Cooling Tower Modeling with PEPSE

Performance Software User's Group Meeting
Idaho Falls, ID
June 2000

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Introduction

Rochester Gas and Electric Corporation conducts the regulated energy business of RGS Energy Group, Inc, with headquarters in Rochester, New York. RG&E has a mix of electric generation, including a 500MW nuclear plant, a 250MW coal plant, three hydro electric plants on the Genesee River with a total output of 50 MW, and two peaking combustion turbines of 18 MW each. The newest addition to the RG&E generation system is a 60MW combined cycle plant, which utilizes a GE LM6000 combustion turbine. The plant was previously operated by an IPP, providing steam to a thermal host and electric to RG&E. The plant now is owned by RG&E and is operated as an electric peaking plant.

Background

RG&E acquired the combined cycle plant in late 1998, and we utilized PEPSE to help characterize plant performance. The plant originally had an extraction from the steam turbine to supply the thermal host, but that is no longer in use, so we evaluated performance without the extraction. A two pressure heat recovery steam generator on the combustion turbine exhaust provides steam at 900 and 150 psi to supply the steam turbine. Duct burners on the HRSG can be used to increase steam flow and temperature, thereby increasing the electric generation from the steam turbine generator.

Circulating water for the main condenser is provided from a two cell mechanical draft cooling tower. The tower has two variable speed fans, each rated at 200 HP, and the fan speed can be reduced to approximately 50% of nominal. In an effort to minimize plant auxiliary loads, we wanted to determine if the fan speed could be reduced while maintaining acceptable tower performance. We utilized PEPSE to characterize the cooling tower and predict performance.

PEPSE Modeling

A cooling tower sub-model was developed to study tower performance, and this sub-model was later incorporated into the plant combined cycle model. The PEPSE cooling tower model is a simple performance mode model, and requires only a few inputs. The approach temperature must be specified, which is the difference between the wet bulb temperature of the incoming air and the water leaving the tower. This is typically at least 5°F, as any smaller value greatly increases the size of the cooling tower, and in our case was specified to be 8°F. Two additional pieces of information are needed for the model, however, that may not be readily available. The first is air flow rate through the tower. If manufacturer's data is not available, an initial guess is to set the air mass flow rate equal to the water mass flow. The tower manufacturer refers to this as the L/G ratio (liquid to gas) and it is typically 1.0 or somewhat less. The second required model input is the temperature of the air leaving the tower. This has a big impact on tower performance, as hotter air can contain more water and therefore provide more capacity for evaporative cooling. It is difficult to predict the air leaving temperature, as it depends upon the degree of contact between the air and the water. To help estimate the exit air temperature, it will be no colder than the inlet air wet bulb, and cannot be any warmer than the return water temperature. We eventually selected a temperature approximately 10° F below the return water temperature, as the PEPSE prediction of tower performance matched fairly well with the manufacturer's data sheet at that temperature.

We also wanted to know the relative humidity of the air leaving the tower, as this should be close to 100%. If the airflow through the tower is excessive, the leaving relative humidity will be low, and the heat transfer due to evaporation will be less than it could be. This represents an inefficiency, with the fan power consumption higher than needed to produce the desired water outlet temperature.

We looked at several operating conditions, with the results presented in the attached tables. Table 1 shows predicted performance with three different exit air temperatures. The inlet air conditions were varied over a range of dry bulb temperatures, while maintaining the design condition of 75°F wet bulb temperature. As the exit air temperature was reduced, the relative humidity of the exit air increased until the air was saturated. The evaporation rate is higher for the hotter/dryer incoming air, and the percentage of heat transfer due to evaporation is maximized. In a typical tower design, 90% of the heat transfer is due to evaporation and 10% due to sensible heating of the incoming air. It certain situations, especially with high air flow rates, the exit air dry bulb temperature will actually be lower than the incoming air dry bulb temperature.

