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Thermal Calculation for Water Cooling Tower To Cool Compressor ATLAS COPCO GA 250 FF

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Abstract

The aim of this paper is to choose the correct capacity of Thermal Calculation for Water Cooling Tower to Cool Compressor ATLAS COPCO GA 250 FF since a cooling tower is considered as an essential component for a compressor in an oil and gas pipe manufacture plant. Cooling tower is an equipment device commonly used to dissipate heat from air conditioning, water-cooled refrigeration, power generation units, and industrial process. In this paper, we use a induced draft counter flow tower for the design of cooling tower which based on Merkel's method. The tower characteristic is determined by Merkel's method. A simple algebraic formula is used to calculate the optimum water and air flow rate. This paper calculate the cooling tower characteristic, air flow required, efficiency, effectiveness, and cooling capacity of cooling tower need to cool the compressor compare with the availability cooling tower product in the market. In this paper, we will design based on calculation thermal capacity which lead to decentralizing the cooling tower to reach better energy efficiency of the plant.

Keywords : Cooling Tower, Thermal Design , Merkel's Method;

1.Introduction

The fall of WTI (West Texas Intermediate) crude oil price is affecting oil and gas company around the world. In this condition, oil companies reducing their investments which causing company that supply the goods and service for them also feel the effect. With this condition the company is in efficiency condition and cost reduction is one of the way to be able to survive from the ongoing crisis.

For supplying company that provide pipe for oil and gas, cost reduction means maximizing their production with minimum variable. Since production is low, not all line production is operating at the same time, so centralized cooling tower is over capacity. In this paper, we will design based on calculation thermal capacity which lead to decentralizing the cooling tower to reach better energy efficiency of the plant.

1.1 Theory and Principle

Cooling tower is heat exchanger that work as heat rejection equipment. The main function is to extract waste heat from water to the atmosphere. Heat transfer in a cooling tower is specified as convection between the droplets of water and the air, and also as evaporation which generate a small portion water to evaporate into moving air, the process is involves heat and mass transfer. Cooling tower are used in the power generation unit, refrigeration and air conditioning industries [1].
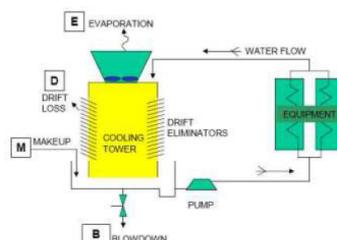

Figure 1. Diagram of Cooling Tower [4]

Water pumped from the tower basin cooling water through the process cooler and condensers in an industrial facility. The water absorb heat from the hot process which need to be cooled or condensed and absorbed heat warms the circulating water. The warm water return to the top of the cooling tower and trickles downward over the fill material inside the tower. Warm water trickles down, it comes in contact with ambient air rising up through the tower either by natural draft or forced draft using large fans in the tower. That contact causes a small amount of the water to be lost as wind age and some of the water to evaporate. The water back to the original basin water temperature and the water is then ready to recirculate [2].

Cooling tower can be classified by the movement of water and air as counter-flow and cross-flow types. Cooling tower can also be classified by air flow into mechanical draft and natural draft types. A cooling tower is a device for evaporative cooling of water using air contact. The main function of cooling tower is to remove waste heat into the atmosphere. Cooling towers are an integral part of much industrial processes such as oil refineries, petrochemical, thermal power plants, and chemical plants and HVAC system for cooling buildings [1], [4].

1.2 Purpose of a Cooling Tower

Cooling Tower is used by industrial applications that produce waste heat as a by-product of their operations. It provides energy efficiency and environmental friendly means of rejecting waste heat, saving our natural bodies of water from receiving quantities of warm water. They allow wind and air circulation to diffuse heat from the factories or manufacturing plants [1].

