Economic and Performance Benefits Resulting From the Use of Large Diameter Fans on Air Cooled Heat Exchangers (A Case Study in the Use of Large Fan Air Cooled Condensers at the Neal Hot Springs Geothermal Power Plant, Oregon)

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Keywords

Air cooler, air cooled condenser, ACC, geothermal, power plant, operating costs, maintenance costs, O&M, O&M costs, capital cost, construction cost, recirculation, fan, fan efficiency, motor efficiency, direct drive motor, wind direction, TAS, Turbine Air Systems, U.S. Geothermal Inc., Hudson

ABSTRACT

A significant improvement in air cooler technology was implemented at the Neal Hot Springs geothermal power plant in Vale, Oregon. Large cooling tower fans were used in an induced draft arrangement (fans above the heat exchanger). The total number of fans was reduced from 270 x 12ft / 3.7m fans to 30 x 33ft / 10m fans. The present value of the O&M and power savings totals $1.6 million dollars. The decision to use variable frequency drives yielded additional power savings with a present value of an additional $3.1 million dollars. While the capital costs were higher, specific design elements were implemented to offset these additional capital costs. Computational fluid dynamics (CFD) was used to show that the large fan design virtually eliminates hot air recirculation yielding substantial annual generation and net revenue benefits, compared to recirculation rates of small fan arrays that produced 5% to 35% recirculation rates.

Introduction

Air cooled condensers (ACC) are a critical piece of equipment in many geothermal power plants worldwide. Installed, they represent on the order of one third of the total capital cost of these plants. Because of the importance of this equipment, an innovative approach to the ACC was undertaken which substituted 30 large cooling tower fans instead of 270 small fans, to create a much lower total cost of ownership. The benefits of the large fan approach are not only applicable to the geothermal power industry, but to the power, energy, and process industries as a whole.

Since electrical power was first produced the heat rejection method of choice has been a water cooled condenser and either a semi closed-loop cooling tower or an open loop to a lake, river, or the ocean. The same is true for other industries in which heat must be rejected. Away from the coasts, cooling water has been supplied from rivers or have tapped into ground water supplies. However with population increases, sources of fresh water are becoming increasingly restricted and expensive. In addition with the focus on power production from renewable resources, this invariably leads to power production in remote areas where water is scarce, including solar thermal and geothermal power production. As such there is increasing need for heat rejection systems that use air as the heat rejection medium not water. This paper highlights the analysis, development and improvement of large air cooled condensers (ACC) arrays which are a dominant feature for any air

Figure 1. The large fan ACC is prominent in the Neal Hot Springs geothermal power plant.

Figure 2. A typical small fan air-cooled condenser on a geothermal power plant.

cooled power or process plant, including Organic Rankine Cycle (ORC) geothermal power plants.

The approaches and innovations to improve the overall installed value over traditional means described in this paper were jointly developed by TAS Energy Inc. (TAS) and U.S. Geothermal Inc. (USG) for USG's Neal Hot Springs geothermal power plant located in Vale Oregon, Figure 1, contrasted with a conventional air cooled condenser installation in Figure 2. While these designs were developed for a geothermal power plant utilizing the Rankine Cycle, the benefits would be applicable to many dry cooling applications.

Description of Power Cycle

The facility is a supercritical Rankine cycle (ORC) power plant, using an organic working fluid (R-134a). R-134a was chosen because of the benefits it offers over hydrocarbon working fluids. These benefits include that it is non-toxic, non-flammable, and has a higher efficiency than the most common ORC working fluid, iso-pentane at these source temperatures. (Augustine et al., 2009)

In the supercritical Organic Rankine Cycle (ORC) the air-cooled condensers reduce the vapor from the turbine discharge to liquid. The cycle pump pressurizes the liquid from 70psi / 4.8bara to over 600psi 41bara. The high pressure liquid refrigerant is then vaporized in a heater by extracting heat from the 280°F / 138°C geothermal brine. Finally, the high-pressure refrigerant vapor expands in a turbine and generator, producing power. As a key component in this system the installed performance of the ACC is critical to overall plant economics.

Air Cooled Condenser Design

Traditional air cooled condensers, have been manufactured for many years in designs configured as factory-built independent modules. The number of modules is determined by the overall heat rejection required. The primary focus has been a system that can be shipped complete from a manufacturing facility and rapidly set in place on the supporting steel. Low purchase price, without consideration for life cycle cost of ownership, including overall construction cost, onsite performance in the presence of wind, mechanical efficiency, and operation and maintenance (O&M) costs. Modular is a great concept but if this affects the long term operational efficiency this is an unacceptable compromise.

The traditional design is a module that can be shipped via road transportation which invariably leads to a typical size of 14ft wide by 60ft long / 4.3 x 18.3m (with maximum realistic shipping dimensions of up to 16 x 70ft / 4.9 x 21m. The design includes a frame supporting a single condenser bundle comprised of finned tubes. Above each bundle are three fans in an induced-draft configuration that is fluidly connected to the bundle by a short plenum. These single-unit modules are very heavy since the frame is typically structural steel, the bundle includes metal finned tubing, and the plenum is typically constructed of heavy gauge steel. The design and selection of fabrication materials is selected in part to withstand shipping vibration forces. The diameters of the fans are limited to no less than the width of the bundle so that the fans and the bundle may be shipped as an assembly. Fan stacks are typically square edged and short such that they provide low aerodynamic efficiency. The fans are typically driven by belts that require maintenance to keep correctly tensioned in different operating conditions (can be summer to winter changes) and that must be replaced at regular intervals.

