New Design Concepts for Natural Draft Dry Cooling Towers

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Design of efficient natural draft dry cooling system is essential for Australian geothermal power plant applications. In fact, dry cooling may be the only option for most geothermal power plants planned to be established in Australia since these areas have limited access to water resource.

Natural draft cooling towers in coal-fired and nuclear power plants have been mainly of concrete construction. It has been reported that the highest concrete cooling tower in the world of 200 meters high has been built at the RWE power station at Niederaussem (Busch et al, 2002). Due to the lower thermal efficiencies of geothermal power plants, the heat rejection per kWh(e) of net generation from these plants will be four or more times as great as from fossil fuelled plants (Kröger 2004), which will require a much larger cooling tower for a geothermal power plant of compared to a coal-fired power plant of similar capacity. The design and construction of such a large concrete cooling tower is extremely expensive and takes a long time to build. The tower structure is heavy and requires substantial foundation.

The Queensland Geothermal Energy Centre of Excellence (QGECE) is to explore new concepts for natural draft dry cooling technologies for geothermal power plants. The aims for the new design concepts are to increase the performance of the cooling tower and reduce the overall cost. Two alternative designs are proposed: low cost air-lift mobile cooling tower (Gurgenci and Guan, 2009) and solar cooling tower.

The design concept for air-lift mobile cooling tower is as follow: the tower is built as a flexible shroud and is held in place in tension by the buoyancy force provided by a lighter-than-air gas. One benefit for the air-lift cooling tower is that the industry can construct very tall cooling towers at an acceptable cost. Other benefits include constructing such towers with a minimum of time and expense, which are of relatively light weight and which are not subject to frequent repairs. The towers are mobile and can be disassembled and moved to a new geothermal plant site with a minimum of time and effort.

The design concept for solar cooling tower includes a solar energy system which is used to preheat the air inside the cooling tower to increase the buoyancy of the natural draft cooling tower. The enhanced buoyancy enable the cooling tower be constructed with either reduced size or with increased tower performance, which is especially beneficial during hottest time period in a day.

Keywords: Geothermal energy, Cooling tower and heat exchanger, natural draft cooling technologies.

Natural Draft Dry Cooling Towers

A natural draft dry cooling tower is a heat rejection device that creates the flow of air through the bundles of finned tube heat exchangers by means of buoyancy effects. Buoyancy occurs due to a difference in air density before and after heat exchanger resulting from temperature and moisture differences. The greater the thermal difference and the height of the tower structure, the greater the buoyancy force. Therefore, the volume flow rate of air across the heat exchanger bundle is directly proportional to the height of the cooling tower.

Natural draft dry cooling towers are particularly attractive as a cost-saving solution for larger power plants where water resource is limited and expensive. The unique economic advantage of natural draft cooling towers lies in their very low electric energy requirement. Fan cost and substantial amount of fan power are saved in this system. The operating costs are minimal.

Natural cooling towers have been designed in various ways. However, reinforced concrete structures have become standard to handle the high cooling water flow rates in large power plants.

Fig.1 shows a configuration of natural draft dry cooling tower used by the thermal power plants.

Fig.2 is a photo taken from Yangchen power plant of China.

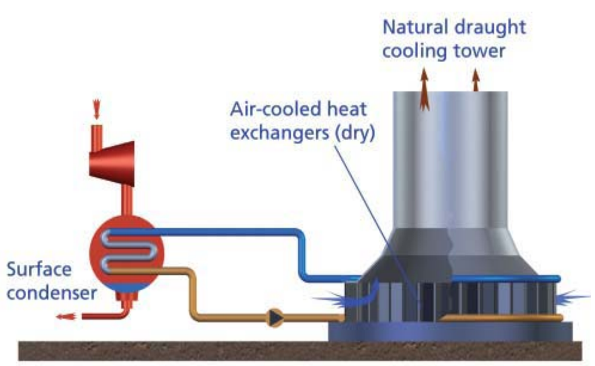

Fig.1 Natural draft dry cooling [GEA Aircooled Systems]

