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# Modification of Wayang Windu Unit 1 Cooling Tower to Improve CT Performance

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**ABSTRACT <HEADING 1 STYLE>**

Unit 1 Cooling Tower (CT) in Wayang Windu Geothermal Power Plant has been operating since 2000. There were excellent works had been conducted by Star Energy Geothermal (Wayang Windu) team in order to improve the CT performance while assuring the excellent CT operation reliability. The first project was replacing the CT fan stack with higher fan stack in 2011. The Unit 1 CT performance test revealed data of decreasing of approach temperature as much as 1.44°C, increasing of range temperature as much as 1.92°C, and increasing of CT effectiveness as much as 5.17%. The impact was equivalent to net generation improvement of 1.44 MW. The second project was replacing the existing low reliable CT gearbox with more reliable gearbox and the increasing number of fan blades to improve the CT performance during CT upgrading project from 2014 till 2017. The CT upgrading project improved the CT thermal performance and the impact was equivalent to net generation improvement of 0.40 MW.

## 1. INTRODUCTION

Wayang Windu Geothermal Power Plant operates 2 (two) units geothermal steam turbine. Unit 1, which has capacity of 110 MWe, was the largest single cylinder turbine in the world when it was commissioned in year 2000. Unit 2, which has capacity of 117 MWe as an improved design of Unit 1, was commissioned in year 2009. Both unit deliver the electricity to PLN (Indonesia's state electricity company).

### 1.1 Unit 1 CT Plume Recirculation Issue

Unit 1 CT fan stack was designed with 6 feet height only and had relatively straight vertical panels which didn't produce significant velocity recovery. In other hand, due to Wayang Windu Geothermal Plant is located in the mountain; the CT is exposed to swirling and shifting winds. These types of winds may force down the exiting plume (hot air) from the CT and drawn back into the CT which increases the entering wet bulb temperature. This phenomenon is called recirculation. The increasing of wet bulb temperature will impact to decreasing of CT performance. Figure 1 shows the plume recirculation in Unit 1 CT.

In order to reduce the effect of plume recirculation, new design with higher fan stack was proposed. In addition, there was an opportunity to increase fan blade efficiency. SEGWWL engineers conducted engineering study based on available design data, simulation and experimental method. The aim is the new fan stack design will produce significant velocity recovery to convert some of the wasted velocity pressure energy at the top of fan stack into useful work at the plane of the fan; thus, fan efficiency will be increased. By improving fan efficiency, additional motor power can be made available to further increase the air drawn through CT; thus, overall CT performance can be improved. The detailed report of Unit 1 CT fan stack replacement had been published in paper of Unit 1 Cooling Tower Fan Stack Replacement to improve CT Perfomance, World Geothermal Congress 2015, Melbourne, Australia.



**Figure 1: Major plume recirculation in Unit 1 Cooling Tower**

### 1.2 Unit 1 CT Gearbox Low Performance Issue

Unit 1 CT gearboxes (brand: Sumitomo, model: PX8065R2Y-RRV) had been operating since commissioning in year 2000. This common industrial gearbox was designed with low thermal Service Factor (SF) design of 0.96 (below minimum thermal SF required of 1.0) and marginal mechanical Service Factor (SF) design of 2.04 (minimum requirement SF for CT is 2.0). Since initial operation, the gearbox failure had been identified during operation which showed low reliability operation due to failure of gear teeth components only in 1-year operation. Further investigation revealed that poor cooling process and H2S exposure at gearbox breathing air were the causes of these failures. The oil cooling system used air withdrawn by radial fan installed at input shaft which produced low heat transfer process due to oil capacity and small size of gearbox housing. Improvement works had been done by installing gas absorbent media at breathing line, providing additional oil tank to improve cooling performance and changing lubricant oil from mineral type to synthetic type. Although these approaches could prolong the gearbox lifetime for 2 to 3 years' operation, however, more maintenance efforts and high cost should be spent specially to purchase the gearboxes spare parts (which became as "obsolete" spare parts) and the synthetic lubricant oil. Due to categorized as "obsolete" spare parts, special spare parts manufacturing was required which impacted to long delivery time and high spare part cost. Figure 2 shows the picture of CT gearbox's gear failure.