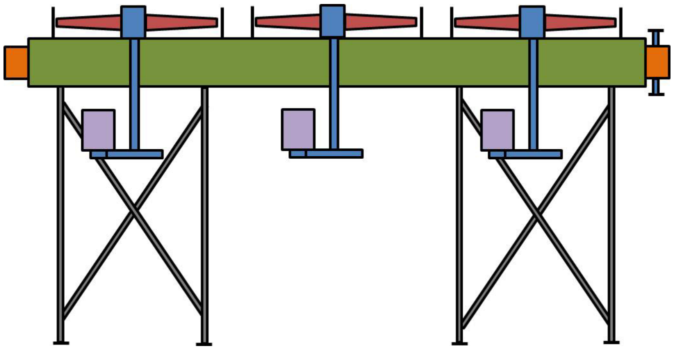

Figure 3. Cross Section of Traditional Induced Draft Air Cooled Condenser.

Typically, a plurality of these single-unit modules are coupled together and held off the ground by heavy steel structures in order to allow sufficient airflow circulation to the fans, which pull air from the bottom of the structure and through the bundles and out of the top of the structure. The typical support structure is typically 4 columns per bundle, with multiple horizontal and angled members both parallel and perpendicular to the long axis of the bundle. Significantly, the effect of the need for many bundles is the need for many fans and many column foundations. Many fans requires significant labor and material costs for electric cabling to each motor, and many column foundations results in high excavation, forming, re-bar tying, and backfilling. These construction costs are often not evaluated in the cost of this construction approach, nor are the substantial ongoing maintenance cost of the belt drives. At Neal Hot Springs, a conventional design would have resulted in 270 belt drive fans and electric motor connections and 372 column foundations. The large fan design resulted in 30 electric motor connections and 99 foundations, a reduction by 89% and 73% of the conventional design. The economic benefit of this improvement is discussed later in this paper.

A significant operational problem that is rarely addressed during the design, but is frequently observed is air recirculation from the discharge of the fans to the intake of the air cooled condensers. Recirculation increases the ACC array's effective air temperature, and consequently reduces the output from the plant. The performance of the ACC array will perform as intended under windless conditions. However, under many conditions when the wind blows, hot outlet air from the outlet of the ACC is readily recirculates back into the inlet of the ACC. Until now, recirculation is an issue that has not been addressed in ACC design except by the installing additional ACC bundles, which increases purchase cost, installation cost, and O&M cost.

A traditional small fan array is shown in Figure 4. Computational Fluid Dynamics (CFD) shows the resultant recirculation of hot air due to an axial wind in Figure 4-1

In summary for traditional designs

- Bundles of shippable dimension complete with fans and drives
- Multiple fans with belt drives

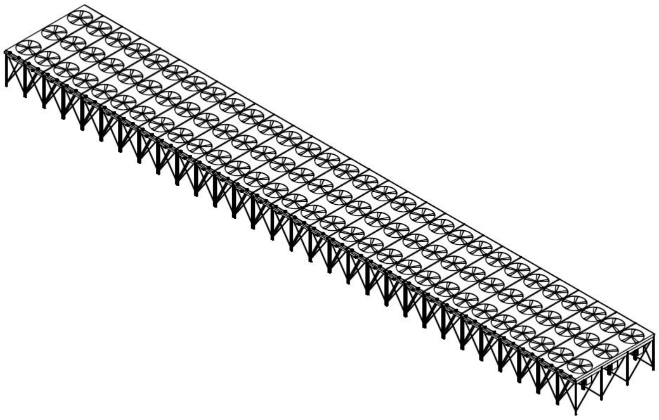

Figure 4. A Traditional Induced Draft Finned Tube Air Cooler.

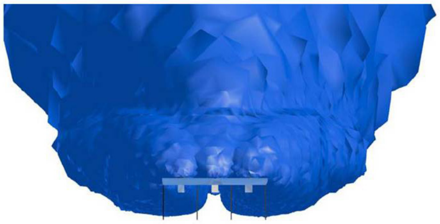

Figure 4-1. Recirculation Occurring on a Traditional Small fan Air Cooler (end view).

Figure 5-1. Site Photo of the New Design Air Cooled Condenser.

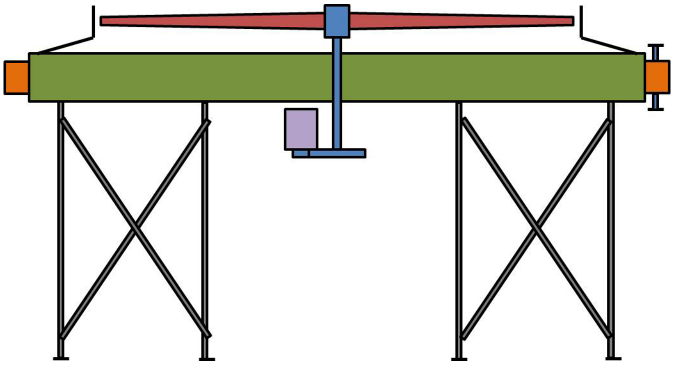

Figure 5-2. Cross Section of Improved Induced Draft Air Cooled Condenser.

- Multiple motors with lots of cabling
- Compromised air side geometry
- Packaging causes air recirculation under non ideal wind conditions

This traditional design includes several areas for improvements in operational performance that have been ignored for many years. The focus on absolute performance driven by the geothermal industry has provided the impetus to improve this situation. Collaboration between the owner, the system designer, and the manufacturer has enabled significant enhancement of the traditional ACC design.