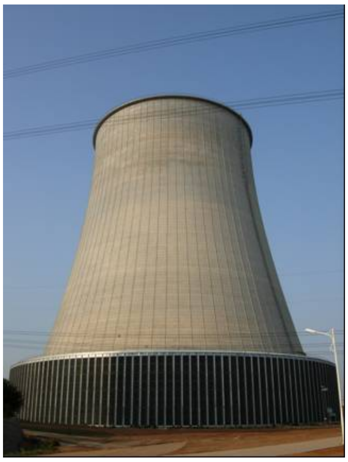

Fig.2 Yangchen Natural Draft Cooling Tower

New Design Concepts

Three design concepts are proposed in this paper. The first concept relies on a conventional steel construction design. The second concept, the air-lifted tower, is a radical invention that proposes the use of helium-filled toroidal rings to provide the tower structure. The third concept is a novel combination of the solar chimney idea with natural draft dry cooling towers.

Steel Towers with Advanced Heat Exchangers

One of the reasons behind the use of reinforced concrete construction as a method of building natural draft dry cooling towers in coal-fired power plants is the concern about corrosion caused by exposure to some of the elements in the flue gases in combination with the ambient effects. These concerns do not apply to a binary geothermal plant. Therefore, the use of steel towers is allowable in geothermal plants and this choice may offer new options that are not available to fossil fuel power plant designers. A combination of steel construction methods with some of the advanced heat exchanger options that deliver high heat exchange rate/ pressure drop ratios could then be a viable option. A steel tower design will be presented that will have the capability to power air-cooled condensers for a commercial geothermal power plant subject to ambient conditions typical of the Australian outback.

Air-lifted natural draft cooling tower

In this design, a flexible shroud is the main body of the tower structure and is held in place in tension by the buoyancy force. This flexible shroud includes stiffening rings, sealing skin and tensioning cables as shown in Figure 3. The shroud can be divided into several sections and prefabricated in factory and assembled/installed quickly in site.

The stiffening rings are made of different diameters and placed periodically to form the desired shape required (such as hyperbolic concrete tower used in most coal-fired and nuclear power plants). The tension cables are connected to the stiffening rings to add strength and hold the shroud in place by tension. The sealing skin can be made of light materials and can be attached to the stiffening rings quickly and economically in site. The flexible shroud can have durability for wind load and weather resistance.

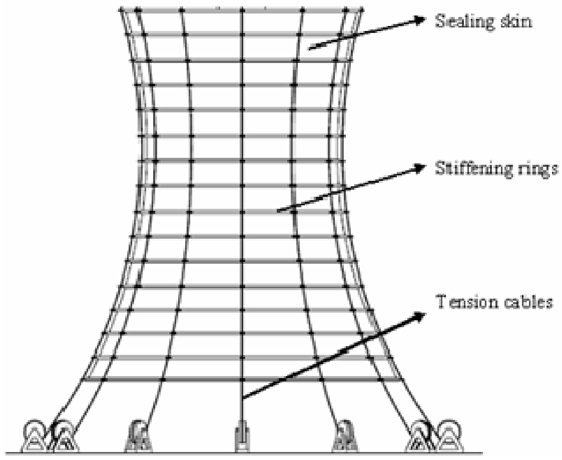

Fig.3 Proposed structure flexible shroud

To provide lifting force to the flexible shroud, stacked helium-filled toroidal vessels are connected directly to stiffening rings separately as indicated in Figure 4 to provide adequate lifting force. Each inflatable donut can pull either a single stiffening ring or several rings together. Each inflatable donut can have its own air inlet and can be pneumatically controlled. Redundancy is desirable in order to ensure that the tower integrity can be maintained during the maintenance and to facilitate repair of leaking donuts.

Not all donuts will need helium or lighter than air gas. Normal air can be pumped into some donuts, probably those towards the bottom, with predefined pressure to provide supporting force for the shroud. The donuts can be further divided into several sections vertically along the shroud (such as four or eight sections). Each vertical section can be individual controlled pneumatically.