1.3 Type of a Cooling Tower

Base on the water and air flow arrangements, cooling towers divided into two type:
1. Natural draft
   Natural draft tower use large concrete chimneys to introduce air through the media. These types of tower normally used by utility power stations [4].
2. Mechanical draft
   Mechanical draft towers are available in the following airflow arrangements:
   - Counter flows induced draft.
   - Counter flow forced draft
   - Cross flow induced draft.

In the counter flow induced draft design, hot water enters to the top, while the air is introduced at the bottom and exits at the top of tower . Both forced and induced draft fans are used. For cross flow induced draft towers, the water enters at the top of tower and passes over the fill. An induced draft fan draws the air across the water fill and exit through the top of the structure [4].
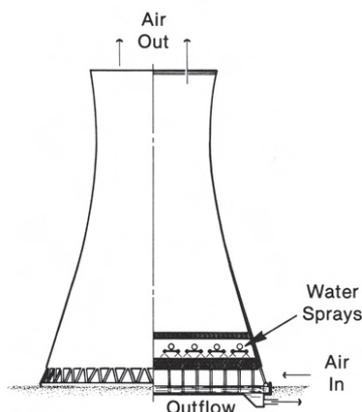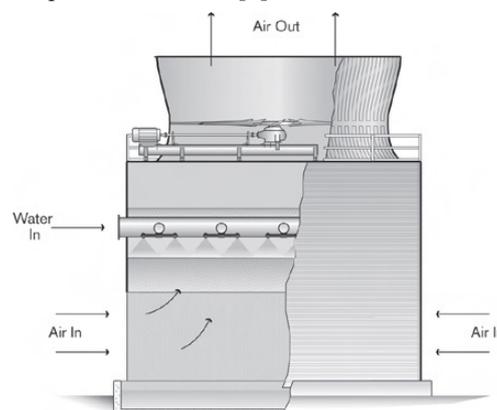

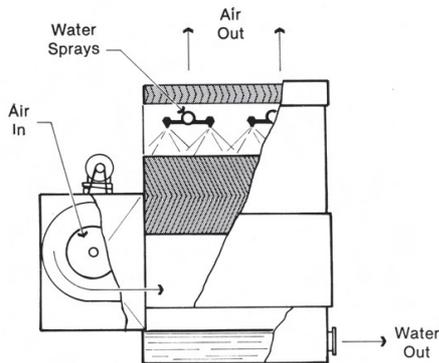Figure 2.Counter flow Natural draft Tower [4]   Figure 3.Induced draft counter flow Tower [4]
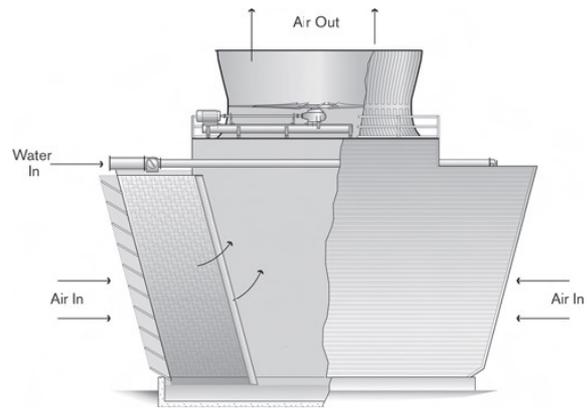
Figure 4.Forced draft counter flow blower fan tower [4]   Figure 5.Cross flow Induced draft [4]

Nomenclature

a	surface area per unit volume (m-1)
Cp,	a specific heat of saturated air, (kJ/kg)
Cw	specific heat of water, (kJ/kg K)
G	mass air flow rate (kg/sec)
Hw	enthalpy of saturated air at local water temperature, (kJ/kg)
Ha	enthalpy of local air stream, (kJ/kg)
Ha1	enthalpy of inlet air, (kJ/kg)
Ha2	enthalpy of outlet air, (kJ/kg)
$\Delta H1$	enthalpy difference, (kJ/kg)
$\Delta H2$	enthalpy difference , (kJ/kg)
$\Delta H3$	enthalpy difference , (kJ/kg)
$\Delta H4$	enthalpy difference , (kJ/kg)
K	mass transfer coefficient, (kg/m2 sec)
L	mass water flow rate, (kg/sec)
P	ambient pressure, (kPa)
ΔTw	water temperature different, (^{o}C) [= (T_1-T_2)]
T_1	inlet water temperature, (^{o}C)
T_2	outlet water temperature, (^{o}C)
Ta1	inlet air temperature, (^{o}C)
T_{wb}	temperature wet bulb, (^{o}C)
V	volume of packing, (m^3)
Vair	volume Air flow capacity (m^3/minute)