**Figure 2: Severe gear tooth defects of CT gearbox**

In order to improve the reliability of the CT gearbox, it was proposed to change the gearbox design by considering also the opportunity to improve the CT performance with economical capital cost. The engineering study and execution work of CT upgrading project are reported in this paper.

## 2. ENGINEERING STUDY

Design of a cooling tower requires a unity of many engineering disciplines involved. Mechanical engineering, chemical engineering, and civil engineering disciplines contribute most in CT design. In this project, SEGWWL engineers conduct engineering study based on available design data, simulation and experimental method. The aim is the new gearbox has good reliability and maintainability to support the continuous operation of Unit 1 power plant.

The scopes of engineering study are as follow:

- CT Gearbox Selection
- Fan blade performance simulation
- CT structure strength analysis
- Air flow measurement before and after modification
- Thermal imaging monitoring

### 2.1 CT Gearbox Selection

Criteria of Unit 1 CT gearbox required for this project are described below:

- It is a common product for CT application and already be used in many industries specially power plant and chemical plant.
- The after sales of service can be provided promptly.
- Minimum modification of gearbox support is required.
- The gearbox load can be supported safely by wooden structure of Unit 1 CT.

Amarillo 1712 gearbox is chosen based on above criteria. Amarillo gearbox has been successfully being used since the early 1970's in many cooling tower applications throughout the world. The spare parts could be purchased with lower cost and prompt delivery time. Table 1 shows gearbox comparison between Sumitomo gearbox and Amarillo gearbox for the same design application.

**Table 1: Sumitomo and Amarillo Gearbox Comparison**

| Description | | Existing Gearbox | Proposed Gearbox |
|---|---|---|---|
| **Physical** | Brand | Sumitomo | Amarillo |
| | Model | 8065 | 1712 |
| | Gear Ratio (Actual) | 12.469 to 1 | 12.5 to 1 |
| | Weight (Lbs/ kg.) | 1500/ 680 | 2125/ 964 |
| **Fan data** | Type | Hudson, Tuflite III | Hudson, Tuflite III |
| | Blade Number | 8 | 8 |
| | Output fan speed (rpm) | 118.7 | 118.4 |
| | Required power (kW) | 113.03 | 113.03 |
| **Cost** | Gearbox cost | USD $72,000 | USD $35,000 |
| | Maintenance cost in 5 years | USD $81,192 | USD $12,370 |
| **Lubrication** | Lubrication Method | Mechanical oil pump | Oil slinger |
| | Lubrication Quantity (liters) | 55 | 80 |
| | Lubricant | Mobile SHC XMV460 (synthetic) | Mobile DTE-BB (mineral) |
| | Oil cost (for 1 gearbox) | USD $1269 | USD $269 |
| | Oil Level Switch | GEM Oil Level Switch | Murphy Oil Level Switch |
| | Recommended Oil Change Frequency (hours) | 2500 | 3000 |
| | Cooling method | radial fan on input shaft | radiant cooling (oil capacity) |
| **Rating** | Motor Rated Capacity (HP/kW) | 177/132 | 177/132 |
| | Gear Reducer Rated Capacity (HP/kW) | 360.7/269 | 422/315 |
| | Mechanical Service Factor (2.0 minimum required) | 2.0378 | 2.3841 |
| | Thermal Service Factor (1.0 minimum required) | 0.96 | not required |
| | Thermal Service Factor de-rating for altitude | 0.9 | not required |
| | Thermal Service Factor de-rating for ambient temperature | 0.87 | not required |

From the table of CT gearbox comparison in Table 1, it is shown that cost of Amarillo 1712 gearbox is about half of Sumitomo 8065 gearbox while oil cost for Sumitomo 8065 gearbox is almost 5 times for Amarillo 1712 gearbox. Amarillo 1712 gearbox's maintenance cost is only 30% of Sumitomo 8065 gearbox's maintenance cost. Besides, service factor rating of Amarillo 1712 gearbox is higher that Sumitomo 8065 gearbox and thermal service rating of Amarillo 1712 gearbox is designed equal or exceed the service factor rating when the discharge air temperature is 120°F or less. So, it is much recommended to choose Amarillo 1712 gearbox for this gearbox replacement plan.

