QGECE Research on Heat Exchangers and Air-Cooled Condensers

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Abstract

The aim of this paper is to give an overview of the research conducted at Queensland Geothermal Energy Centre of Excellence (QGECE) on air-cooled condensers for application in geothermal power plants. The application of metal foam heat exchangers in Natural Draft Dry Cooling Towers (NDDCTs) has also been studied in detail. Samples of the numerical and experimental results are presented. These findings are then backed up by theoretical modelling that enables us to run parametric studies which are sensible to different working/environmental conditions.

Keywords: Air-cooled condensers, NDDCT, heat exchangers, theoretical, experimental, CFD

Introduction

Australia's current policy targets an annual renewable energy generation of 45,000 GWh by 2020. Geothermal energy systems have the potential to produce a base load generation capacity capable of replacing existing coal-fired plants. However, there are some technical challenges to be overcome first. One of the major technical difficulties is the cooling system. Although wet cooling is more efficient than dry cooling, water shortages and harsh environmental conditions in areas such as the Australian desert have forced designers to consider less efficient and more expensive air-cooled systems, or dry-cooling as it is often termed.

Air-cooled plants offer potential economic advantages due to plant sitting flexibility. Both natural draft and mechanical draft dry-cooling towers, equipped with air-cooled heat exchangers (almost always with extended airside surface area), are used. The fan-driven systems can be built quickly and at relatively low cost but their operating costs are higher due to their higher maintenance requirements and the parasitic losses associated with running the fans. The cooling system is a significant cost item in the power plant and affects the performance of the entire power cycle. If the cooling system does not provide adequate cooling, the overall plant efficiency plunges with serious economic consequences (e.g. decreased electricity production).

It has been reported that approximately 0.3 GWh (per year) of electricity generation in the United States is lost because of cooling towers operating below their design efficiency. This corresponds to an economic penalty of around 20 million US dollars per year [1]. It is therefore, very important to design and analyse highly efficient dry cooling systems for power plants.

Though air-cooled condensers are not very popular, their application to power industry is not a new practice. Interestingly, a hyperboloid cooling tower was patented in 1918. The reason for the renewed interest in air-cooled condensers is scarcity of water or high humidity [2]. In either case fan-cooled systems can lead to high parasitic losses. This makes the NDDCT an ideal option for such cases. The reason for QGECE's interest in NDDCT is obvious. Most of our geothermal resources are located where there is no water. Besides, the thermal efficiency of our binary power plants is already so low that we cannot afford parasitic losses (fans).

Methodology

In view of the above, QGECE has been looking into applying efficient heat exchangers to reduce the cost of towers. This would have been impossible unless a proper test bed is provided. In doing so, a 2m height cooling tower is built and is operational at our QGECE lab, see Figure 1.

Figure 1: The QGECE lab scale model for a NDDCT.

The tower has a square cross-section with 1.4x1.4 m^2 base area and 0.9167x0.9167 m^2 tower exit area. The heating elements are four electrically heated copper bars of 10 mm diameter. At the same time, a numerical model is built, as depicted by Figure 2, so that parametric study of the problem is possible [3]

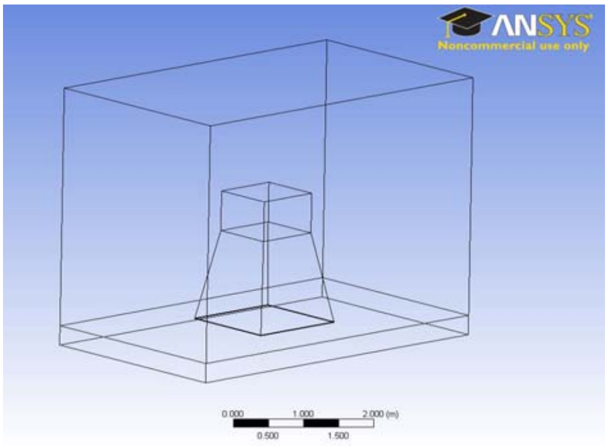

Figure 2: The computational QGECE lab scale model for a NDDCT.

Parallel to these tests and simulations a theoretical model is developed to shed some light on the scaling of such NDDCTs under no wind conditions [4].