Table 2 shows the effects of increasing the air flow rate at a given air exit temperature. Again a range of inlet air dry bulb temperatures were studied. The relative humidity of the exit air decreased as the flow rate increased. The L/G ratio was varied from 1 to .5, typical values for a mechanical draft cooling tower.

Summary

The PEPSE modeling indicates that air flows greater than that required for 100% relative humidity in the exit air do not improve tower performance, and do not result in reduced water outlet temperatures. If the air flow is too low, the evaporative cooling will be insufficient and the desired approach temperature will not be achieved. It is also beneficial to maximize the air exiting temperature, but there is little the user can do to affect this.

Future Work

We intend to measure the exiting air temperature, using a grid pattern to determine an average value at the outlet of the fanstack. This will help validate the PEPSE model and confirm the tower performance calculations. We do not know of a simple method to determine the exiting air relative humidity, so that will be estimated through calculations. We should be able to use the PEPSE model to predict the minimum air flow required to provide sufficient cooling. And even without the modeling, we can reduce the airflow until the water outlet temperature begins to rise, and we will be reasonably confident that that is the point of 100% relative humidity in the exiting air.

Conclusion

The PEPSE cooling tower model is a useful tool for analyzing tower performance and it can provide information on the variables affecting operation. The model can help characterize tower performance and provide a basis for assessing current condition.

Table 1
PEPSE Cooling Tower Model Output
Analysis of Exit Air Temperature

Inlet Air			Exit Air			Air Flow	Water Flow	Makeup	Water Temp	
DBT	WBT	RH	DBT	WBT	RH	KLB/Hr	KLB/Hr	KLB/Hr	Inlet	Outlet
100	75	32	99	90	70	15,000	15,000	227	99	83
90	75	50	99	90	70	15,000	15,000	198	99	83
80	75	80	99	90	70	15,000	15,000	160	99	83
75	75	100	99	90	70	15,000	15,000	144	99	83
100	75	32	95	90	81	15,000	15,000	242	99	83
90	75	50	95	90	81	15,000	15,000	212	99	83
80	75	80	95	90	81	15,000	15,000	174	99	83
75	75	100	95	90	81	15,000	15,000	158	99	83
100	75	32	90	90	99	15,000	15,000	260	99	83
90	75	50	90	90	99	15,000	15,000	230	99	83
80	75	80	90	90	99	15,000	15,000	192	99	83
75	75	100	90	90	99	15,000	15,000	176	99	83

Notes:
1) DBT is Dry Bulb Temperature, F

2) WBT is Wet Bulb Temperature, F

3) RH is Relative Humidity, %

Table 2
PEPSE Cooling Tower Model Output
Analysis of Air Flow Rate

Inlet Air			Exit Air			Air Flow	Water Flow	Makeup	Water Temp	
DBT	WBT	RH	DBT	WBT	RH	KLB/Hr	KLB/Hr	KLB/Hr	Inlet	Outlet
100	75	32	90	90	99	15,000	15,000	260	99	83
100	75	32	90	87	87	20,000	15,000	271	99	83
100	75	32	90	84	80	25,000	15,000	283	99	83
100	75	32	90	83	75	30,000	15,000	295	99	83
90	75	50	90	90	99	15,000	15,000	230	99	83
90	75	50	90	86	87	20,000	15,000	230	99	83
90	75	50	90	84	80	25,000	15,000	230	99	83
90	75	50	90	83	75	30,000	15,000	230	99	83
80	75	80	90	90	99	15,000	15,000	192	99	83
80	75	80	90	87	87	20,000	15,000	181	99	83
80	75	80	90	84	80	25,000	15,000	169	99	83
80	75	80	90	83	75	30,000	15,000	157	99	83
75	75	100	90	90	99	15,000	15,000	176	99	83
75	75	100	90	87	87	20,000	15,000	159	99	83
75	75	100	90	84	80	25,000	15,000	141	99	83
75	75	100	90	83	75	30,000	15,000	123	99	83

Notes:
1) DBT is Dry Bulb Temperature, F

2) WBT is Wet Bulb Temperature, F

3) RH is Relative Humidity, %