Further study shows more options can be derived by choosing Amarillo 1712 gearbox or using the same gearbox design of Unit 2 CT (Marley 4000) for this plan so maintenance team only conduct maintenance of 1 type of gearbox and reduce spare holding costs. Moreover, larger capacity gearbox has more flexibility to drive more fan blades in order to obtain more air flow for CT air flow improvement if required.

However, there are some constraints should be considered for CT air flow improvement as follow:

- Rated capacity of Unit 1 CT service transformer is 1900 kVA.
- Performance verification of balance of plant (BOP) equipments.
- CT wooden structure capacity to withstand load for heavier gearbox safely.
- Unit 1 cooling tower motor circuit breaker system.

Table 2 shows table of specification comparison between Amarillo 1712 gearbox and Unit 2 Marley 4000 gearbox.

**Table 2: Amarillo and Marley Gearbox Comparison**

| Description | Option 1 | Option 2 |
|---|---|---|
| Brand | Amarillo, 1712 | Marley, 4000 |
| Gearbox cost | USD $35,000 | USD $73,500 |
| Gear Ratio (Actual) | 12.5 to 1 | 12.98 to 1 |
| Output fan speed (rpm) | 118.7 | 114.0 |
| Weight (Lbs/ kg) | 2125/ 964 | 3200/1451 |
| Mechanical Service Factor (2.0 minimum required) | 2.3841 | 2.9717 |
| Oil cost (for 1 gearbox) | USD $269 | USD $235 |
| Maintenance cost in 5 years | USD $12,370 | USD $17,030 |
| Change of Drive Shaft | Not required | Yes, cost USD$ 14,000 |
| Modification of gearbox support | cost USD $ 3,000 | cost USD $ 5,000 |
| Modification of fittings (hub, coupling etc) | cost USD $ 5,000 | cost USD $ 5,000 |
| Flexibility to achieve higher CT performance | None | very flexible to drive more fan blades |

From Table 2, it can be concluded that option 2 (Marley 4000) has the best performance compares to other options. With the highest SF of 2.971, Marley 4000 can also give better contribution to increase CT performance by driving more fan blades which will produce more air flow. This improvement can be achieved by replacing existing electric motor with higher capacity electric motor. However, with the constraint of Unit 1 CT service transformer rated capacity, the power required to drive higher capacity electric motor isn't adequate. There are 8 cells (cell A, B, C, D, E, F, G, H) in Unit 1 CT to support the CT operation. If all gearboxes in 8 CT cells are replaced, it requires huge effort and high cost to conduct CT Service Transformer upgrade and BOP equipment replacement. The performance of BOP equipment such as HWP, GRS etc. are designed to achieve maximum generation of 116 MW gross. Besides, more effort and structure strengthening works are also required to assure CT wooden structure is safe to withstand the additional load. Based on the selection criteria and constraints of existing equipment design, project team proposed to change 4 gearboxes of CT cells (A, D, E, H) from Sumitomo 8065 gearbox to Amarillo 1712 and 4 gearboxes of CT cells (B, C, F, G) from Sumitomo 8065 gearbox to Marley 4000 including electric motor upgrading with opportunity to install additional fan blades. See calculation of Unit 1 CT service transformer capacity in Table 3.

### 2.2 Fan Blade Performance Simulation

There are many data can be obtained from fan blade performance simulation as follow:

- Air flow
- Thrust load
- Motor capacity required
- Fan blade load
- Blade noise level, etc.

Thrust load data is a main input data required for CT structure strength analysis along with weight of new gearbox and electric motor. The sample of fan blade performance simulation is shown in Figure 3.