The new air cooler design covers the complete packaging around the air cooled heat exchanger (condenser in this case) and does not impact the heat transfer design itself and incorporates the use of traditionally designed and fabricated ACC bundles. The design provides several distinct advantages that primary address the deficiencies in the traditional design:

Improved Airside Geometry for the Large Fan Design Option

Figure 5-1 & 5-2 shows the general configuration of the air cooled condenser for the Neal Hot Springs project.

The improved design makes no significant change to the air flow into the bottom of the cooler. But there are two areas where the large fan improves air flow geometry out of the bundle: Air recirculation and fan efficiency. Figures 6-1 and 6-2 illustrate the how the geometry of the large fan separates the exit of the fan stack from the inlet to the air cooler. For a small fan, the 4ft / 1.2m straight-sided fan cylinder rests on top of a short plenum so the edge of the fan stack is only 4ft / 1.2m from the edge of the bundle, giving a total minimum recirculation air travel distance of 8.6ft / 2.6m. By contrast, the large fan uses a 14ft / 4.3m tall velocity recovery that is 15ft / 4.6m from the edge of the bundle. The fan stack rests on top of a 10ft / 3m tall plenum, resulting in a minimum recirculation air flow distance in excess of triple that of the small fan, or 31.3ft / 9.5m. The benefit of this increased geometry was quantitatively determined using computational fluid dynamics (CFD), as discussed later in the paper. The CFD results show that the area of the bundles affected by recirculation in the

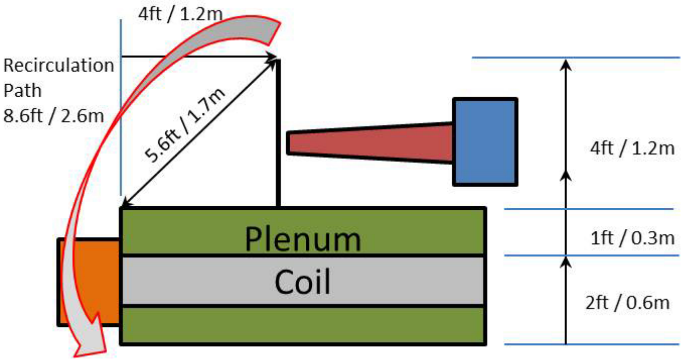

Figure 6-1. Geometry of Traditional Air Coolers (not to scale).

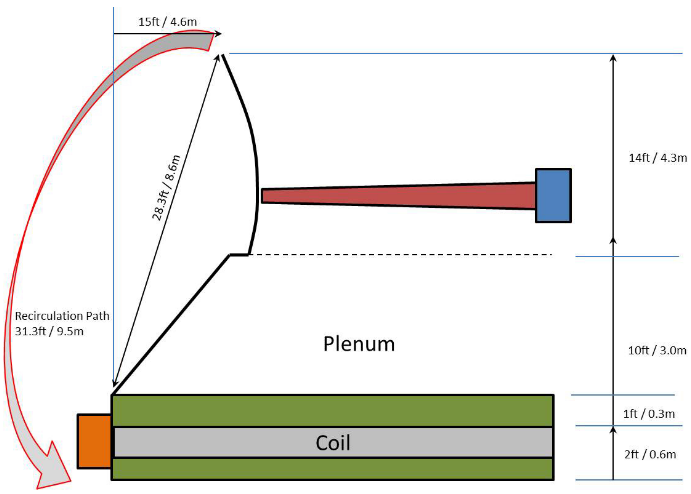

Figure 6-2. Geometry of Improved Air Coolers (not to scale).

large fan design is only 1.2% with a low temperature rise, compared to the small fan design at 35.7% with a high temperature rise.

Large fans cover more than one bundle and allow for greater plenum volume. The tall plenum and fewer larger fans allows for aerodynamic velocity recovery stacks which together with the large fans themselves improves fan efficiency.

Economic Analysis of the Operational Benefits of Large Fan Air Cooled Condensers

It is a well understood axiom in industrial and power facilities that there is an economic benefit in larger facilities and equipment over smaller facilities and equipment, which is described as "economy of scale". In air cooled condensers, this axiom has not previously been captured.

Large diameter fans provide several opportunities to capture the benefits of economy of scale. These opportunities are:

1. Reduce the number of pieces of rotating equipment.
2. Improve efficiency of the equipment
3. Eliminate recirculation
4. Minimize any increase in installation costs by better design

Reduced Number of Rotating Equipment Components

To reject the waste heat from the 22 MW power plant at Neal Hot Springs, 90 air cooled condenser bundles are required. Under a typical small fan arrangement with three fans per bundle, 270 fans would have been required. This large number of fans negatively impacts the budgeted O&M costs for the plant, which means lower earnings. Instead, 30 large diameter fans were used, resulting in a reduction of 89% in the number of pieces of rotating equipment. There is, at a minimum, an equally large reduction in the O&M costs.

For the typical induced draft fan arrangement (fan blades on top of the cooler), the motor is located below the bundle. Power from the motor is transferred to the drive shaft via pulleys and a belt(s). The drive shaft mounts to the fan above the bundle and is supported by two bearings between the motor and the fan. The maintenance costs for the small fans drive lines are as follows (Personal communication with Plant Manager, 2012):

- Replacement cost for belts is approximately $250 per year with installation labor. This excludes issues with belts loosening or needing to be readjusted as temperatures change from -20°F to 110°F / -29°C to 43°C over the peak temperatures of a year.
- Bearings have a multi-year life if they are greased 2 times per year with synthetic grease.
- Motor life: excellent with regular greasing or sealed bearings.
- The total estimated O&M cost are $400 - $500 per year per fan, or an NPV of about $5,000 per fan.

