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KOGAN CREEK PROJECT

DRY COOLING TECHNOLOGY INVESTIGATION

FINAL REPORT

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SOUTHERN COMPANY

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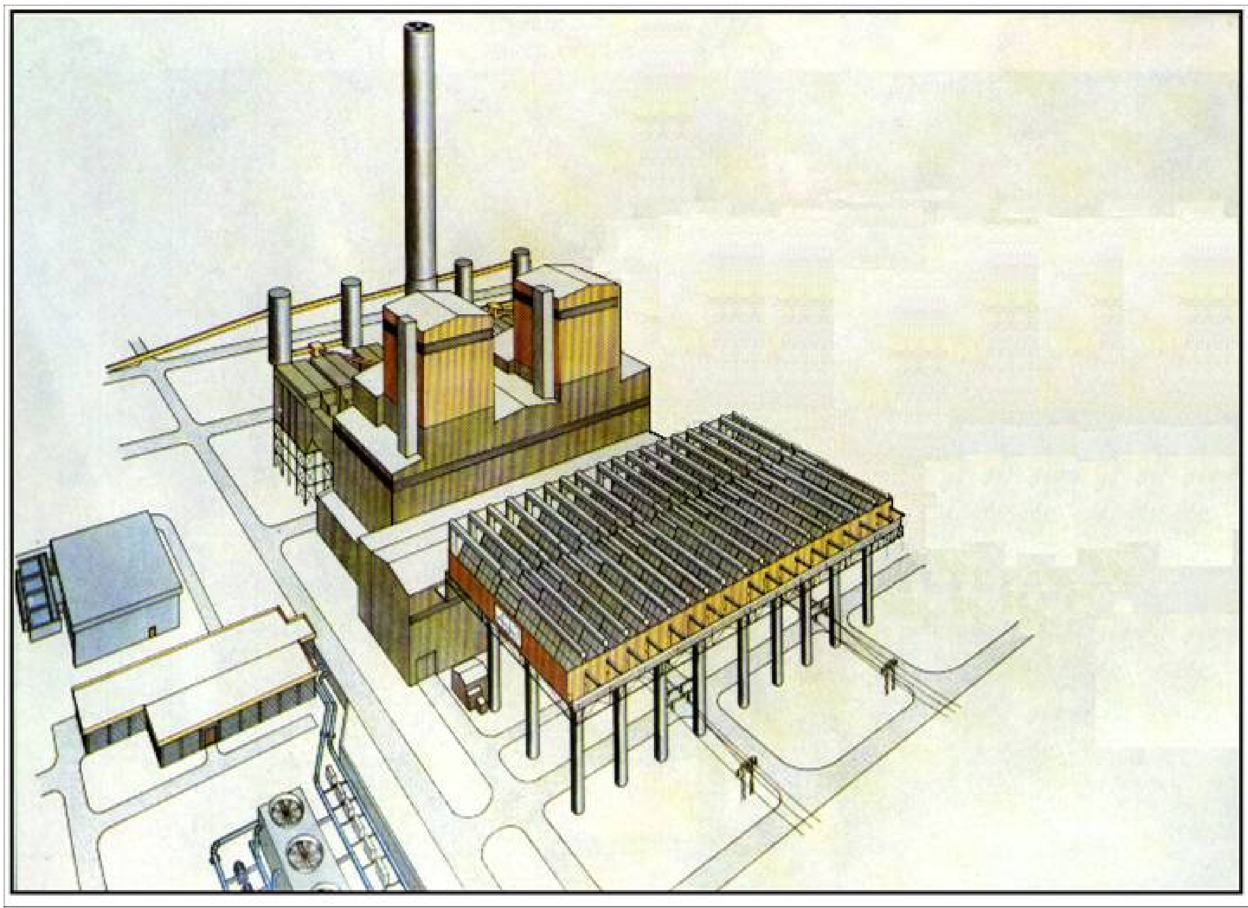

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KOGAN CREEK PROJECT
DRY COOLING TECHNOLOGY INVESTIGATION
EXECUTIVE SUMMARY

This report discusses the pertinent findings while visiting various ESKOM generating stations in South Africa which employ dry cooling/condensing technologies. These sites included the Kendal, Majuba, and the Matimba generating stations. The dry cooling/condensing system technologies consisted of air-cooled condenser (ACC) systems and an indirect cooling system (IDC).