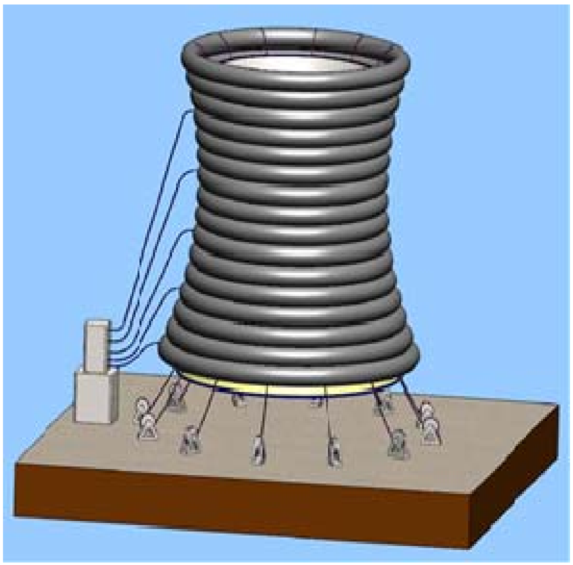

Fig.4 Design of donut-shaped air-lifted cooling tower

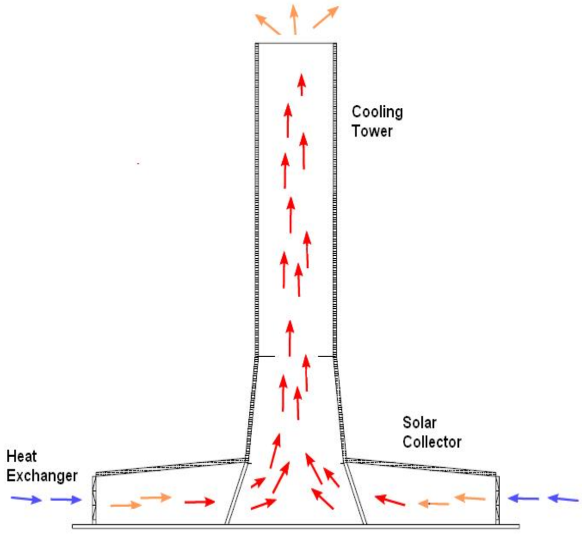

Fig.5 Schematic of solar natural draft cooling tower

Solar enhanced natural draft cooling tower

In this design, based on the principal of solar chimney, a solar collector is placed at the base of a natural draft cooling tower between the tower and the vertically arranged heat exchanger. Heating of the air behind the heat exchanger (inside the tower) will enhance convection, and hence more airflow through the heat exchanger.

The cooling ability of this tower depends primarily on two factors: the size of the solar collector area and tower height. With a larger solar collector area, a greater volume of air is warmed to flow up the tower. With a larger tower height, the pressure difference increases the buoyancy effect.

Figure 5 shows schematic drawing of proposed design of solar enhanced natural draft cooling tower. In this design, heat exchanger bundles are placed circumferential at the base of the tower. A solar collector is added between the heat exchanger bundles and the cooling tower to heat the air below. Due to the upstream air temperature of the heat exchanger has been heated and much higher than the downstream air temperature, the flow rate of the air through the heat exchanger increase, which results either the tower size can be reduced (for fixed heat sink) or the performance of the tower increases (for fixed tower size).

The cooling tower structure can be a standard concrete tower used in power plant or it can be a chimney shape as shown in figure 5. The air-lift cooling tower can also be used in this design.

Air-Lifted Tower Construction

To erect the air-lift cooling tower shown in Figure 4, the stiffening rings are placed first around the bases in order and the top stiffening ring is connected to the first donut shape vessel and the top end of the tension cables. Helium is then pumped into the top donut vessel which lifts the first stiffening ring and part of the tension cables. After the first ring has been raised to a desired position above the ground, the second top ring can be connected to the tension cables in the same way. The ascending height of the assembled rings is controlled by the release of tension cables. The sealing skin can be formed and fixed to the already assembled stiffening rings with various fixing mechanisms.