By comparison, the maintenance cost on large shaft-driven cooling tower fans is "almost zero" and the mean time between failure is extremely long. While this is very low, U.S. Geothermal Inc. elected to use the Baldor direct drive fan motor, which may require greasing as seldom as one time every two years. However, assuming a two time per year motor greasing, the rough labor and grease cost would be $100 per year, resulting in a present value of about $1,000 per large fan. Table 1 is the tabulation of O&M savings from the large fans over the small fans.

Table 1. Comparison of Annual and Present Value (8%, 25yr) Costs of Small and Large Fan O&M.

Comparison Basis	Annual Small Fan	Annual Large Fan	Annual Benefit	PV of 1 Small Fan	PV of 1 Large Fan	Net PV Benefit
For each large fan that replaces 9 fans	$500	$100	$4,400	$5,340	$1,100	$46,960
For the ten large fans that comprise one Unit	$45,000	$1,000	$44,000	$480,360	$10,670	$469,700
For the three Units that comprise the Facility	$135,000	$3,000	$132,000	$1,441,080	$32,010	$1,409,100

It is reasonable to expect that this estimate of O&M savings is conservative, because it does not address the O&M of the electrical equipment, which is also 9:1 for motor starters or VFDs, electrical connections, fan blade clamp tightening, etc.

Higher Mechanical Efficiency

The efficiency of the translation of electric power to net air flow out of the fan stack can be an important consideration in the life cycle cost of ownership. Inefficiency translates into higher parasitic power, and hence less saleable power from the power plant, or for a process facility, higher parasitic power expenses.

It is well known that large electric motors are more efficient than small electric motors, so it would seem that the larger motors required for the larger fans would offer an advantage. However, the higher efficiency of a large motor is offset by the lower efficiency of a gear box in a traditional drive shaft and gear box large fan drive system.

At Neal Hot Springs the decision was to use the Baldor direct drive fan motor. This is a permanent magnet motor that uses an integrated VFD to drive the motor at only about 100 rpm instead of the 1800 rpm at which the four pole motor would otherwise run. Because of the high turndown, the motor efficiency is only about 92%, but there are no drive losses to the fan since the fan is direct coupled.

Table 2 compares the motor to fan shaft efficiency of the small fans, and the large fans with a conventional fan gear box, and with the Baldor direct drive motor.

Table 2. Total Efficiency Is Not A Factor For One Large Motor Versus Nine Small Motors.

Size	Drive	Motor E	Drive E	Net E
15 hp	Belt	93%	99%	92.1%
100 hp	Gear Box	96%	95%	91.2%
100 hp	Coupled	92%	100%	92.0%

While the overall efficiency of electric power to shaft power is similar, regardless of fan size, multiple small fans are less aerodynamically efficient than fewer larger fans. Losses from fan tip edge effects, hub effects, and the use of straight fan cylinders vs. velocity recovery cylinders are reduced with large fans. These efficiency benefits cumulatively favor large fans by a minimum of 1%, but can be as high as 3% (Personal communication with DesJardins, 2011).

Table 3 provides the annual and present value savings from the higher efficiencies obtained by using larger fans. The table compares 100 hp of fan shaft power. The basis of the calculation is a 1.5% efficiency improvement, with a 75% annual load factor, and a cost of power of $0.09/kWh. The present value calculations are 8% discount rate for 25 years.

Table 3. Annual and Present Value of Reduced Power Costs From Using One Large Fan Versus Nine Small Fans.

Comparison Basis *(Net Fan Efficiency Difference = 1.5%)*	**Annual Benefit**	**PVof Small Fans**	**PV of Large Fan(s)**
For each large fan that replaces 9 fans	$590	Base Case	$6,300
For the ten large fans that comprise one Unit	$5,900	Base Case	$63,000
For the three Units that comprise the Facility	$17,700	Base Case	$189,000

Elimination of the Belt Fan Drive System

With the introduction of new low frequency variable speed motor controller technology it has been possible to eliminate the entire mechanical speed reduction system. The fans at Neal Hot Springs are driven directly by the motor. There are no other moving parts or maintenance items. Inherent with this fan drive is a Variable Frequency Drive (VFD), which allows for the necessary modulation in air flow across the ACC to allow the geothermal plant to operate at optimum conditions under all ambient temperatures, and most importantly at very low ambient temperatures. The use of VFDs is not restricted to the large fans, but its exclusive use is not common in air cooled condensers. And while small fans can be turned off it is not as effective at conserving power as a VFD.

For the VFD case air flow is proportional to fan speed while the required power is proportional to fan speed cubed. If the only option to reduce air flow is to shut off fans, then both the air flow and the required fan power are proportional to the number of fans running. Hence the load reduction by reducing speed is far greater than the load reduction by reducing the number of fans. Table 4 compares the annual power costs when using a 97% efficient VFDs year-round which are used to slow all of the fans versus a strategy of stopping whatever small fans are not needed.

Table 4. Comparison of Annual Fan Power Consumption With and Without VFD Motor Controllers.

Req'd Air Flow	Months per Year	Large Fan Power (kwh)	Small Fan Power (kwh)
100%	5	8,413,761	8,168,700
75%	4	2,839,644	4,901,220
50%	3	631,032	2,450,610
Total	12	11,884,437	15,520,530
VFD Savings		3,636,093	-
VFD Savings		**23%**	

This analysis led to the decision that VFDs would be used on all of the fans of the ACC. At a power cost of 8 cents per kwh, the annual value of the saved power is $290,000 per year, with a present value of $3.1 million dollars. Driving all the fans of an ACC with a VFD, whether large or small are used, is economically beneficial.