2. Cooling Tower Performance and Characteristic

Before designing a cooling towers, very important to determine the range and approach. Approach varies the entering air wet bulb temperature, flow rate of water and heat load. The first step in design cooling tower is to choose the design condition like inlet water temperature, outlet water temperature, water flow rate and inlet air wet bulb temperature [3].

The parameters from the point of determining the performance of cooling towers, are:
1. Approach
   is the difference between the cooling tower outlet cold water temperature and ambient wet bulb temperature. [1].
2. Range
   is the difference between the cooling tower water inlet and outlet temperature
3. Characteristic of Cooling Tower Heat transfer [5]
   This heat transfer process can generally be modeled using the Merkel Equation :

$$KaV/L = \int_{T_2}^{T_1} dT/(h_w - h_a) \tag{1}$$

where
KaV/L = Cooling tower characteristic;
K = Mass transfer coefficient, lb water/hr ft2;
a = contact area/tower volume, 1/ft;
V = active cooling volume/plan area, ft,
L = water mass flow rate, lb/hr ft2;
T1 = entering (hot)water temperature, ^{o}F;
T2 = leaving (cold) water temperature, F;
T = bulk water temperature, 8F,
hw = enthalpy of air–water vapor mixture at bulk water temperature, Btu/lb of dry air;
ha= enthalpy of air–water vapor mixture at wet bulb temperature, Btu/lb of dry air.

While the tower characteristic can be calculated from eq (1) using numerical method, it can be also be represented graphically as shown in figure below:
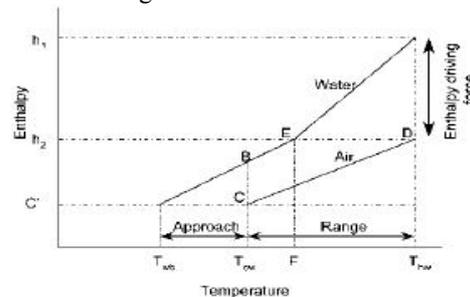

Figure 6. Graphical representation of the cooling tower characteristic [5]

where

C'	entering air enthalpy at entering air wet bulb temperature (T_{wb}),
BC	initial enthalpy driving force
CD	air increasing enthalpy line with slope L/G
DEF	projecting the leaving air point onto the water operating line and then onto the temperature axis yield the outlet wet bulb temperature
ABCD	the area within this region is graphical solution for cooling tower characteristic.

The amount of the heat lost by water is equal to the enthalpy rise is the air [3]. The heat balance equation is written as :

$$C_W \, \Delta t_w \, L = \Delta H_a \, G \tag{2}$$

Cooling Tower Efficiency
since a cooling tower base on evaporative cooling, the maximum cooling tower efficiency is influenced by the wet bulb temperature (T_{wb}) of the cooling air [1]
The cooling tower efficiency can be expressed as

$\eta = (T_1 - T_2)100/ (T_1 - T_{wb})$ (3)

where η = Cooling tower efficiency, T_1 = inlet temperature of water to the tower,
T_2 = outlet temperature of water from the tower ,
Twb = wet bulb temperature of air

Cooling tower effectiveness
*i*s the ratio of range, to ideal range, difference between cooling water inlet temperature and ambient wet bulb temperature, or in other words is = Range / (Range +Approach) [1],[2].
The effectiveness of cooling tower can be expressed as

$\varepsilon = (T_1 - T_2)/(T_1 - T_{a1})$ (4)