During the early 1980's, ESKOM made a decision to build six 4000 MW coal fired power stations each 6x665 MW, to meet the expected load demand of the 1990s. Three of the power stations were located in arid conditions at mine-mouth sites and employed dry cooling system technology. Two of these stations employ ACC systems and one station employs an IDC natural draft tower system. These stations were and still are the largest projects employing dry cooling technologies. Consequently, the ESKOM experiences with large-scale dry cooling technologies are of significant value in setting the industry design standards and/or guidelines for future applications involving dry cooling.

Early experience at the Matimba station encountered a number of problems, which impacted unit performance and availability. These problems were related to both ACC design (thermal) and station configuration (six-pack configuration, building structures, etc.) Experience at the Majuba station is somewhat limited in that Majuba is not a base loaded station. Also, the Majuba station was designed with more conservatism (thermally) and is located at a cooler geographical location. The Kendal station is a base loaded plant.

The advantages and disadvantages of each system are discussed in the report. The information and guidance from the ESKOM plant experience will of tremendous value in designing plants employing dry cooling technologies. The Matimba station problems have been mitigated to some extent by removing building cladding and adding wind-walls which enhanced air-inlet profiles to the ACC.

Based on the information obtained by this investigation, it was concluded that either type of technology can be applied without substantial unit degradation provided that prudent design criteria is implemented (see further detail in report). It is anticipated that an ACC system will be the selected technology for the Kogan Creek merchant plant based on preliminary information and experiences of the ESKOM generation stations.

ACKNOWLEDGEMENT

The Southern Company along Southern Energy would like to express sincere appreciation to ESKOM for the cooperation of its employees and for providing the opportunity to visit the ESKOM generating stations in South Africa. The employees at all stations and engineering offices were very candid in providing valuable information for our use in the design of future projects. We would particularly like to express our appreciation to Mr. Phillip Henderson for hosting the investigation team and for being the technical liaison. Mr. Henderson's experience was a great asset in the investigation of dry cooling technologies.

DRY COOLING TECHNOLOGY INVESTIGATION

This report discusses the pertinent findings while visiting various ESKOM generating stations in South Africa which employ dry cooling system technologies. The technology investigation team included the following personnel:

Jim Cuchens	– SCS Engineering, Principal Engineer/Cooling Systems
Peter Shaw	– CEPA Project Management, Brisbane, Australia
Jim Webber	– SEI / Operations Consultant, Philippines
Ferrel Norwood	– SEI / Maintenance Manager, Suall Power Station
Phillip Henderson	– ESKOM / Chief Engineer

The Kendal, Majuba, and the Matimba generating stations were visited for investigating the differences in each type of dry cooling system technology for potential application on a supercritical merchant generating station. Figures 1, 2, and 3 attached show a picture of each plant respectively.

The investigation of dry cooling technologies also included visiting the ESKOM engineering offices for discussion with design and consulting engineering personnel. The issues discussed with ESKOM engineering and plant personnel included plant layout/equipment orientation considerations, equipment thermal design considerations, maintenance considerations, station service requirements, modeling capabilities, and the consumptive water requirements for the various dry cooling systems.

This report also includes a comparison of design issues concerning the use of an air cooled condenser (ACC) system versus a natural draft cooling tower indirect dry cooling (IDC) system.

SYSTEM DESCRIPTIONS

The following is a brief description of each type of dry cooling and/or condensing system:

<u>Majuba and Matimba Stations - Air Cooled Condenser System</u>

The air-cooled condenser systems typically included the following equipment related to the condensing and turbine cycle:

- Air-cooled Condenser
- 2 – 100 % Condensate Extraction Pumps
- 2 – 100 % Steam Jet Air Ejectors (SJAE)
- 2 – 100 % Motor Driven or Steam Driven Boiler Feed Pumps
- Auxiliary Cooling Tower
- Auxiliary Service Water Pumps

Steam from the exhaust of the low-pressure turbine generator was condensed with the use of an air-cooled condenser. Steam is routed from the turbine exhaust via a large insulated main steam duct to the air-cooled condenser. The air-cooled condenser is comprised of finned tube bundles arranged in an A-frame configuration. Air flowing through the finned tube bundles condenses the steam which is collected in condensate headers. Condensate from the air-cooled condenser is routed to a condensate collection tank. SJAEs are utilized to remove non-condensables. The condensate extraction pumps take suction from the condensate collection tank.

