Reflux Sub-cooling of Condensate in biomass power plant

By

Emamode A Ubogu

Abstract

In this project the effects of injecting sub-cooled water into the path of exhausted steam before an air cooled condenser (ACC) has been analysed under various mass flow rates and temperatures during high ambient temperatures. The analysis has been carried out using the basic heat transfer mathematical model in addition to the principle that lowering the condenser pressure can increase the efficiency of a steam cycle. From the analysis it is evident that introducing sub-cooled water into the system reduces the temperature of the condensate and increases the amount of heat rejected by the ACC. Ultimately this can lead to a 2 to 3 percent increase in power output of the power plant.

Introduction

Cooling of exhaust steam is an important part of a thermal power plant and can affect the overall efficiency of a power plant. Against water cooling which is used in large thermal power plants and must be situated close to a reliable source of water, air cooling condensers (ACC) are now becoming more important from the economic and environmental standpoint [1].

In ACC, air is forced through bundles of tubes carrying steam by fan units in a closed steam cycle as a result condensation with the heat rejected to the environment. The amount of heat rejected is influenced by environmental parameters such as ambient temperature, the wind speed and the direction of the wind[2]. Also, the desire to increase physical parameters such as an increase in the generation capacity of the power plant affects the ACC performance. These conditions impacts on the back pressure, temperature of the exhausted steam or the time exposed to the condenser which can tweak the performance of the system. This directly affects the output of the steam turbine as a result of the dynamic interaction between the ACC and the steam turbine[1]. Adjusting the speed of the ACC fan units to raise the mass flows of air through the bundle of tubes or addition of fan units with the expansion of the ACC are known remedies[1].

The purpose of this project is to explore the use of sub-cooling and direct condensation to boost the performance of the ACC. This is when sub-cooled water is injected in the path of the steam after the turbine, recovered after the condenser and recycled through the process, Fig 1. In this study, the data of an ACC obtained from bio-mass power plant located in Scunthorpe, England, which works on the Rankine steam cycle have been analyzed extensively.

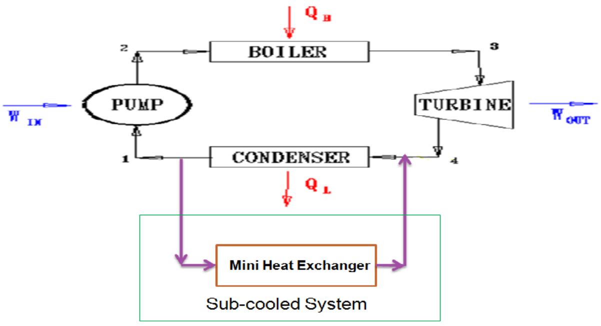

Fig.1. Power Plant Cycle with Sub-cooling.

Power Plant Description

The power plant has been designed for a power output of 13.5 MW for a 10 degree ambient temperature operating condition during which the ACC is expected to reject 28.4MW of heat, Fig 2.

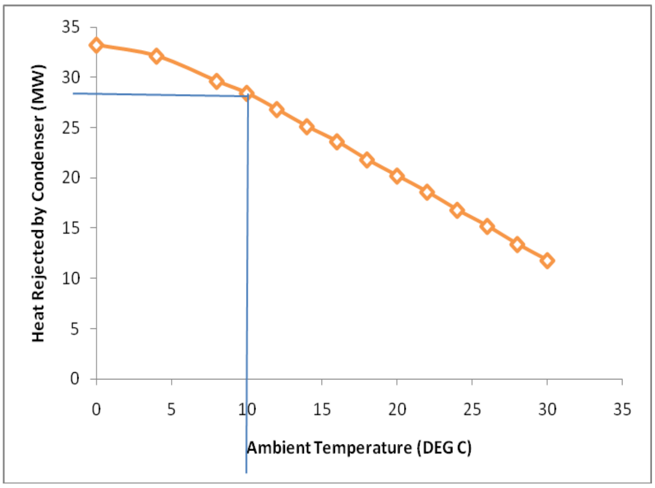

Fig.2. Effect of ambient temperature on heat rejected by the ACC.