Cooling Capacity
Cooling Capacity is the heat rejected given as product of water mass flow rate, water specific heat and temperature difference [1],[2].
   The cooling capacity can be expressed as
   HL(Heat Loss) = L x Cw x Δtw (5)

3. Design of Cooling Tower

In company ABCD, the fall of crude oil price effected of productivities in pipe production became 30% of total production capacity. This condition affected of production schedule that not all machine operation every day. Atlas Copco GA 250 FF Rotary Screw Oil Injected Air Compressor. Motor speed 1487 rpm, power 263 kW, 400V, intensity 440. Air flow rate 1236 cubic feet/minute (35 m3/min), maximum working pressure 118 psi (8.2 bar).[6]. Instead of 4 compressor running continues together in normal production, now a day only running 1 until 2 compressor intermittent base availability material to process.

Data Measurement Temperature and Flow Water
The data that collected is the data that come from manual book and also data from measurement temperature of water and air in the utility area where the compressor installed and also the current central cooling tower was installed. in this calculation was limited to 1 time measurement, there is possibilities the variant of temperature change affected by weather when the ambient temperature getting hot or cloudy/rain.

Table 1. Data Measurement Temperature and Water Flow

Water Temperature Outlet Compressor	39.7	°C
Water Temperature inlet compressor	30	°C
Temperature ambient	28	°C
Cooling Water flow	5.6	l/s
Humidity	80	%
Assume temperature Outlet Cooling tower	33	°C
Temperature wet Bulb	25	°C

Psychrometrics of Evaporation
Understanding the evaporation cooling process can be enhanced by tracing on psychometric chart (fig.7) the change in condition of a pound of air as it moves through the tower and contacts a pound of

water (L/G =1), as denoted by solid line. Ambient air , at 78 ^{o}F DB and 50% RH, enters to the tower at point 1 and begin to absorb moist in an effort to gain equilibrium with the water. This process continue until the air exits the tower at point 2 [4],[5].
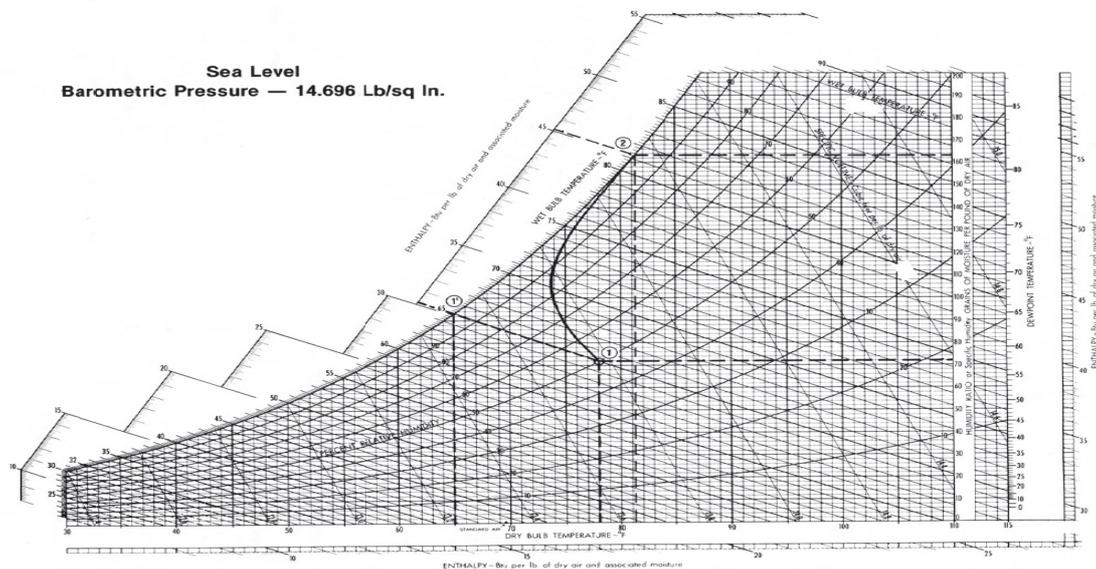