Kendal Station - Indirect Dry Cooling System

The IDC system included the following equipment related to the condensing system and turbine cycle:

Natural Draft Indirect Dry Cooling Tower
Steam Surface Condenser
2 – 100 % Condensate Extraction Pumps
2 – 100 % Steam Jet Air Ejectors (SJAE)
2 – 100 % Motor Driven or Steam Driven Boiler Feed Pumps
2 – 50 % Motor Driven Horizontal Split-Case Circulating Water Pumps
Auxiliary Cooling Tower
Auxiliary Service Water Pumps

Steam from the exhaust of the low-pressure turbine generator is condensed with the use of a steam surface condenser. Cooling water is pumped by circulating water pumps from the discharge of the dry cooling tower, through the condenser, and then recirculated back to the cooling tower. An independent auxiliary cooling tower cools Service water for auxiliaries. Non condensables are removed from the steam surface condenser with the use of SJAEs.

Cooling water is pumped through the steam surface condenser and then cooled by the use of a natural draft counterflow cooling tower. The dry cooling tower is comprised of finned tube bundles arranged in an circular plot configuration. Air flowing through the finned tube bundles cools the circulating water which is which is then routed back to the suction of the horizontal circulating water pumps.

The IDC tower is typically erected on a concrete foundation which may require extensive supports (caissons, pilings, etc.) depending ion site soil loading capabilities.

STATION DESCRIPTION/OPERATING EXPERIENCE

Kendal

The ambient conditions at Kendal range from -5.0°C to 28.0°C. The climate at the Kendal Station is cooler than at the Majuba and Matimba Stations. Consequently, wind effects were moderate (with round natural draft IDC) and do not apparently impact the unit performance substantially as much as an ACC. Also, increased boiler firing is used to offset any degradation during high (summer) ambient conditions. Plant scheduled outages are on 18 month cycles. The Kendal plant was designed for zero discharge. Kendal IDC experienced minor degree of fouling from dist/dirt on surface of tube bundles. The IDC also experienced unexpected problems associated with birds being attracted to the IDC for nesting habitat. Bird droppings evidently was very aggressive (corrosive) on tube bundles such that occasional leaks were experienced. Plant personnel utilized shotguns in attempts to deter bird from inside the IDC. However, due to concerns for shooting holes in tube bundles, plant personnel resorted to poisoning in attempts to eliminate birds inside the IDC. Birds were still present during our inspection of the IDC tube bundles and fans.