**Table 3: Unit 1 CT Service Transformer Capacity**

| Item | Service | Space heater | Arranged by | Equipment | | | | Plant rated operation | | | | | E |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Capacity | Quantity | | | Shaft power | Motor | | D | Required capacity | |
| | | | | kW | A | B | C | kW | Eff % | PF % | | kVA | |
| 1 | Incomer feeder from C/T service TR | | DSGE | | 1 | | | | | | | | ACB |
| 2 | Cooling tower fan A | S | DKP | 151.8 | 1 | | | 121 | 94.1% | 89.0% | 1.0 | 170.56 | ACB |
| 3 | Cooling tower fan B | S | DKP | 214.4 | 1 | | | 121 | 94.1% | 89.0% | 1.0 | 240.90 | ACB |
| 4 | Cooling tower fan C | S | DKP | 214.4 | 1 | | | 121 | 94.1% | 89.0% | 1.0 | 240.90 | ACB |
| 5 | Cooling tower fan D | S | DKP | 151.8 | 1 | | | 121 | 94.1% | 89.0% | 1.0 | 170.56 | ACB |
| 6 | Cooling tower fan E | S | DKP | 151.8 | 1 | | | 121 | 94.1% | 89.0% | 1.0 | 170.56 | ACB |
| 7 | Cooling tower fan F | S | DKP | 214.4 | 1 | | | 121 | 94.1% | 89.0% | 1.0 | 240.90 | ACB |
| 8 | Cooling tower fan G | S | DKG | 214.4 | 1 | | | 121 | 94.1% | 89.0% | 1.0 | 240.90 | ACB |
| 9 | Cooling tower fan H | S | DKG | 151.8 | 1 | | | 121 | 94.1% | 89.0% | 1.0 | 170.56 | ACB |
| 10 | Spare | | DSGE | | | | 1 | | | | | | ACB |
| TOTAL LOAD (kVA) | | | | | | | | | | | | 1,645.84 | |
| C/T SERVICE TRANSFORMER CAPACITY (kVA) | | | | | | | | | | | | 1,900.00 | |
| SPARE CAPACITY (kVA) | | | | | | | | | | | | 254.16 | |

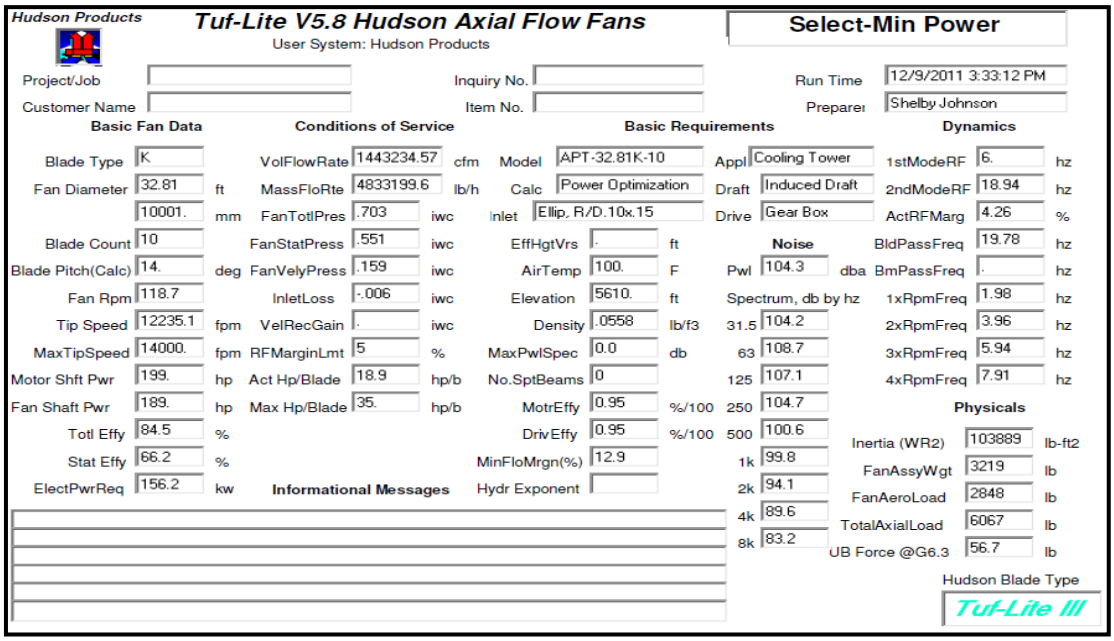



**Figure 3: Fan Blade Performance Simulation**

### 2.3 CT Structure Strength Analysis

CT structure strength analysis was conducted to assure CT structure is strong enough to withstand the produced load while the CT is in operation. The flow chart to conduct CT structure strength analysis is shown in Figure 4.

