ECONOMIC BENEFITS OF HYBRID TURBINE INLET CHILLING FOR A SMALL GAS TURBINE IN AN INDUSTRIAL PROCESS

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INTRODUCTION

This paper examines the yearly economic benefits of installing a hybrid turbine inlet chilling system in an industrial plant.

Small gas turbines are frequently used in industrial applications, with the gas turbine driving an electrical generator for plant power, or a mechanical drive for an important element of the plant’s process. Often the turbine’s waste heat is then also used for another portion of the plant’s operations.

Although gas turbines are widely used in industrial settings, they lose both power and efficiency during periods of higher ambient temperatures, potentially reducing the plant’s throughput, and hence its economic return, during critical times of the year. The loss of power and efficiency is caused by a reduction in ambient air density as temperatures rise. Since turbines are mass flow machines with a volumetrically limited intake, less dense intake air results in degradation of power output and increase in engine fuel consumption.

Inlet cooling can restore the turbine’s hot day power and efficiency, increasing the plant’s throughput without making mechanical or process changes to the system – it simply allows the turbine to operate as it would in cooler ambient conditions. Inlet cooling also increases the total heat content of the turbine’s exhaust, further adding to its economic effectiveness.

However, conventional inlet cooling techniques are often misapplied, or can be impractical in different circumstances. Examples include conventional evaporative cooling in relatively humid climates, or the comparatively higher capital costs and yearly operation costs related to the parasitic power loads of conventional mechanical refrigeration, especially on smaller gas turbines.

BACKGROUND

The Enterprise Products natural gas liquids (NGL) complex in Mt. Belvieu, TX uses several small gas turbines in various different NGL trains. In their “Seminole” plant two Rolls-Royce 501KC5 turbines drive large refrigeration compressors used for cryogenic distillation in a de-ethanizer process. Waste heat from the turbines is collected and sent to a large furnace, reducing the fuel required for furnace heating operations. The plant needed more power from their gas turbines especially in the hot and humid summer months when the turbine performance falls substantially.
The climate in South Texas is characterized by periods of high temperature and high humidity, but also periods where temperatures are relatively high, but the humidity is lower.

**FIGURE 1 HOUSTON, TX CLIMATE MAP**

*Source: NOAA*

**THE PROBLEM**

The Rolls Royce 501 KC5 engines, like all gas turbines, are rated for full power at ISO/ISA conditions (59 °F at 60% RH and sea level) and lose power at higher ambient inlet air temperatures and elevations. The Enterprise turbines had previously been fitted with direct evaporative cooling which now required replacement. Direct evaporative cooling did not provide the air density increase and subsequent power gains desired by the plant during many hours of operation throughout the year.

The pre-existing inlet filterhouse locations for the gas turbines were situated next to a furnace where heat from plant processes could raise the actual inlet air temperatures several degrees higher than the site ambient temperature, further compounding the turbine power output problems.
Combining data for annual temperature and humidity and the turbine output vs. temperature, gives the total annual horsepower-hour “loss” due to site ambient temperature compared to the engine ISO/ISA rating.

**FIGURE 2: ANNUAL LOST OUTPUT DUE TO TURBINE INLET TEMPERATURE IN MONT BELVIEU**

Enterprise evaluated several inlet cooling methods. Conventional evaporative cooling already installed on the engines was concluded unsatisfactory. Conventional mechanical chilling was not practical due to the long installation time and higher capital costs associated with a complete system. In addition, the parasitic loads to operate the mechanical chilling system, integrated over a full year, were deemed high.

Given these limitations, Enterprise Products elected to install Everest Sciences’ patented ECOChill hybrid inlet chilling system. This multi-staged inlet air handling
solution includes an integrated filterhouse, an *indirect* evaporative heat extraction process, and is finished by a mechanical chilling process. This paper explores the economic and technical factors leading to this decision.

**FIGURE 3: ROLLS ROYCE 501 KC5 OUTPUT VS. INLET TEMPERATURE**

![Graph showing output vs. temperature for Rolls Royce 501 KC5 engine.](source)

*Source: Everest Sciences and Rolls Royce EnginAid Published data*

**INDIRECT EVAPORATIVE COOLING**

*Direct* evaporative cooling is a process where water is evaporated into the turbine intake airstream. The phase change from liquid to water vapor results in a reduction of the “dry bulb” temperature of the airstream, but does not change the thermodynamic energy of the air, or it does not reduce its “wet bulb” temperature or enthalpy. In contrast,
Indirect evaporative cooling does actually change the thermodynamic energy of the turbine intake air stream by reducing its enthalpy. This is because the evaporation is done in a separate “secondary” airstream and then heat energy is transferred from the turbine intake air across the heat exchanger walls to the secondary airstream. It is a heat extraction or heat removing process unlike traditional evaporative techniques. The cooling process does not introduce water to the turbine inlet airstream. The net result is a turbine inlet airstream with a lower dry bulb temperature, a lower wet bulb temperature, and lower enthalpy (see Figures 4 and 5.)