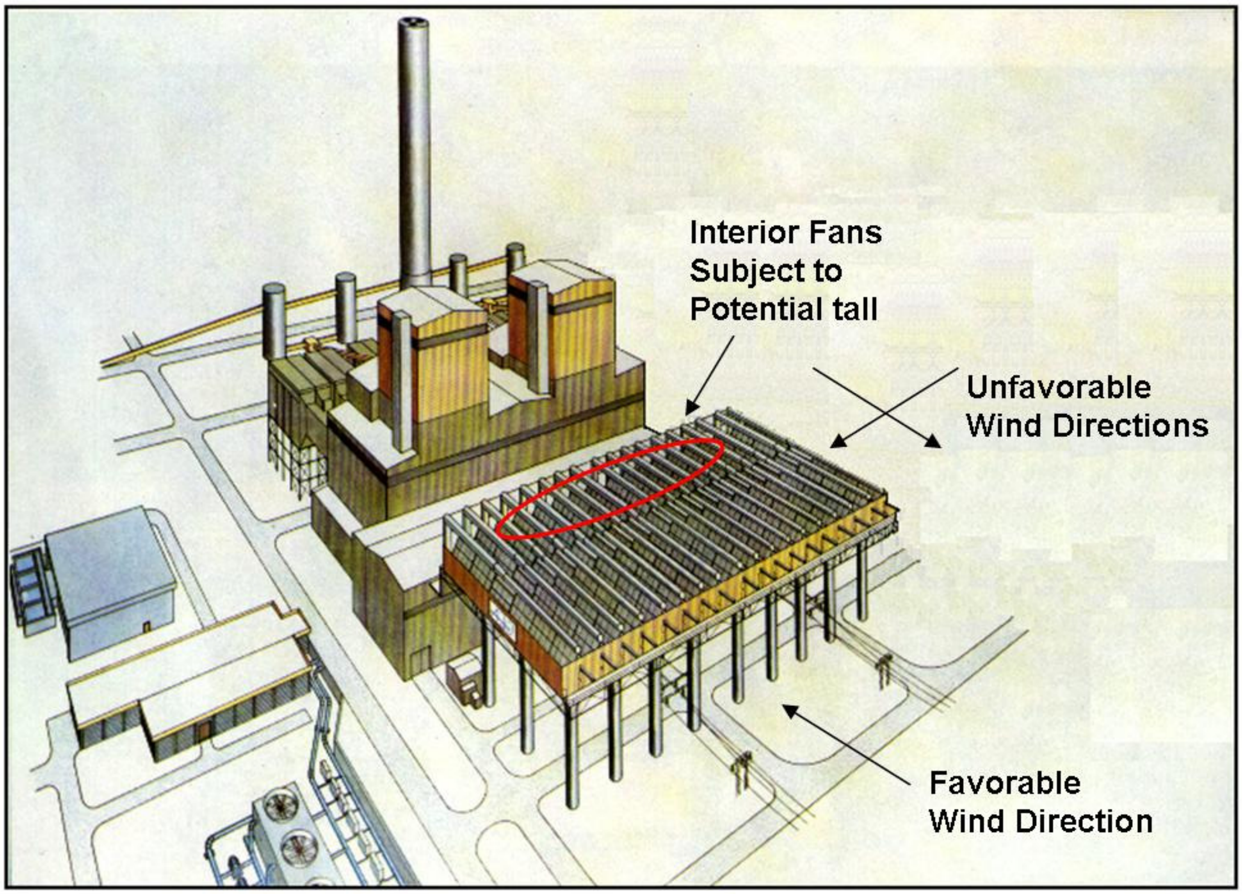
Majuba

Majuba is a mine mouth station but unsuitable coal from the local mine necessitated shipment of coal from other sources. This has impacted plant economics and operations such that dispatch of the plant is currently on a two-shift operation (load demand). The ambient conditions at Majuba range from -2.0°C to 30.0°C. Wind effects were moderate to heavy depending on ambient conditions during high or unfavorable wind excursions. Also, wind impacts were considered minimal since it was primarily on 2-shift operation (not base loaded). Experience at the Majuba station has encountered relative few problems with the ACC system. This is largely due to the additional conservatism in ACC thermal design (10 %) combined with lower ambient conditions and cyclic unit operations. Majuba did experience some degree of tube fouling (dirty) as well as fan (stalling) and gearbox problems even with minimal operating experience.

Matimba

Matimba is a base loaded plant and now has approximately 15 years of operating service and experience. The ambient conditions at Matimba range from +6.0°C to 38.0°C. Early experience at the Matimba station encountered a number of problems which impacted unit performance and availability. These problems were related to both ACC design (thermal) and station configuration (six-pack configuration, building structures, etc.). Wind effects are moderate to heavy which impacted the unit generation (back-pressure) substantially in earlier years of operation resulting in load swings and/or unit trips. ESKOM has done extensive mathematical modeling (computational fluid dynamics - CFD) in efforts to assess potential modifications for improving ACC performance at Matimba as well as determining guidelines for future

ACC design applications. None of these modifications were implemented at Matimba due to financial constraints. Some operational problems at Matimba were minimized by modifications to the existing turbine building siding and adding wind-walls which enhanced air flow into the ACC. The installation of an evaporative spray cooling system also provided some backpressure relief during unit operations at high ambient conditions. Matimba also experienced fan stalling of interior fans during operation with unfavorable wind conditions (note: fan stalling can occur when fans cannot get adequate inlet air flow (starved) due to poor inlet air distribution see illustration below).