Figure 7. Psychrometric Chart Air - Water temperature curve [4],[5]

4. Conclusion

Base on the Calculation we choose cooling tower type induced draft counter flow cooling tower. In the market we found some cooling tower manufacturing and type of cooling tower, in this design we choose induced draft counter flow cooling tower due to more compact size with capacity same as calculation result : capacity air volume 559 m3/min. and water flow capacity is bigger than calculation 336 l/min. In the ideal condition, the heat loss by water must be equal to heat that absorbed by air, but in the actual practice it is not possible because some type of loses. In order to cover some losses, we have to choose the cooling tower that we need to multiply by 1.25 of calculation capacity as safety factor. The product we choose is a product with one level higher than ideal calculation which is a cooling tower with air volume capacity 700 m3/min to compensate the variation of ambient temperature if the ambient temperature increasing during the day.

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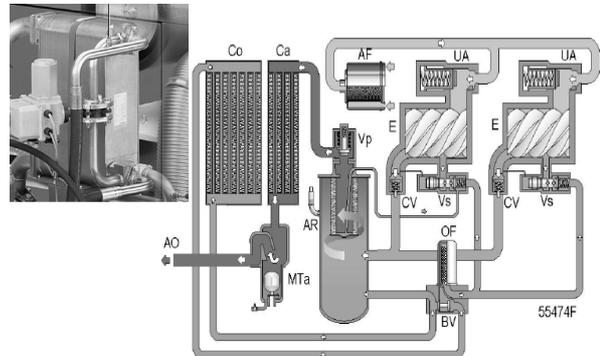
Appendix A.

A.1 Specification of Cooling Tower
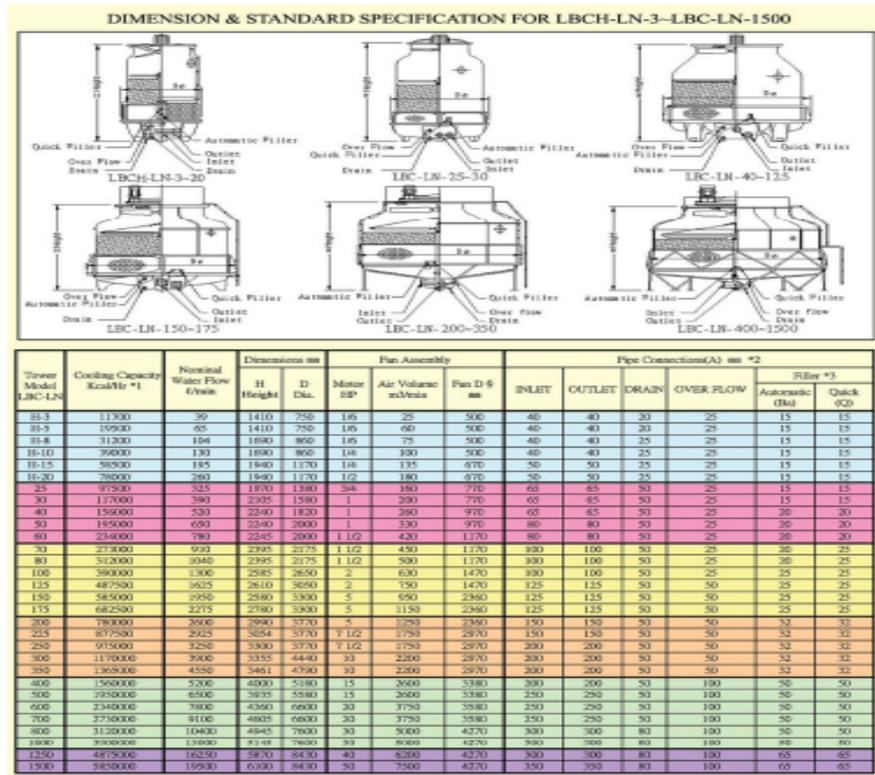
A.2 Compressor and Flow Diagram