With the same process repeated as above, the controlled upward motion of the lifting donut vessels result in a corresponding advance of the cooling tower shroud. The intermediate advance of the installation of the cooling tower is shown in Figure 6.

Once the bottom ring has been assembled and raised to desired position, the tension cables are then secured to their respective anchors.

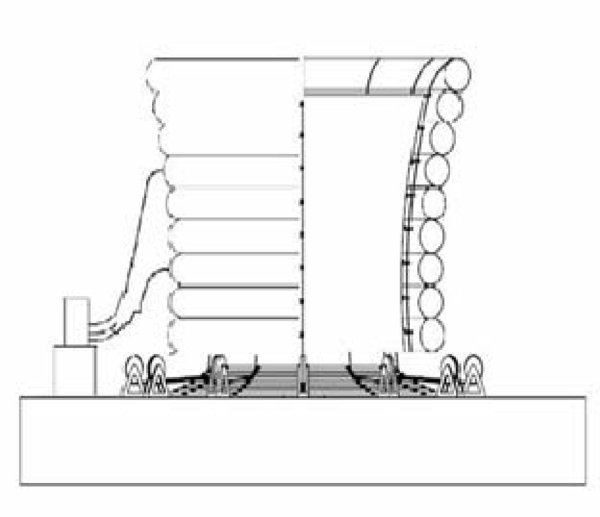

Fig.6 Intermediate position of installation

Future Work

An engineering feasibility study on the above new design concepts will be carried first based on the environmental conditions in the proposed geothermal power plant sites.

Should the feasibility study favour the air-lift cooling tower concepts, a detailed design of such cooling tower for a planned 50MW geothermal power plant will be conducted. A 3D model is to be built to predict tower deformation and its performance under various wind conditions.

Simulation and modelling of the solar natural draft cooling tower will be carried out by the PhD student Zeng Zhang who started his study in March 2010.

Full economic study needs to be performed for both conventional concrete cooling tower and the new design concepts as proposed in this paper. Once the study favours air-lift option, a scaled physical model will be built and tested in our mobile plant. Different wind loads will be simulated and the best stabilizing controlled mechanism will be identified. All modelling and simulating results will also be confirmed by the laboratory testing results.

Materials for the toroidal vessels, sealing skin and stiffening rings of the shroud play important roles in cost reduction and durability of the tower. It is therefore required to search, identify and test different materials suitable for the shroud and vessels.

Optimisation of the area of solar collector and size of the tower for solar enhanced natural cooling tower will be carried in future by a PhD student.

Stress analysis for tower structure for new design concepts will be done to determine the strength of the structure.

Conclusions

Air-lift cooling towers provide an alternative to the widely used concrete cooling tower used in power industries. This alternative will achieve a construction with minimum of time and expense.

Since materials of the tower can be made of nonferrous and light materials, the resulting tower will therefore be corrosion free and it will be lightweight allowing quick installation with the advantages of easy disassembly and mobilisation at a minimum of time and effort. The whole tower can be reused in a new site.

The inflatable donuts (cells) can be divided into portions which are so arranged that malfunction of one or more of them will not interfere with operation of the tower as a whole. Such redundancy provides reliable maintenance and repair.

The shroud is made of light material and can be factory manufactured in segments or as a whole. This provides for a quick and easy field installation. Since there is less material (weight) to be transported to the construction site, it will reduce the cost of transportation which may have significant impact when the site is located in a remote area.

The most serious concern on air-lift cooling tower is its deformation and stabilization under strong wind which could affect the performance of the tower. Mechanism for improving design and control will be identified.

By adding solar collector to preheat the upstream air temperature of the heat exchanger, it results a more air flow rate through the heat exchanger due to a much higher buoyancy effect. This can either reduce the tower size (for fixed heat sinking) or increase the performance of the tower (for fixed tower size).

A comparative life cycle cost analysis for both conventional and the new design concepts of natural draft dry cooling tower is necessary in future work.

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