The Matimba station ACC systems have required considerable fan gearbox and motor maintenance. The Matimba ACC system does not have a centralized oil fill/drain system which would provide substantial benefits in reducing maintenance expenses. Plant scheduled outages are on 18 month cycles. Matimba also experienced tube bundle fouling (dirty) requiring periodic washing of tube bundles in efforts to maintain maximum ACC performance capability.

FACTORS IMPACTING TECHNOLOGY DECISION

The availability or water will impact the decision on what type of system to employ and/or implementation of design features. The amount of real estate (land) and/or the location of the facility (due to noise) could also impact the decision on using air cooled condensers. The environmental requirements associated with water permits, discharge permits, could impact the decision on what type of system and/or materials to employ. The unit operating characteristics will also impact the type of cooling/condensing system. The following is a brief list of factors which impact the decision concerning the feasibility and type of dry cooling technology/system to employ:

- Site location
- Geological conditions (wetbulb, drybulb, wind, etc.)
- The availability of water, potential sources of cooling water, and/or cost of water.
- Environmental considerations (plume, drift, noise, real estate available, proximity to other structures, etc.).
- Energy Requirements (station service)
- Capital cost
- Operation & Maintenance Cost associated with mechanical/electrical equipment, and potential fouling of tube bundles
- Turbine design and performance limitations (i.e. exhaust pressure correction curve, alarm and trip points).
- Unit capacity factor (loading characteristics)

DESIGN GUIDELINES AND/OR RECOMMENDATIONS

The following recommendations are made based on operating experience and discussions with engineering and plant personnel:

- The ACC or IDC system should be designed in accordance with site climatological conditions (wetbulb/drybulb profiles, site altitude, predominant wind direction, wind speeds, rainfall, etc.).

- The ACC design should consider an option for furnishing an evaporative spray system for use in power augmentation during high ambient conditions.

- The ACC or IDC thermal design capability should be based on Valves-Wide-Open (VWO) turbine exhaust conditions (exhaust pressure, flow, enthalpy, etc.).

- The design of the ACC or IDC system should be based on average annual drybulb conditions with adequate thermal margin (minimum ≈10 % ±) as necessary to avoid load curtailments and/or unit operating restrictions (trips, load cuts, etc.) during **maximum ambient conditions.**

- ACC performance during wind directions other than the predominant direction can result in substantial performance degradation (above expected). Orientation of an ACC system adjacent to the turbine building should consider the design of an open turbine building for enhancing air inlet if the ACC is not separated from the turbine building. Orientation of ACC away from power house may experience additional airflow anomalies not coincident with those of Matimba and CFD modeling should be considered as part of conceptual design review.

- The ACC system should be designed to minimize duct losses while maximizing air inlet profiles. Depending on other design considerations implemented, the location and orientation of the ACC should consider separation from the turbine building (~5 to 10 meters) for enhanced air-inlet profiles to the ACC.

- Gearbox service factors should be a minimum of 2.0 for the ACC fans.

- Consideration of maintenance should include on-line cleaning provisions (both ACC & IDC).

- Design for both the ACC and IDC systems should consider fouling potential and mitigation of fouling sources (concrete/dust-free surfaces under coolers). Maintenance considerations around perimeter of structure should minimize potential for grass influent as well as bird interference (sanctuary, fin fouling, etc.).

- ACC system maintenance considerations should include the use of a centralized oil fill/drain system.

- Design and configuration of the piping system and electrical control system should consider the use of automated controls for optimizing station service under stable climatological conditions.

- Design and procurement of both the ACC and/or IDC systems should employ prudent and aggressive quality controls to ensure reliable equipment operation.

- Design of both the ACC and/or IDC systems should employ require galvanized finned tube bundles in lieu of aluminum for enhanced corrosion protection.