Compressor GA 250 FF

Flow diagram Compressor GA 250 FF

A.3 Cooling tower calculation

Cooling Tower Approach

$CTA = T2 - T_{WB} = 30 - 25 = 5°C$

Cooling Tower Range
   Range = T1 - T2 = 40 - 30 = 10 °C

Heat Balance Equation
   The amount of heat removed from the water must be equal to heat that absorbed as shown by equation below :

   Cw x Δtw x L =ΔHa x G
   4.186 (40-30)5.6 = (117.46 - 95.36) G

   Since we need to find air flow rate of cooling tower, we assume that the air outlet cooling tower is the same value of Cooling tower Approach 5°C, so we can define 28°C + 5°C , using enthalpy air at 33°C   we can get air flow rate required to cooling tower is G = 234.42/22.1 = 10.6 kg /s. From the calculation we can found also the water to air mass flow ratio (L/G) from the equation = 5.6 /10.6 = 0.528. To find Volume of air required in the cooling tower can be shown by equation
   Vair= G x VS1 ,

where
Vs1 is Specific volume of air inlet temperature 28° C = 0.879 M3/kg.

So Vair= 10.6 x 0.879 =9.317.06 m3/s.≈ 559 m3/min.

   Merkel gives the cooling tower characteristic equation as :
   $KaV/L = \int_{T_2}^{T_1} dT/(h_w - h_a)$
   (KaV/L) = [(T1 - T2)/4] x {(1/Δh1) + (1/Δh2) + (1/Δh3) + (1/Δh4)}

   now

   Δh1 = Value of Hw - Ha at T2 + 0.1(T1 - T2)
   Δh2 = Value of Hw - Ha at T2 + 0.4(T1 - T2)
   Δh3 = Value of Hw - Ha at T1 - 0.4(T1 - T2)
   Δh4 = Value of Hw - Ha at T1 - 0.1(T1 - T2)

Calculation for ΔH1
= T2 + 0.1(T1 - T2)
= 30 + 01(40 - 30)
= 31 °C
Value of Hw at 31°C = 129.23 KJ/Kg
Value of Ha at 31°C = 109.32 KJ/Kg
ΔH1 = Hw - Ha = 19.91 KJ/Kg
Calculation for ΔH2
    = T2 + 0.4(T1 - T2)
= 30 + 04(40 - 30)
= 34 °C
Value of Hw at 34°C = 142.47 KJ/Kg
Value of Ha at 34°C = 130.25 KJ/Kg
ΔH2 = Hw - Ha = 12.22 KJ/Kg
Calculation for ΔH3
    = T2 - 0.4(T1 - T2)
= 30 - 04(40 - 30)
= 26 °C
Value of Hw at 26°C = 109.04 KJ/Kg
Value of Ha at 26°C = 86.06 KJ/Kg
    ΔH3 = Hw - Ha = 22.98 KJ/Kg

Calculation for ΔH4
= T2 - 0.1(T1 - T2)
= 30 - 0.1(40 - 30)
= 29 °C
Value of Hw at 29°C = 121.57 KJ/Kg
Value of Ha at 29°C = 97.69 KJ/Kg
    ΔH4 = Hw - Ha = 23.88 KJ/Kg
so (KaV/L) = [(40 - 30)/4] x {(1/19.91) + (1/12.22) + (1/22.98) + (1/23.88) = 0.525
Efficiency of Cooling Tower
 η = (T1 - T2)/(T1 - T_{WB})
 η = (40 - 30)/(40 - 25) = 66.7 %
Effectiveness of Cooling Tower
 ε = (T1 - T2)/(T1 -Ta1)
 ε = (40 - 30)/(40 - 28) = 0.833
Cooling Capacity
HL= L x Cw x Δtw
    = 4.186 (40-30)5.6
    = 324.4 KJ/s ≈ 843 897.6 KJ/hr