A new design for tubes in air-cooled condensers is currently being examined at QGECE. The idea is to replace the fins by a layer of metal foams, see Figure 3, to increase the heat transfer area and, hence, reduce the total tube numbers and heat exchanger size/cost [2]. This can significantly reduce the cost as an efficient heat exchanger will lead to a less expensive (and shorter) cooling tower.

Figure 3: The metal foam-wrapped tube used in QGECE labs to conduct experiments on air-cooled condensers.

Theoretical and numerical analysis of such foam-wrapped tubes in air-cooled condensers have been reported in an earlier study [5]. Thus, experimental analysis followed initial high-level theoretical investigations. Figure 4 illustrates a photo of our test section where air is forced (by a suction fan) to flow over a heated metal foam-wrapped tube. The tube surface temperature is kept constant by using a circulation heater that pumps water (at adjustable flow rates) through the tube to keep the tube surface temperature uniform and constant similar to a condenser where the fluid flowing in the tubes undergoes phase change. The same test section is used to collect data for a finned-tube of 30 mm OD with (197 fins of 0.6 mm thickness per meter). This is a typical design for an air-cooled condenser; similar to the ASPEN design one analysed in [3].

Figure 4: The low speed wind tunnel test facility; the hot water circulator and data acquisition system (sitting on the desk).

Results and discussion

Cooling tower results

Experiments are conducted to evaluate the tower frictional (shape) resistance, i.e. by excluding the heat exchanger resistances. A total of 25 data-points were used to measure the air temperature at the exit from the tower, as depicted by Figure 5. The results are then compared to numerical and theoretical predictions. The result from the temperature measurements involves the uncertainty of measurements which is estimated by using a basic uncertainty analysis [6]. The measured air velocity at the exit is 0.543±0.064 m/s which is very close to both theoretical (0.515 m/s) and numerical (0.515 m/s) predictions.

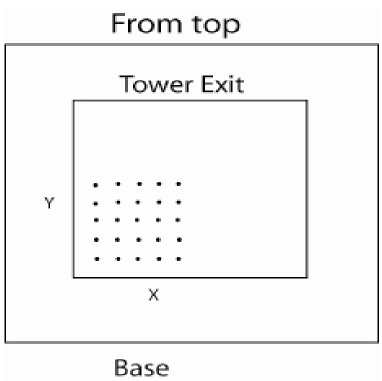

Figure 5: The location of the thermocouples to measure the air temperature at the exit from the tower.

The following formula [4] has been used to predict the tower inlet velocity, *U*, for the empty tower

$$U \sim \sqrt{\frac{2g\Delta\rho H}{k}} \quad (1)$$

and for the case where heat exchangers introduce a resistance to flow

$$U \sim \sqrt{\frac{\sqrt{K}gH\Delta\rho}{tC_F}} \quad (2)$$

with k, g, K, H, t, C_F, and Δρ being the frictional loss coefficient, gravitational acceleration, bundle permeability, the tower height, the bundle thickness, form drag coefficient, the inlet-outlet air density difference, respectively.

Figure 6 illustrates the results of numerical simulations compared to theoretical predictions for taller cooling towers where the bundle velocity is plotted versus the tower height on a log-log scale. The 200m tower is designed to dump 283 MW of heat for a power plant that generates 50MWe [3]. The volumetric heat generation rates for shorter towers are then scaled down and implemented as inputs to our CFD simulations. As seen, the developed theory in [4] is capable of predicting the thermohydraulic performance of a NDDCT under no wind conditions. However, as wind can dramatically affect the performance of a NDDCT [7-12], QGECE is focusing on better understanding of the effects of cross-wind on scaling of the cooling towers.

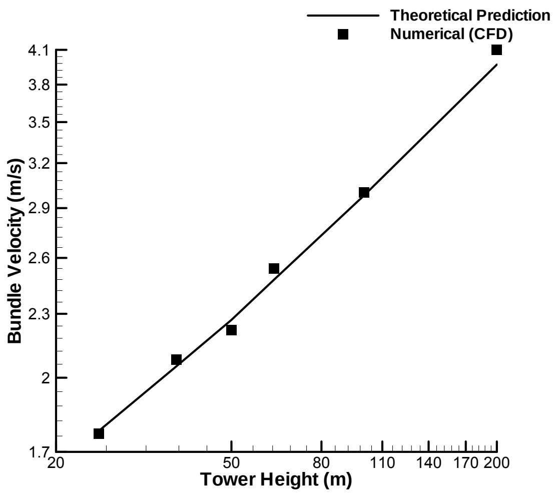

Figure 6: Numerical and theoretical prediction of bundle velocity for towers of different heights.

