temperature °F	84
Tube Cleanliness Factor %	85
Absolute Pressure inches of Hg	3.17

Tubes	Air Core Section and Impingement Areas	Bulk of Condenser
Number	1760	20156
Size O.D.	1.00"	1.00"
Wall	18 BWG	18 BWG
Length	38'2.5"	38'2.5"
Material-ASTM	B-111 90-10 CuNi Alloy 706	B-111 Admiralty-Alloy 44

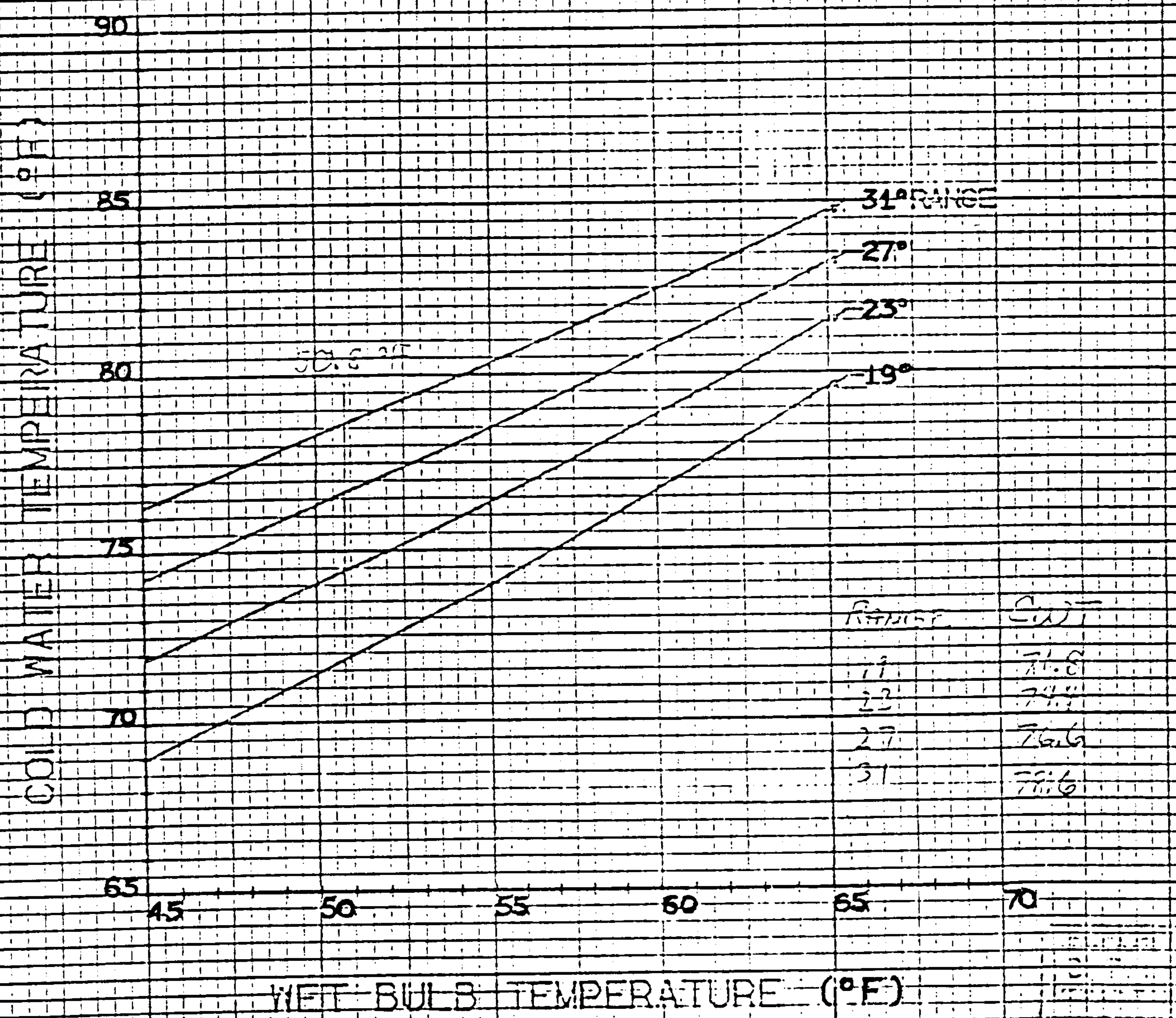
APPENDIC C

PERFORMANCE CURVE
FOR
COLORADO-UTE ELECTRIC ASSOCIATION
CRAIG STATION-UNIT 1 OR 2

MODEL 6516-4-10 COOLING TOWER
336 HP24-8 FANS AT 170 BHP/137 RPM