Nomenclature			
C_g	latent heat capacity	T_1	temperature of mixture
C_p	specific heat capacity	T_2	temperature of sub-cooled water
m_{es}	mass flow rate of exhausted steam	T_3	temperature of exhausted steam
m_{sc}	mass flow rate of sub-cooled water		

The condensing pressure of the steam at this point is supposed to be 0.09bars for that amount of heat to be rejected and the power output sustained. Fig 3 shows how the power output drops when the back pressure increases.

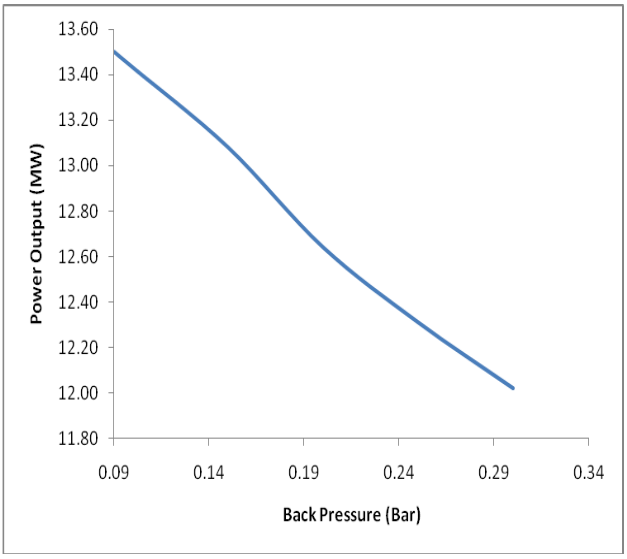

Fig.3. Relationship between the back pressure and power output.

In perspective, the ambient temperature and heat transfer design of the ACC affect the condenser pressure which in turn affects the power output of the entire plant[3]. For 23% of the year, the ambient temperature is greater than 15 degrees; consequently the power plant operates below its full potential for 23% of the year.

Theory of ACC Enhancement

Enhancing the power output of a thermal power plant can be achieved in different ways which include the – Lowering the condenser Pressure, superheating the steam to High Temperatures and increasing the boiler Pressure. The parameter relating the efficiency of an ACC to the output of the turbine is the back pressure. An inefficient condenser would cause a rise in the back pressure in the system which impacts on the effectiveness of the steam turbine. Lowering the back pressure can be achieved by lowering the temperature of the steam as the pressure and temperature directly relates. Injecting sub-cooled water at a lower temperature into the path of the steam after the turbine would significantly reduce the temperature of the steam thereby making it easier for the ACC to condense the steam quickly.

The sub-cooled water injected experience heat gain which is lost from the steam and can be expressed by the equation below.

$$m_{sc}C_p(T_1\text{-}T_2)= m_{es}C_g(T_3\text{-}T_1)$$

To further analyse the effects of the sub-cooled system on the output, the following assumption and variations have been made:

- The mass flow rate of exhaust steam is constant - m_{es} = 14.811Kg/s
- The introduction of sub-cooled water have been varied between a percentage range of the exhaust steam mass flow rate m_{sc} *= 5 to 15% of 14.811Kg/s*
- The sub-cooled water is varied from zero (0) to ten (10) degree Celsius.

Result Analysis

Injecting sub-cooled water into the exhaust steam reduces the temperature of the steam invariably reducing the back pressure as well. Fig. 4 shows the mass flow rate vs the percentage increase in output power at constant exhaust steam temperature and back pressure i.e 57.8^{0}C and

0.18bar respectively. It confirms that as the mass flow rate of the sub-cooled water injected is raised regardless of the temperature, the percentage power output of is also increased.