### 2.4 Air flow Measurement Before and After Gearbox Replacement

Air flow measurement before and after gearbox replacement will be conducted to know the improvement of CT performance. The result data will be compared with simulation data for further study.

### 2.5 Thermal Imaging Monitoring

Monitoring by using thermal imaging will be conducted to know the change of water outlet temperature after the new gearbox and electric motor have been installed. The monitoring data is used to confirm the improvement of CT performance

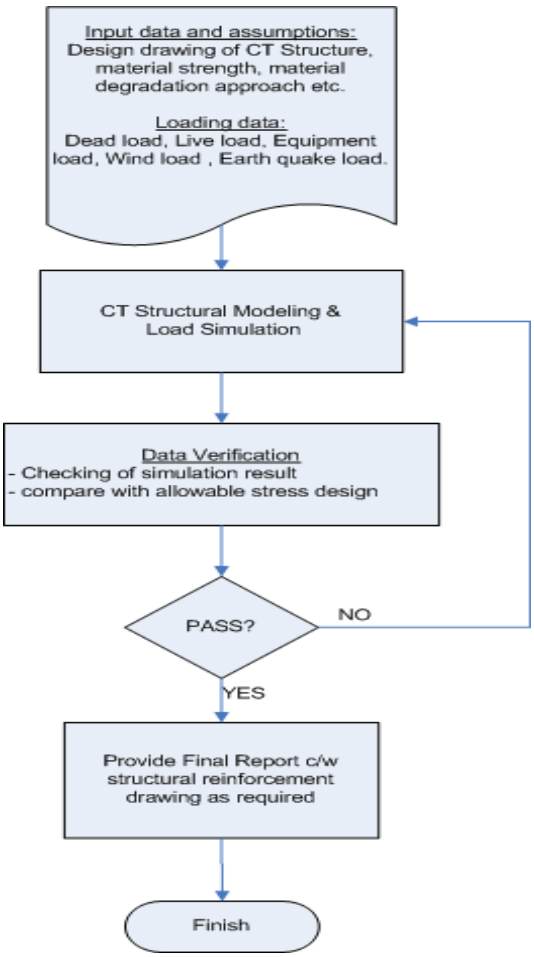



**Figure 4: CT Structure Strength Analysis Flow Chart**

## 3. RESULT AND DISCUSSION

Simulation of fan blade performance provides technical data which will be used as input data to CT structure modeling despite of static load data of new gearbox and new electric motor taken from the specification catalogue. The CT modelling will provide good technical data to assess the CT equipment upgrading design and to prepare strategy to handle any technical issues which could become obstacles in executing the project.

To assure the new gearbox and electric motor can be supported safely by existing CT wooden structure, CT structure strength analysis is conducted by using SAP program. By following the flow chart in Figure 4, there are several steps required to conduct structure analysis using SAP program. The modeling of CT fan stack and blades is shown in Figure 5.

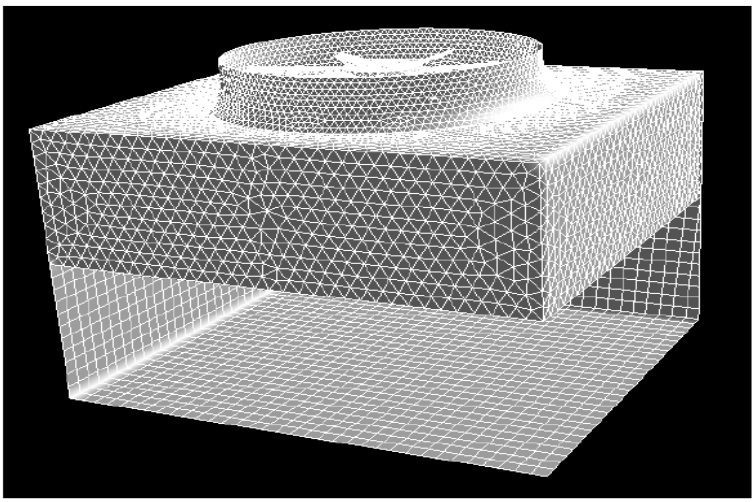


**Figure 5: CT Fan Stack & Blade Modelling**

After modeling of CT structure, loading simulation is conducted as shown in Figure 6. In this case, there are several loading simulations conducted as follow:

- $D$
- $D + L$
- $D + (W \text{ or } 0.7E)$
- $D + 0.75(W \text{ or } 0.7E) + 0.75L$
- $0.6D + W$
- $0.6D + 0.7E$

Whereas: D = dead load, L = live load, W = wind load, and E = earthquake load

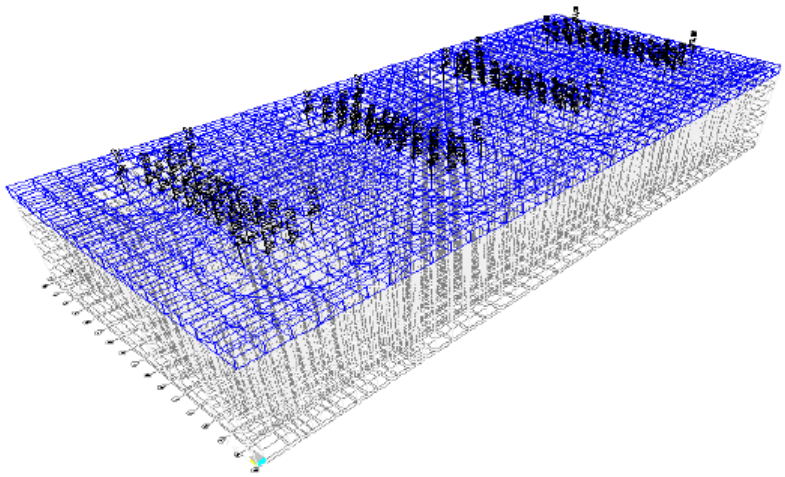


**Figure 6: CT Structure Load Modelling**

From this simulation, there are some reinforcement works for CT structure required in order to provide safe operation of CT. Figure 7 shows a drawing sample of wood reinforcement position that should be conducted.

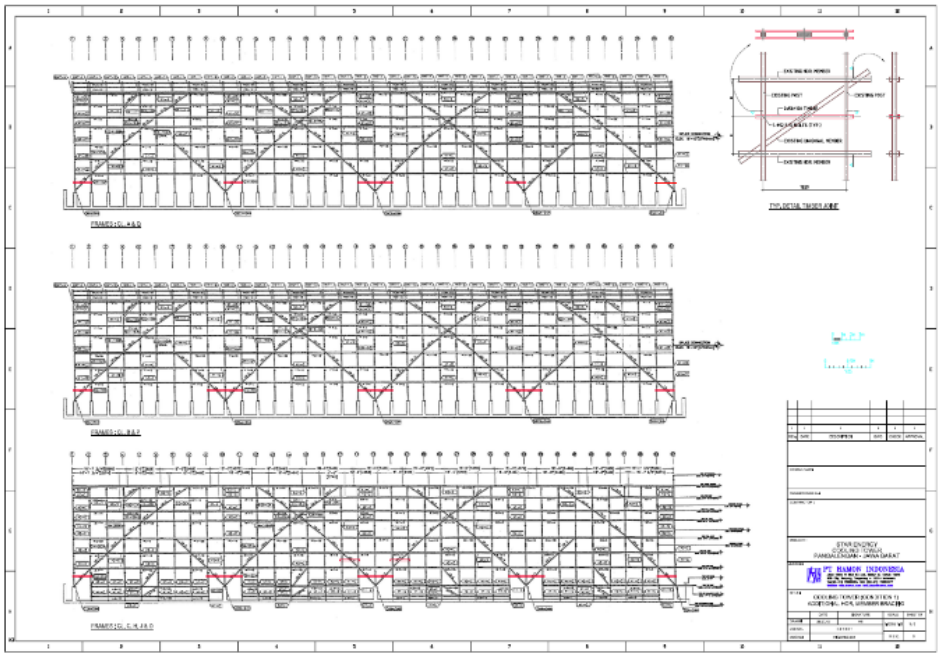


**Figure 7: CT Structure Wood Reinforcement Point**

The execution works were conducted with good preparation and completed within one month for each cell. The works were started from dismantling existing torque tube, CT hub and fan blades; continued with modification of torque tube frame (steel frame for gearbox and electric motor mounting), CT structure reinforcement work and reinstalled back the torque tube, hub and fan blades. The

final step is assembly of drive shaft and final alignment between gearbox and electric motor. Figure 8 shows photographs of work execution.