Therefore, indirect evaporative cooling provides similar heat rejection characteristics to mechanical chilling, however, unlike mechanical chilling; only fans and pumps are required for heat extraction along with the indirect evaporative heat exchange mechanism. When compared to conventional mechanical refrigeration, indirect evaporative cooling significantly reduces the parasitic power required per ton of rejected heat.

**FIGURE 4: DRAWING OF AN INDIRECT EVAPORATIVE HEAT EXCHANGER**

Source: Everest Sciences
**HYBRID COOLING WITH INDIRECT EVAPORATION AND REFRIGERATION**

On first glance, a hybrid system combining direct evaporative and mechanical refrigeration cooling might seem attractive. However, the power required to cool air with refrigeration is a function of the total enthalpy change desired between a starting temperature and the target temperature. Because direct evaporative techniques do not change the airstream’s enthalpy, there is nothing to be gained from the attempt to add together the results of a direct evaporative system and a mechanical refrigeration system.

On the other hand, because indirect evaporation actually reduces the enthalpy of the turbine inlet airstream, it is *additive* with mechanical refrigeration when combined. This can dramatically reduce the total mechanical refrigeration capacity required to achieve a given target temperature. The reduced refrigeration capacity required also means that
less “work” is needed from the refrigeration compressors to reach target temperatures and therefore the associated parasitic power draw to chill the air is reduced.

A necessary byproduct of indirect evaporation is a secondary air stream in which water is evaporated. This secondary airstream is a high volume source of cooler-than-ambient air which can be used for refrigerant condensing, making a separate cooling tower unnecessary.

**FIGURE 6: PSYCHROMETRIC CHART WITH COMBINED INDIRECT EVAPORATION AND REFRIGERATION**

- Ambient Conditions
  - Dry-bulb = 95 F
  - Relative Humidity = 30%
  - Wet-bulb = 71 F

Less refrigeration means **Lower** parasitic power loads

Therefore, in a hybrid *indirect* evaporative cooling system coupled with a stage of supplementary mechanical refrigeration, two air streams are produced. The first air stream is the turbine intake air which has heat removed by the indirect evaporative heat exchange process and is then further chilled (as needed) by a supplementary chilling coil to reach the target turbine intake air temperature. The second air stream produced is a cooler than ambient moisture laden air stream that can be used for heat rejection on the refrigeration condensing section reducing the chilling circuit parasitic loads and without the need of a separate cooling tower.
EVEREST SCIENCES ECOChill HYBRID TURBINE INLET COOLING

Everest Sciences’ ECOChill hybrid turbine inlet systems combine an indirect evaporative process with supplemental refrigeration with the following properties.

- Lower power consumption and corresponding operating cost during a significant portion of the year.
  - This is because the indirect evaporative system uses low powered fans and pumps, while power consumption associated with the refrigeration compressors can remain OFF during many hours of the year.
  - Fully integrated supplemental refrigeration sized to meet cooling requirements on the hottest days is incorporated, but only used when and as required to meet temperature targets. On peak temperature days, the indirect evaporative stage performs the initial heat rejection followed by mechanical chilling. Therefore, less heat rejection is required from the refrigeration compressors leading to lower associated parasitic power loads to operate the overall chilling process.

- The indirect evaporative secondary airstream is used for condensing so that no separate cooling tower is required, while still providing condensing temperatures below ambient dry bulb temperature.

- Cold water which condenses on the chilling coil on is fed back to the *indirect* evaporative stage significantly reducing the system’s external water requirements to make up evaporated water in the secondary air stream.

- Water used in the indirect evaporative process is isolated from the turbine intake air eliminating intake air contamination concerns from water born minerals.

- A pre-packaged and factory assembled system allows for installation with minimal turbine downtime.

- Integrated filtration so that the Everest Sciences system can be a direct drop in replacement for the filter house.

- Integrated, fully automatic control of all components maintains turbine intake air at the target temperatures without the need of operator interface and provides for plant control room communication.