Structural Design Elements for the Large Fan Coolers

The benefits of the large fan coolers come at the compromise of a non-modular package that cannot be shipped to site fully packaged. Of course it would not make economic sense if all these additional operating benefits come at a prohibitively high site construction cost. As such significant focus was made to ensure the resulting installation materials and costs would not outweigh the operational benefits, or might even be of lower overall cost than conventional small fan ACCs.

Lightweight Structure for the Plenum

To create the necessary plenum volume economically it was necessary to ensure the parts necessary could be economically fabricated at the manufacturing plant and rapidly erected at site. The plenum skin should be similarly cost effective to install. The design incorporates a lightweight prefabricated truss structure and a lightweight building material skin for covering the plenum which provides for rapid site construction and reduces the support steelwork and plenum weight to facilitate lower fabrication and site construction costs

Fan Drive System

The mounting of the motor / fan assembly that includes maintenance access was considered. Given the energy required to move the air and the tight tolerances required between the fan tip and the velocity stack this structure should be rigid and adjustable to allow for site installation tolerances. Further the support structure must also be modular and cost effective to install.

Suitable Maintenance Access

Although both the fan and drive are virtually maintenance free with the new design, it was considered prudent at this stage of the product development that good access for maintenance of these items must be provided. Since there is no equipment whatsoever on the fan deck, and the direct drive motors must only be grease between twice a year and one every two years, no permanent access to the fan deck was provided. Access is only by man-lift. The work areas with OSHA hand rails were restricted to areas where the fan cylinder doors were located, reducing the cost of these expensive areas to less than 20% of the total fan deck area, at substantial cost savings. Tie-off points were provided over 100% of the fan deck.

Improved Substructure Design

While not inherent to the performance of the ACC array, given the necessity for a modular construction for the plenum and fan drive it was also an opportunity to evaluate an improvement in the support steelwork supporting the whole array. Typically such ACC bundle arrays are supported 20ft / 6m or greater above grade. For such installations a very simple array of hundreds of vertical supports and cross bracing is typically employed. This involves many foundation points, manhandling of all individual components and bolting each of these together. Each foundation point is costly especially in poor soil conditions. It was considered that savings could be made in the same modular approach was adopted for the superstructure (plenum)

Installation Optimization

With all the key features being considered the installation process was also examined to ensure the maximum advantage was realized for the complete installed cost of the ACC array

At Neal Hot Springs, a conventional design would have resulted in 372 column foundations. The large fan design resulted in only 99 foundations, a reduction of 73%. The total amount of concrete used in the large fan ACC will be larger because of the large wind-affected plenums and fan cylinders. However, the speed with which the fewer larger foundations could be excavated, formed, tied, and poured is so much faster that the overall cost of foundation construction is estimated to be between 10% and 25% lower than for the conventional substructure. Elements that contribute to these savings include:

- Smaller percentage of over excavated area compared to foundation area. This is because a minimum area is needed all around the foundation, regardless of the foundation size.
- Larger foundations allow the use of larger excavation equipment, including dozers and track hoes with 4ft / 1.2m buckets, versus back hoes with 2ft / 0.6m buckets.
- For the improved substructure design, the rows of foundations are separated by 42ft / 12.8m, versus 14ft / 4.3m for conventional designs. This allows large equipment to access and turn around inside the construction area during and after the foundation construction, including large compactors instead of hand tampers.
- The labor hours to tie one large foundation are estimated to be equivalent to that required to tie between two to four of the smaller foundations. As such, in this area alone, savings of 50% to 75% may have been achieved with the new design.

For the electrical installation, a small fan design requires 270 electric motor connections. The large fan design requires only 30 electric motor connections, or a reduction of 89%. Some of this benefit is lost because of the labor to pull larger cable, but the net savings are substantial. Again, savings of 50% to 75% are the estimated benefit for both cable cost and installation cost.

Summary of the Economic Benefits of the Large Fan

The performance of large fans on an air-cooled condenser reduces maintenance costs, the parasitic load of the air cooled condenser, and has offsetting costs on the installation cost versus the initial capital costs. The Present Value of the operation and maintenance savings and the higher efficiency of the larger fans totals $1.5 million dollars, as tabulated in Table 5.

Table 5. Present Value of Avoided Operational Costs of the Large Fan ACC.

Comparison Basis	O&M Reductions	Fan Efficiency Power Savings	Total Benefit
For each large fan that replaces 9 fans	$47,000	$6,300	$53,000
For the ten large fans that comprise one Unit	$470,000	$63,000	$533,000
For the three Units that comprise the Facility	$1,410,000	$189,000	$1,599,000

The benefit of using variable frequency drives to control the motors is estimated to reduce operational power costs by an additional $3.1 million dollars, although this benefit is not unique to the large fan ACCs, just easier to implement.

Offsetting the benefits of large fans are greater costs in the on-site construction, requiring labor and lifting equipment that is not required for small fan coolers. These are primarily:

- ◦ Assembly and installation of the plenum and fan deck
- ◦ Installation of the motor/fan support system
- ◦ Assembly of the 33ft / 10m diameter and 14ft / 4.3m tall fan cylinders
- ◦ Additional structural steel weight and total foundation area as a result of taller structures with higher wind loading
- ◦ Additionally, the large fan ACCs resulted in higher shipping costs than would have occurred with the small fan ACC.