- Design of both the ACC and/or IDC systems should employ steam jet air ejectors (SJAE) when the station includes multiple generating units. Single unit station design's are anticipated to require liquid ring vacuum pumps for startup (hoggers) and SJAE for normal operation.

- A universally accepted test code for testing performance of ACC/IDC systems currently does not exist. The ASME is currently in the progress of developing a test code for ACC systems under PTC23 (atmospheric cooling equipment). Consequently, acceptance of either the ACC and/or IDC systems should be contingent upon a mutual agreement for testing guideline. Performance warranties and/or guarantees should be contingent upon mutually acceptable test guidelines.

- The design of the ACC systems should insure that fan blade loading does not exceed ~ 25 Hp/blade (minimum 8 blades except when using low noise fans).

- Design of the ACC systems should evaluate multi-speed motors for elimination of gearbox and associated maintenance expenses.

- Location of the main transformers under the ACCs resulted in several maintenance problems (oil dropping from gearboxes, noise, access, etc.). Consequently, location of the transformers should be relocated when at all possible.

- Performance degradation of a single-unit station employing an ACC system is not anticipated to have problems similar to Matimba 6-pack unit configuration. However, performance degradation with multi-unit installations is dependent on ACC configuration and orientation (see comment above concerning orientation of ACC away from power house) and potential need for CFD modeling.

- Design of the ACC steam duct should ensure proper condensate/drain system design.

- Implementation/Use of High ITD (i.e. > 65°F at Majuba and Matimba) on dry cooling technology to minimize size, capital cost, O&M, and potential impact from adverse climatological conditions (wind, etc.)

- Minimize potential of dust entrainment around ACC by avoiding close proximity to coal piles, unpaved or highly traveled roads, farm lands on un-vegetated dirt areas.

Note: The above design considerations and recommendations are considered to reflect prudent design practices to date based on experience with large ACC and IDC cooling systems within South Africa. Unit and/or system designs employing design practices and/or technologies different than those reflected should be evaluated based on site specific design considerations in conjunction with the design issues and practices documented in this report.

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COMPARISON OF DRY COOLING TECHNOLOGY/SYSTEM REQUIREMENTS

The cooling water flow requirements for an evaporative type of coal-fired closed loop cooling system (steam surface condenser & cooling tower) can also be approximated to be 360 GPM per Mw (~ 288,000 for ≈ 800 Mw Unit). The makeup requirements for a closed loop cooling cycle due to losses from evaporation is approximately 2 percent of the total cooling water flow (0.02 X 288,000 GPM ≈ 5,760 GPM for an 800 Mw Unit). The use of a dry-type cooling and/or condensing system is predominantly dictated by the availability of water resources for consumptive use. On fossil type generating units, the heat load (Btu/Hr) to the condenser (either type) from the steam turbine can be approximated to be 4.7×10^6 Btu/Hr per Mw. For a 800 Mw unit steam cycle, the condenser duty will be approximately 3,760 Btu/Hr $x10^6$. An ACC or IDC system essentially has no makeup requirements due to evaporative losses or chemistry control (cycles of concentration of constituents in cooling water). The pros and cons of each type of dry technology/system are briefly described as follows:

Design Considerations		
	Air Cooled/Dry System	**Indirect Dry Cooling System**
Equipment Requirements	Air Cooled Condenser SJAE/Vacuum System Condensate Pumps Service Water System Steam Header Piping Backpressure Turbine Auxiliary Cooling Tower Boiler Feed Pumps Dimeneralized Water/System	Steam Surface Condenser SJAE/Vacuum System Condensate Pumps Auxiliary Cooling Tower/Pumps Circulating Water Pumps/Sump Circulating Water Piping/Valves Natural Draft Cooling Tower Cooling Tower Foundation Dimeneralized Water/System
Real Estate	The ACC design typically requires substantially more real estate than an IDC design. The ACC must be located to provide optimum air inlet distribution	The IDC cooling tower cycle typically requires less real estate than an ACC design. The IDC cooling tower must be located away from plant structures to avoid air inlet interference. The IDC cooling tower can be oriented in any direction without detriment from wind affects.
Building Impact	The ACC is isolated outside the boiler that reduces the building size and cost. Also, the use of an open turbine building can further lower building costs.	The IDC design requires a steam surface condenser (titanium tubes) which requires a larger turbine building (and pedestal) and higher cost.