**Figure 8: Photographs of work execution**

During CT cell commissioning and monitoring phase, CT outlet temperature and condenser pressure data were taken for comparison. It is revealed that the outlet water temperature after modification is lower than before modification and the condenser pressure after modification is lower than before modification as shown in Table 4. Trending of outlet water temperature data is also taken which can be seen in Figure 9. Within time period 1 month before at November 2014 and after modification at January 2018, the decreasing water outlet temperature is clearly shown by the trending chart.

**Table 4: Water Temperature and Condenser Pressure Data Comparison**

| Time | Outlet Water (°C) | Design (°C) | Difference (°C) | Condenser Pressure (bara) |
|---|---|---|---|---|
| **Before** | 27.76 | 23.50 | 4.26 | 0.126 |
| **After** | 26.62 | 23.50 | 3.12 | 0.117 |

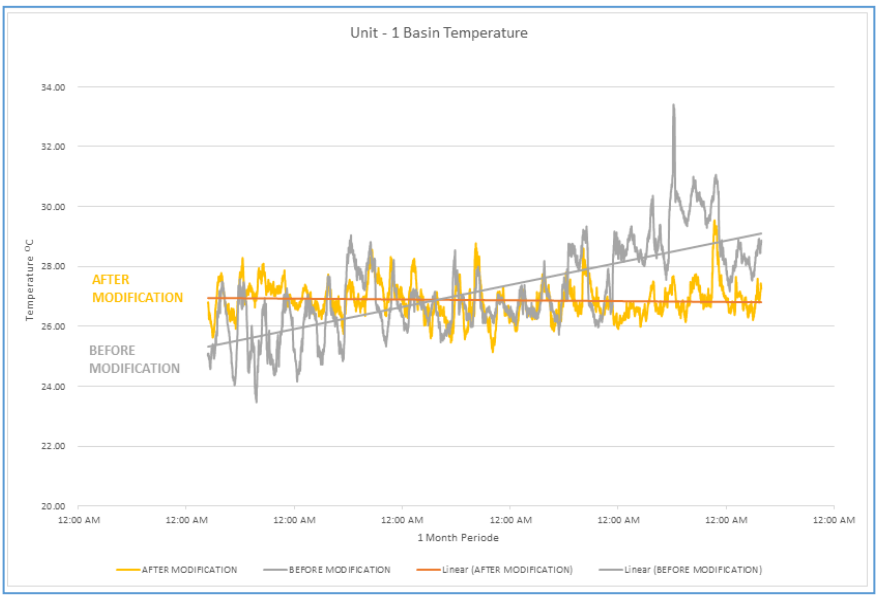



**Figure 9: Trending of CT Outlet Water Temperature**

In addition, air flow measurement and thermal imaging monitoring were conducted. The point of thermal imaging measurement in shown in Figure 10.