DESIGN 153,000 GPM AT 110.6 84 63

THE MARLEY COOLING TOWER COMPANY
MISSION, KANSAS
C.O. 12-197-74 / 12-209-74

90% DESIGN FLOW
137,700 GPM



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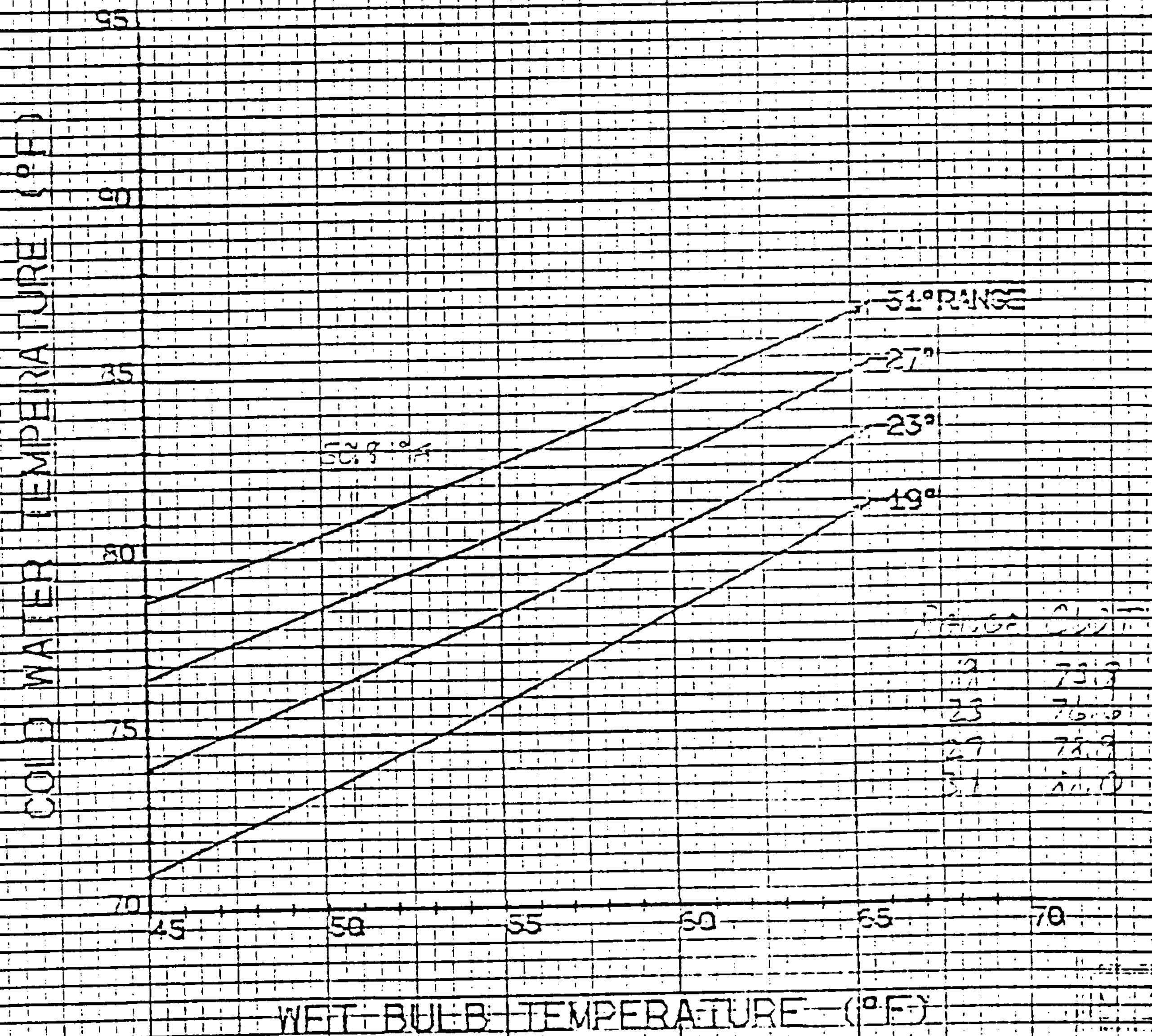
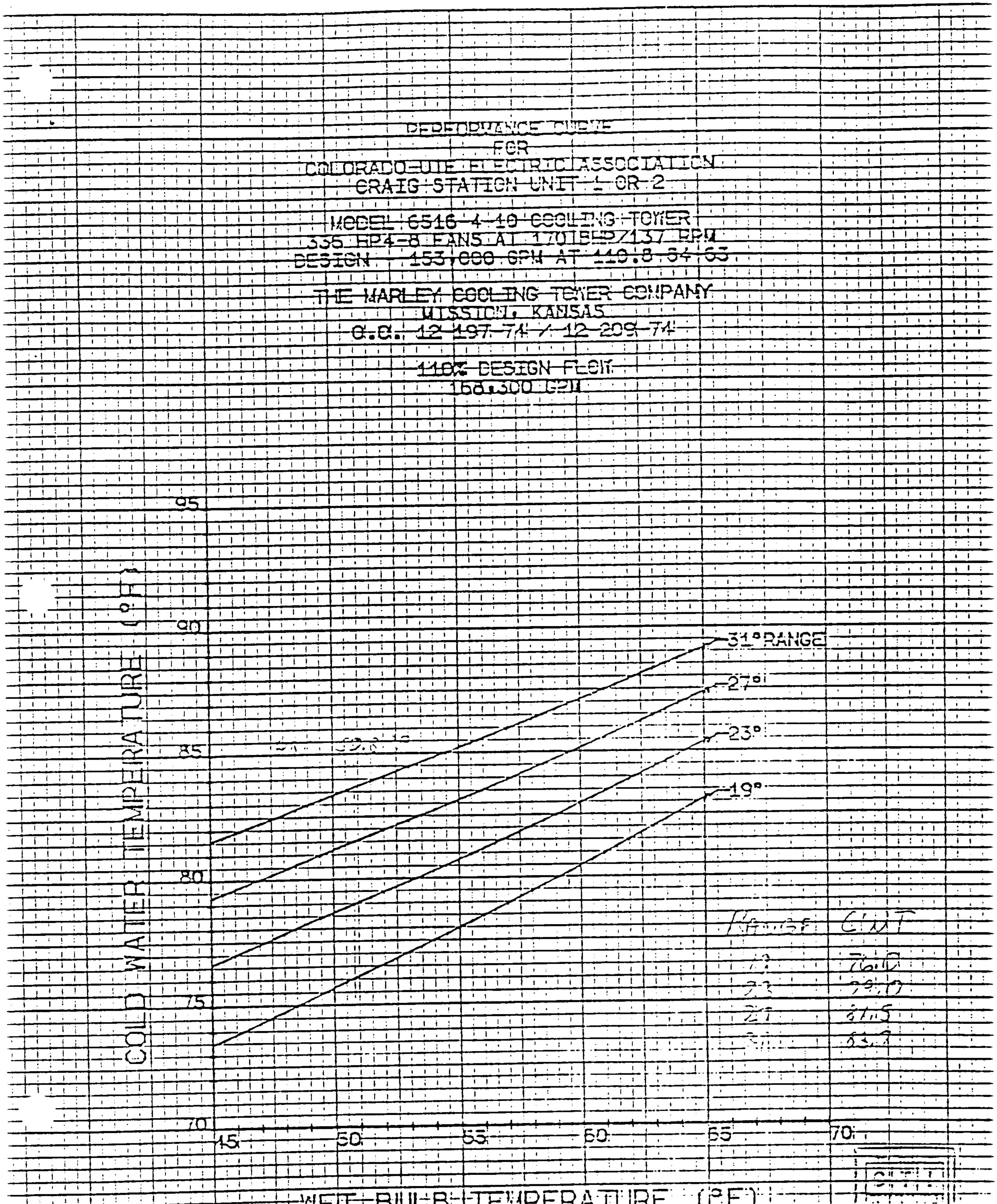
PERFORMANCE CURVE
FOR
COLORADO-UTE ELECTRIC ASSOCIATION
CRAIG STATION UNIT 1 OR 2

MODEL 6516-4-10 COOLING TOWER
336 HP 4-8 FANS AT 170 BHP/137 RPM
DESIGN 153,000 GPM AT 110.3 84 63

THE MARLEY COOLING TOWER COMPANY
MISSION, KANSAS
O.O. 12-197-74 / 12-209-74

100% DESIGN FLOW
153,000 GPM




PERFORMANCE CURVE
FOR
COLORADO-UTE ELECTRIC ASSOCIATION
CRAIG STATION UNIT 1 OR 2
MODEL 6516-4-10 COOLING TOWER
335 HP4-8 FANS AT 170 BHP/137 RPM
DESIGN - 153,000 GPM AT 110.8-54-63
THE MARLEY COOLING TOWER COMPANY
MISSION, KANSAS
O.C. 12-197-74 / 12-209-74
110% DESIGN FLOW
168,300 GPM
COLD WATER TEMPERATURE (°F)
WET BULB TEMPERATURE (°F)
95
90
85
80
75
70
45
50
55
60
65
70
31° RANGE
27°
23°
19°
Range
CWT
81.5