Careful design efforts were made to mitigate these known cost adders, including:

- ◦ Modular pre-fabricated plenum trusses

  - Conventional metal roofing techniques for the plenum sides
  - Improved substructure design resulting in faster assembly and lower foundation costs than traditional substructures.

Big Fans Eliminate Performance Degradation Due to Recirculated Air

Wind-induced recirculation is the effect of hot air from the condenser discharge being drawn under the tube bundle, raising the effective temperature of air to the condenser and reducing output from the power plant. It is widely believed to especially be a problem in those hours in which the wind is blowing in a direction other than parallel to the axis of the condenser. With an increased physical separation (both vertically and horizontally) between the air leaving the array and the air entering the array, the large fan design was shown, using computational fluid dynamics (CFD), to virtually eliminate hot air recirculation due to wind.

The CFD analysis definitively showed that wind-induced bypass is much greater with small fans. Large fans provide cooling performance that is much closer to the still air design condition for the many hours when winds deteriorate the performance of air-cooled condensers with small fans. The surprising result of the CFD analysis however is that recirculation is more extreme when the wind blows in a direction that is parallel to the axis of the cooler, rather than when it is perpendicular.

CFD Modeling

The purpose of the CFD study was to use software to examine the performance improvement of the new design relative to the traditional ACC with respect to hot air recirculation. The study was conducted in two phases where the first used a theoretical flat plane and the second used actual site geometry to account for site effects. In the first phase the traditional and the new design were modeled on a flat plane without any obstacles to create eddies and other disturbances so that the recirculation inherent in the ACC array could be determined. It should be noted how recirculation was defined. The equipment design data sheet indicated that the design temperatures were 52.0°F / 11.1°C for the air entering the array and 70.8°F / 21.6°C for the air exiting the array. The amount of recirculation was calculated by using the following equation:

$$\text{Recirculation} = \frac{Temperature - 52}{70.8 - 52} \cdot 100\%$$

In each case, the long axis of the array was aligned along a North-South axis. Three wind directions were used in the study: a North (N) wind, a Northeast (NE) wind, and an East (E) wind. Two wind speeds, 6 miles per hour (mph) / 10 kilometers per hour (km.hr^{-1}) and 20mph / 32km.hr^{-1}, were used as the basis for these models. Wind speed was selected by analyzing project site wind data over the period from August 2008 to May 2009. A project site wind rose and bins are shown below in Figure 7 and Figure 8.

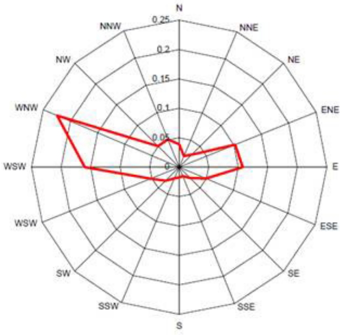

Figure 7. Wind Rose for the Neal Hot Springs Site (Aug '08 to May '09).

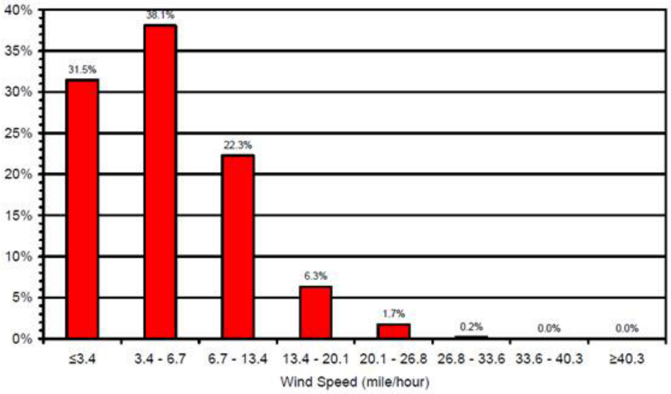

Figure 8. Wind Bins for the Neal Hot Springs Site (Aug '08 to May '09).

The wind velocity profile used in the model was the wind velocity profile presented in Chapter 16 of the 2005 ASHRAE Fundamentals Handbook. These velocity profiles include different coefficients based on the surrounding area which affect the shape of this profile. In this study, a profile assuming scattered, low lying obstructions was used. Figure 9 shows the velocity profile for a wind speed of 6 mph / 10km.hr^{-1} at the standard anemometer height of approximately 33ft / 10m above ground. As the wind speed varies, the shape of the profile remains the same.

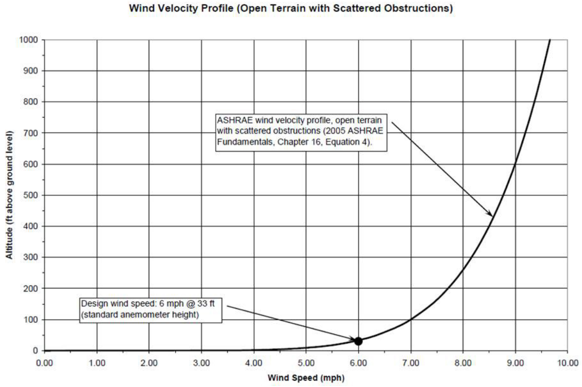

Figure 9. Typical Wind Profile.