- The multi-staged hybrid cooling approach provides Enterprise redundant cooling capacity. As the hybrid chilling system has two stages of cooling, some cooling will be available even if maintenance is required for the one of the two stages. The probability of losing all intake air chilling is low.
FIGURE 7: PHOTOS OF TWO EVEREST SCIENCES ECOChill SYSTEMS INSTALLED AT ENTERPRISE PRODUCTS, MT. BELVIEU, TX

Source: Everest Sciences
TOP LINE CONSIDERATIONS

At the Enterprise Products installation, the Everest Sciences ECOChill system allows the turbines to maintain better than ISO rated full power through most hours of the year.

**FIGURE 8: ROLLS ROYCE 501 KC5 OUTPUT VS. INLET TEMPERATURE**

This means the system can recover all the “lost” horsepower-hours shown in Figure 2, i.e. 2,380,000 HPh per year and can reclaim an additional 1,568,000 HPh by lowering the intake air temperature below ISO conditions.

Enterprise’s opportunity costs due to the lost horsepower-hours are proprietary to Enterprise Products. However, from experience across a range of process industries, Everest Sciences has found $0.25 to $0.30/HPh to be a good first estimate of the gross margins associated with additional horsepower in a gas processing plant. In other words, this is the additional gross margin to be gained each year from the introduction of a turbine inlet cooling system per additional HPh. (Of course, gross margins for a
particular site will depend on the particular process, current product prices and spreads, etc.).

Combining data developed above, Figure 9 gives the total yearly economic benefit from the system.

**FIGURE 9: ESTIMATED ANNUAL ECONOMIC BENEFIT OF EVEREST SCIENCES ECOChill INSTALLED ON ROLLS ROYCE 501 KC5 AT MT. BELVIEU, TEXAS**

| Economic snapshot below represent using ECOChill for 10.3 months per year. |
|---------------------------------|-----------------|--------------|
| $ / Yr                          | Comment:        |
| 3,948,121 HPh (7543 hrs/yr)     | Additional Base Power $1,026,512 @ $0.26 $/HPh |
| 7,462 MMBTU's Value of incremental additional waste heat content: $29,847 @ $4 $/MMBTU's |
| 30,907 MMBTU's Additional Fuel Burned **: ($123,629) @ $4 $/MMBTU's |
| -162 (kGAL) Cooling system operating costs: ($6,220) |
| 0 (kGAL) Untreated Water Consumption: N/A @ $3 $/kGAL |
| 776,717 kWh Treated Water Consumption: N/A @ $10 $/kGAL |
|                                | Cooling System Power Consumption: ($225,248) @ 0.29 $/kWh |
|                                | Net Yearly Economic Value: $701,261 |

** Average Heat Rate and Emissions for incremental power is 21% less than base case **

Source: Everest Sciences

To complete the economic calculation for a site, the final installed cost of a hybrid turbine inlet cooling system, like the Everest Sciences ECOChill product, will of course depend on a number of factors including, turbine size, site climate, existing space constraints and turbine downtime required. Most applications will see cash basis payback periods of less than 2 years, sometimes considerably less.

The Enterprise example discussed was installed on an elevated platform above existing pipe racks with ducting for the chilled inlet air from the ECOChill system to the gas turbines. This installed configuration relocated the turbine intakes away from the existing furnace adjacent to the old turbine filterhouse and intake. In addition, it provided the needed clearance around the gas turbine for plant operations.
SUMMARY AND CONCLUSION

In many process applications the economic output of the plant is limited by the power output of a gas turbine driving a key process within the plant. Since gas turbines can lose a significant portion of their output power during high ambient temperature conditions, improving gas turbine performance with inlet cooling can have a direct positive impact on plant throughput and revenue.

Faced with this situation, Enterprise Products compared a (replacement) direct evaporative cooling system, a conventional refrigeration system, and Everest Sciences ECOChill hybrid indirect evaporative cooling systems. The direct evaporative system was deemed not to meet the plant’s current output targets. The conventional refrigeration system had high electrical power loads, and associated costs, throughout the year, and its condensing requirements imposed a load on the plant’s water cooling system which would have required either an additional new cooling tower, or an upgrade to the existing cooling tower.

The hybrid ECOChill system from Everest Sciences was selected based the best project economics that included:

- Project revenue
- Cooling capacity equal to conventional refrigeration
- Lower electrical power load and resulting costs
- No additional cooling tower installation costs
- A packaged solution that allowed for minimal turbine downtime and its associated costs

Everest was chosen by Enterprise Products for their innovative and efficient chilling technology for inlet air chilling to the Rolls Royce gas turbines. Enterprise is now able to consistently reduce inlet air temperatures to their gas turbines, giving Enterprise the ability to provide needed refrigeration horsepower to their process plant.
Everest Sciences Corporation

Thank you for your interest in Everest Sciences Corporation. For more information about our comprehensive air handling solutions, please feel free to call us, toll-free:

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