Metal foam results

In our last year report at Australian Geothermal Conference, it was numerically shown that the metal foams can be used in air-cooled condensers with a potential to reduce the size and cost of the condensers [13]. It has been argued that the area goodness factor (j/f; dimensionless heat transfer to pressure drop ratio) of the foam heat exchanger is higher than that of an ASPEN designed finned- tube one; see Figure 7.

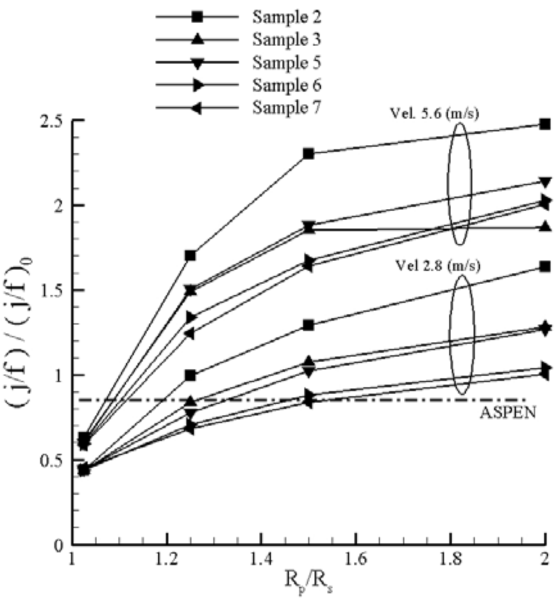

Figure 7: Normalized area goodness factor versus porous layer thickness for different samples and free stream velocities (samples 2-7 refer to commercially available ERG metal foam samples).[13]

Figure 8 illustrates a sample of our recently collected experimental data. This figure shows plot of heat transfer ratio versus the approaching air velocity.

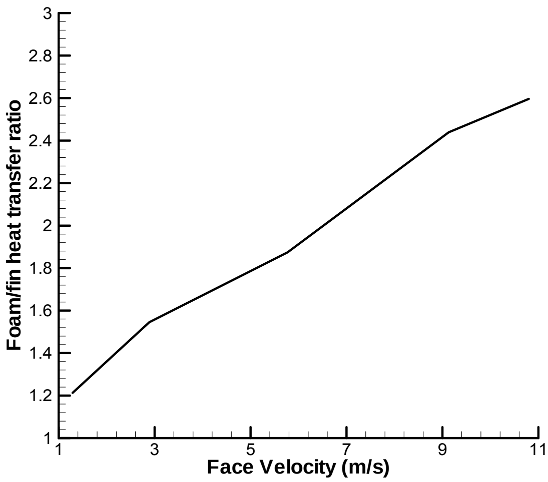

Figure 8: Heat transfer ratio (foam-wrapped tube divided by finned-tube) versus face velocity. Finned-tube is designed by ASPEN where tubes are 30 mm OD with 197 fins per meter. Fin diameter is 60 mm and the fin plate thickness is 0.6 mm; see [3] for more details.

Interestingly, with the same pressure drop, the heat transfer from a foam-wrapped tube is always higher than that of a finned tube. The ratio can figure out at 2.6 at high velocities which can lead to more compact tube bundles and thus results in decreasing the capital cost. This gain for fan-cooled systems can lead to significantly reduced parasitic loses as with new design the number of bundles is almost halved (so are the parasitic losses). Furthermore, the pressure drop in the air cooled condenser is reduced as the number of the bundles is almost halved. Another point in favour of such compact systems is the lower tube-side pressure drops because of the elimination of a large number of the tubes in the condenser.

Concluding remarks

An accurate model, compared to experimental and CFD results, is developed to predict the heat and fluid flow through NDDCTs. Metal foam heat exchangers are tested and found to be superior to fins for air-cooled condensers. Further research is planned at QGECE to examine different working and environmental conditions.

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