CFD Results for an Infinite Flat Plain—Comparison of Small Fan and Large Fan ACCs

The modeling indicated that the conventional array experienced recirculation of the exhaust plume for all wind conditions in the study. When the wind was aligned with the long axis of the array, the array experienced some recirculation (4.7%) with a 6mph / 10km.hr^{-1} wind, and significant recirculation (35.7%) with a wind speed of 20mph / 32km.hr^{-1}. When the wind was at a 45° or 90° angle from the long axis, the conventional array had high recirculation rates (13.0% and 5.8%, respectively) with a wind speed of 6mph / 10km.hr^{-1} recirculation. The recirculation rates were lower for the 45° or 90° angle wind (2.3% and 0.7%, recirculation) when the wind speed increased to 20mph / 32km.hr^{-1}. This difference appears to be the results of the higher wind speed forcing more ambient air into the area under the air intake, reducing the amount of recirculation. The new design experienced a small amount of recirculation (1.2%) when the wind was aligned with the long axis of the array and the wind speed was 20mph / 32km.hr^{-1}. The new design experienced no recirculation with the other wind conditions in the study. Figures 10-1, 10-2, 10-3, 10-4, 10-5, 10-6, 10-7, and 10-8 present CFD results but not discussed.

Table 6. Recirculation Summary for a Infinite Flat Plain Model.

	Traditional (small fan)		New Design (large fan)	
Wind Direction	**6mph 10km.hr^{-1}**	**20mph 32km.hr^{-1}**	**6mph 10km.hr^{-1}**	**20mph 32km.hr^{-1}**
North	4.7	35.7	0.0	1.2
Northeast	13.0	2.3	0.0	0.0
East	5.8	0.7	0.0	0.0

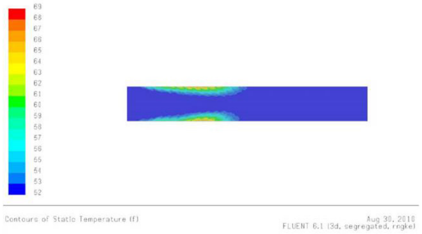

Figure 10-1. Small Fan ACC Temperature Contours – North (0°), 6mph / 10km.hr^{-1} (Max temperature increase = 13.0°F / 7.2K).

Figure 10-2. Small Fan Isometric of Plume – North (0°), 6mph / 10km. hr^{-1}.

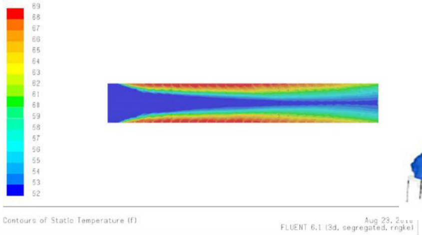

Figure 10-3. Small Fan ACC Temperature Contours – North (0°), 20mph / 32km. hr^{-1} (Max temperature increase = 16°F / 8.9K).

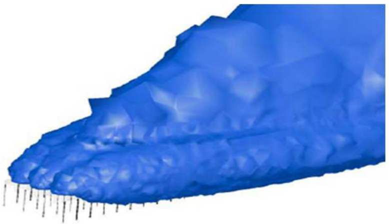

Figure 10-4. Small Fan Isometric of Plume – North (0°), 20mph / 32km. hr^{-1}.

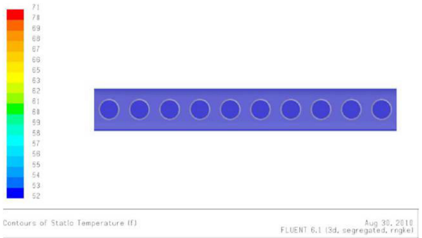

Figure 10-5. Large Fan ACC Temperature Contours – North (0°), 6mph / 10km. hr^{-1} (Max temperature increase = 0°F / 0K).

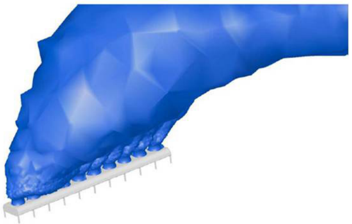

Figure 10-6. Large Fan Isometric of Plume – North (0°), 6 mph / 10km. hr^{-1}.

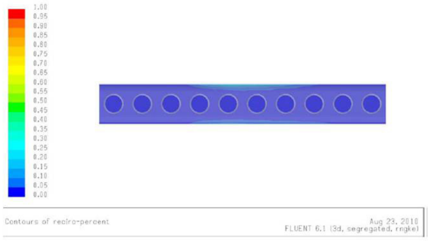

Figure 10-7. Large Fan ACC Temperature Contours – North (0°), 20mph / 32km. hr^{-1} (Max temperature increase = <0.3°F / 0.17K).

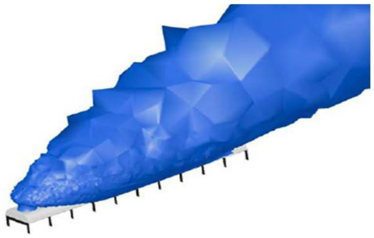

Figure 10-8. Large Fan Isometric of Plume – North (0°), 20mph / 32km. hr^{-1}.

CFD Analysis of Large Fan Recirculation in the Actual Topography of the Site

In the second phase of the study an attempt was made through the use of CFD to determine the effect the surrounding topography has upon the exhaust recirculation experienced by the ACC when subjected to different wind conditions. The previous modeling indicated that the highest recirculation rate of 1.2% occurred when the wind direction was aligned with the long axis of the array. In this phase, three arrays were modeled as they would be built on the actual project site. Topographical data for the site were used to develop a model of the landscape of a 2 x 2 miles / 3.2 x 3.2 km area surrounding the arrays and three arrays were located roughly in the center of the 2 x 2 miles / 3.2 x 3.2 km area. A nominal wind speed of 20mph / 32 km.hr^{-1} and six different wind directions were used in this study. The wind directions were North, East, East-Southeast, South, West, and West- Northwest. The East-Southeast and the West-Northwest directions aligned the wind with the long axis of the arrays. Three different ambient temperatures were studied: 25°F / -4°C (average winter temperature), 52°F / 11°C (design temperature), and 93°F / 33.9°C (average summer temperature). The results showed very little recirculation for all wind directions and ambient temperatures. The large scale eddies and turbulence created by the surrounding topography appeared to affect the size, shape and direction of the plume rather than the recirculation of the hot exhaust. The lack of recirculation appears to be mainly the result of the relatively large distance between the stack outlet and the intake on the bottom of the array. Figures 11, 12, 13-1, 13-2, and 13-3 presented but not discussed.