Design Considerations *(continued)*		
	Air Cooled/Dry System	**Indirect Dry Cooling System**
Building Impact	The ACC is isolated outside the boiler that reduces the building size and cost. Also, the use of an open turbine building can further lower building costs.	The IDC design requires a steam surface condenser (titanium tubes) which requires a larger turbine building (and pedestal) and higher cost.
Station Service	The ACC system typically requires more station service than an IDC system. Depending on ACC design, the ACC system could double the energy requirements.	The IDC system typically requires less station service than an ACC system. The only major energy requirement with an IDC system is the cooling water pumps.
Water Consumption	An ACC design requires no water unless an evaporative spray system is used for power augmentation during high ambient conditions	An IDC system requires no water makeup.
Unit Performance	Unit performance with an ACC system is anticipated to be poorer than an IDC system due to increased susceptibility of degradation due to wind/recirculation effects. Implementation of prudent design criteria can mitigate most of the degradation potential.	Unit performance with an IDC system is anticipated to be better than with an ACC system but is still worse than that of a wet evaporative cooling tower..
Capital Cost	The capital cost for an ACC system is anticipated to be substantially less than an IDC system.	The capital cost for an IDC system is anticipated to be ≈ 2x to 3x the cost for an ACC system (with ≈ thermal design).
Noise	Noise levels for an ACC system will be substantially higher than an IDC system due to the large number of fans, motors, and gearboxes. Also, the location of the ACC fans results in substantial noise levels below the ACC (ground reflection).	Noise levels for an IDC system are minimal since there is essentially no machinery required.

Design Considerations *(continued)*		
	Air Cooled/Dry System	**Indirect Dry Cooling System**
Water Treatment	An ACC system requires the use of demineralized water. Consequently a water is treatment facility is required to provide high quality water and water chemistry control.	An IDC system requires the use of demineralized water. Consequently a water is treatment facility is required to provide high quality water and water chemistry control.
Plume	No plume and/or fogging is anticipated to occur with an ACC system.	No plume and/or fogging is anticipated to occur with an ACC system.

ACC SYSTEM DESIGN PARAMETERS		
	Majuba Station	**Matimba Station**
Number of Units at Station	6	6
Number of Units with ACC system	3	6
Unit Mw Rating	665r	665
Design inlet air temperature	Later (°C)	Later
Design steam flow	Later	Later
Design heat load	Later	7500 GWh
Backpressure @ design	Later	Later
No. of ACC modules/fans	48	48
Air side surface area	Later	120 ha
Air inlet/platform height	45 m	45 m
Inlet air velocity	Later	Later
Main Steam Duct Diameter	~ 5 m	~ 5 m
Platform height	Later	Later
Length	Later	72 m
Width	Later	85 m
Fan diameter	9.1 m	9.1 m
Horsepower per fan	Later	Later
Motor nameplate	Later	Later
IDC SYSTEM DESIGN PARAMETERS	**Kendal Station**	
Number of Units at Station	6	
Number of Units with ACC system	6	
Unit Mw Rating	685	
Design drybulb/wetbulb temperature	Later	
Design approach temperature	Later	
Design heat load	Later	
Inlet water temperature	48.0°C	
Outlet cold water temperature (CWT)	33.0°C	
Design water flow	Later (m^3/s)	
Air inlet height	Later	
Tower Height	165.0 m	
Tower Diameter @ Base	165.0 m	
Tower Diameter @ top	104.2 m	
Tower Diameter @ throat	101.7 m	
Condenser backpressure @ CWT	Later (kPa)	
Condenser Surface Area	20,383 m^2 (x2)	
Number of Condenser Tubes	23,976 (x 2)	
Condenser tube material / Length	Later / 12.38 m	
Condenser tube BWG / O.D.	Later / Later	
Number of shells	2	

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Figure 1 - Kendall IDC

Figure 2 - Majuba ACC

Figure 3 - Matimba ACC