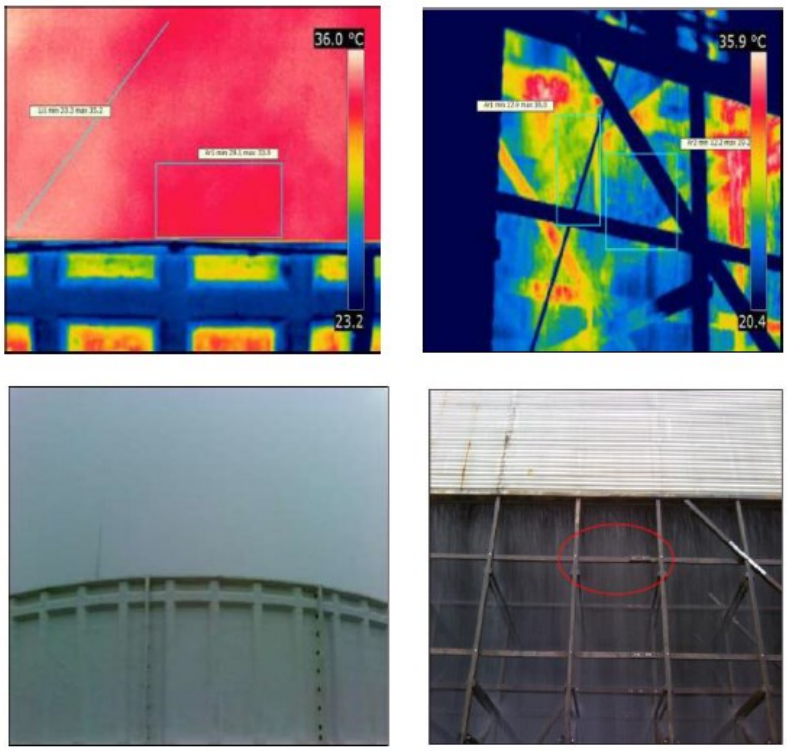



**Figure 10: Thermal Imaging Measurement Point**

As shown in Figure 11, significant improvement of heat recovery from new fan stack was revealed in comparison of condition before and after CT upgrade project. The outlet plume temperature is hotter and the outlet water temperature is cooler after project work. These data confirmed the improvement of CT performance.

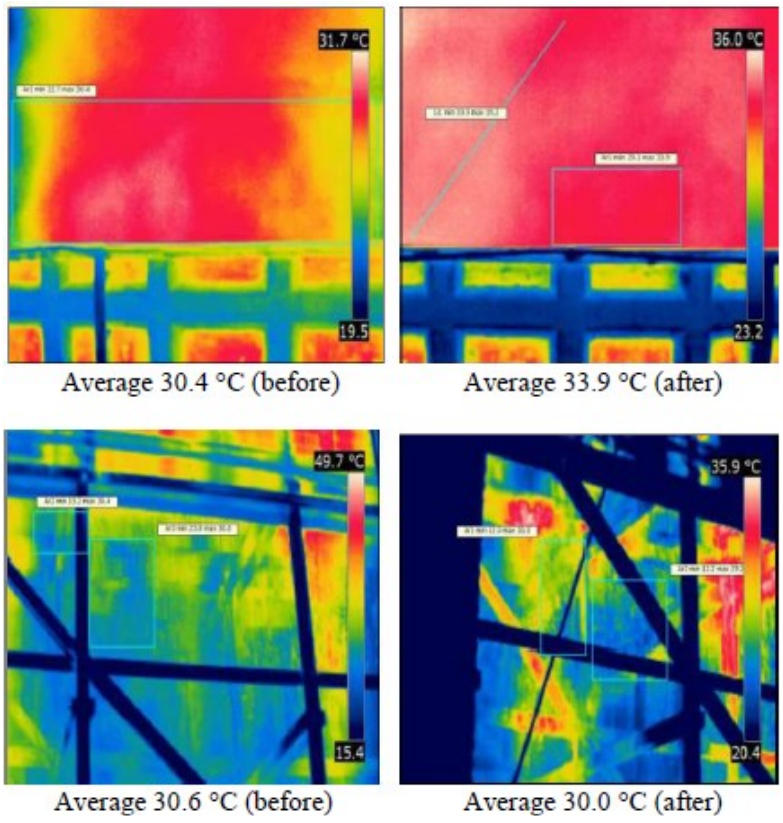



**Figure 11: Thermal Imaging Data Comparison**

## 4. CONCLUSION

The project of CT component upgrade which was started from 2014 till end of 2017 had been successfully conducted by replacing the gearboxes with the more suitably selected ones and adding fan blades to improve the thermal performance of the cooling tower. The proposed budget was USD 800,000, but the real total capital cost for this project was USD 615,072 so the cost saving was USD 184,928. The CT upgrading project improved the CT thermal performance and the impact was equivalent to net generation improvement of 0.40 MW which provided additional daily revenue around USD 900/ day and the calculated BEP is 689 days.

## ACKNOWLEDGEMENTS

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Amarillo Gearbox Model 1712 Specification

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