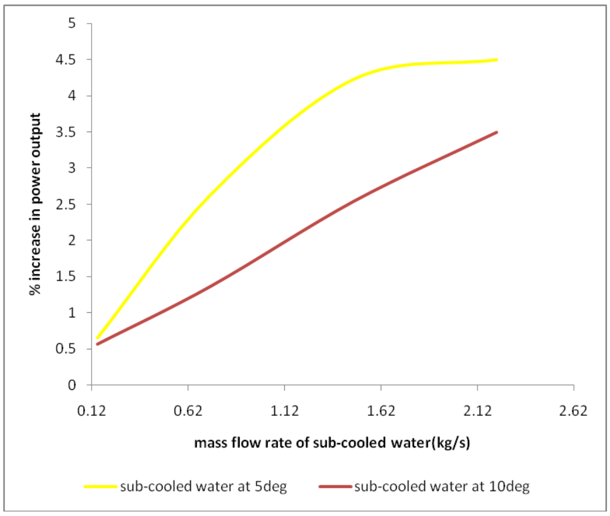

Fig.4. Comparing the effect of sub-cooled water at constant exhaust steam temperature - 57.8^{0}C.

It can however been seen that when the temperature of sub-cooled water is much lower the change in net power is higher.

In reality, it would be costly or labour intensive to vary the temperature of the sub-cooled water. Since the ambient temperature directly affects the ACC which impacts on the condensing pressure and temperature, it is therefore necessary to have a constant temperature for the injected sub-cooled water.

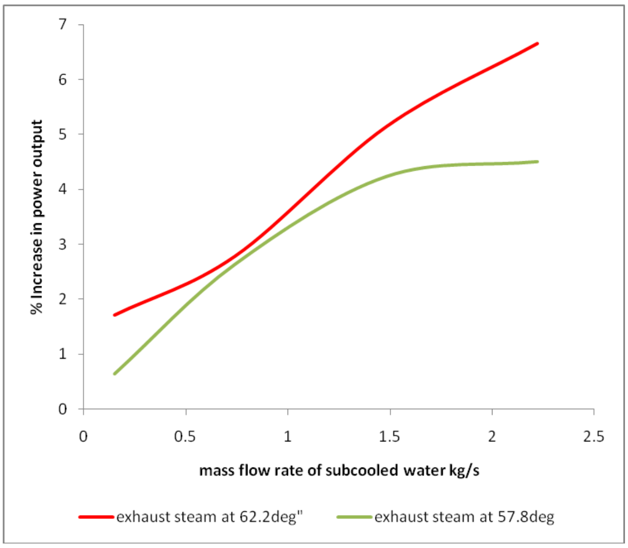

Fig.5. Effect of sub-cooled water at at constant temperature - 5^{0}C.

Fig 5 is a graph of the mass flow rate of sub-cooled water at a constant temperature of 5^{0}C against the increase in power output. It corroborates fig. 4 and also reveals a convergence between the exhaust steams lines. The convergence illustrates an approximate mass flow rate value at which sub-cooled water at 5^{0}C can be injected at the exhaust steam conditions. The graphs there gives a picture that at an estimated mass flow rate of 0.8kg/s of injected sub-cooled water will lead to about 2.8% increase in power output.

Conclusion

Installing a sub-cooled system would raise the power output by 2 to 3% (approximately 400KW). This can be achieved by injecting sub-cooled water between a mass flow rate of 0.15 and 1kg/s at a temperature of 5^{0}C.

Future work would look at the power input needed to realise the required enhancement and the cost of setting up the sub-cooling unit.

Acknowledgements

I am grateful to Dr Yajue Wu and Aren Houghton for their support and guidance throughout the project.

References

[1] M. Pieve and G. Salvadori, "Performance of an air-cooled steam condenser for a waste-to-energy plant over its whole operating range," *Energy Conversion and Management,* vol. 52, pp. 1908-1913, 2011.

[2] P. Liu*, et al.*, "Numerical investigation of hot air recirculation of air-cooled condensers at a large power plant," *Applied Thermal Engineering,* vol. 29, pp. 1927-1934, 2009.

[3] C.-C. Chuang and D.-C. Sue, "Performance effects of combined cycle power plant with variable condenser pressure and loading," *Energy,* vol. 30, pp. 1793-1801, 2005.

[4] Y. R. Mayhew and G. F. C. Rogers, *Thermodynamic and transport properties of fluids: SI units*: Basil Blackwell, 1972.