Table 7. Recirculation Summary by Season Inclusive of Site Topography.

	Design	Winter	Summer
Wind Direction	**Recirculation Rate (%)**		
North	0.1	0.1	0.2
East	0.0	0.0	0.0
East-Southeast	0.0	0.0	0.0
South	0.0	0.0	0.0
West	0.0	0.0	0.0
West-Northwest	0.2	0.3	0.3

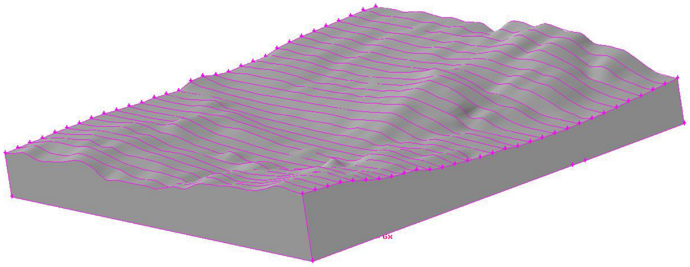

Figure 11. Geography of site used in the CFD Analysis.

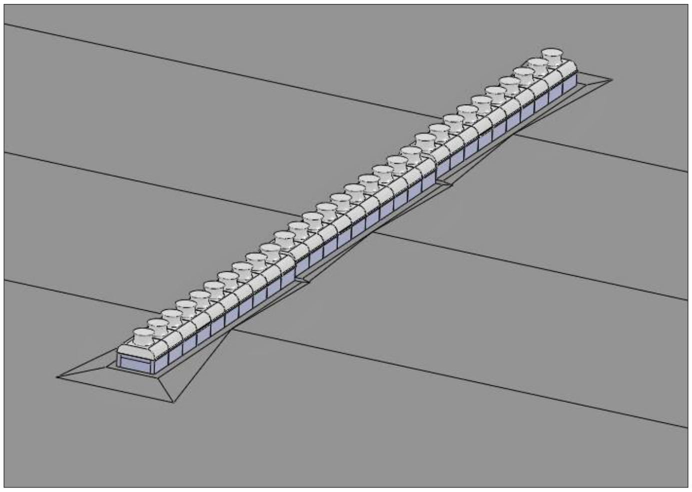

Figure 12. Close up of ACC Array on the Facility Site (12ft / 3.7m of elevation rise along the 1,200ft / 366m total length of the three Units, 44ft / 13.4m height to top of fan stacks).

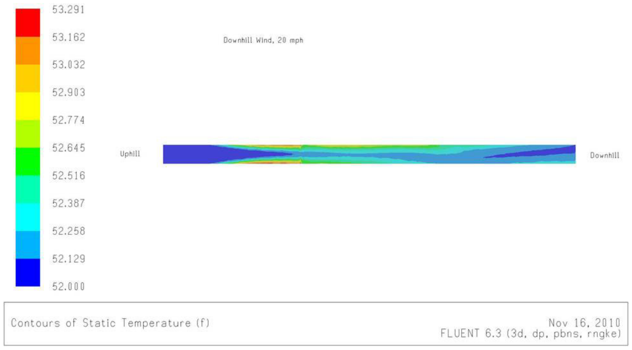

Figure 13-1. Temperature contours down the valley 20mph / 32km.hr^{-1}.

Conclusion

A top down, functional decomposition of an air cooled geothermal plant's heat rejection needs, when met with a clean sheet design, yielded a significant improvement in air cooler technology. Large diameter and efficient cooling tower derived fans paired with velocity recovery stacks were used to reduce the total number of fans. The use of direct drive motors significantly reduces maintenance costs by eliminating belt or gearbox drives. The decision to use variable frequency drives yielded additional power savings. The presented technology virtually eliminates hot air recirculation, one of the most troublesome problems encountered in an air cooled array. While overall design modifications increased the capital costs, the careful consideration of the design to minimize the installed costs to mitigate these yielded a better fully installed value. The combination of these design features provides increased annual generation and net revenue benefits as compared to traditional designs.

Figure 13-2. Temperature contours up the valley.

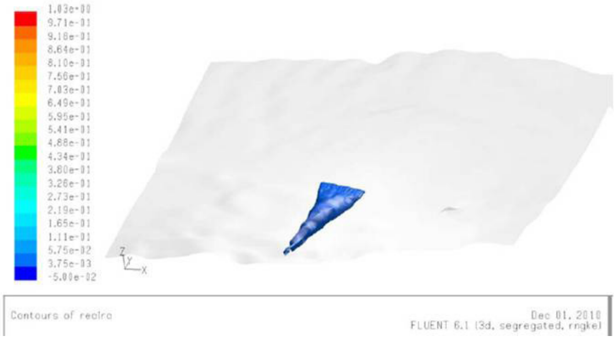

Figure 13-3. 20mph Isometric of plume, 20mph / 32km.hr^{-1}, Wind from North.

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