International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 7 Issue 4 Ser. I ǁ 2019 ǁ PP. 78-84

Plan, operation and Performance Analysis of the adhesive factory commissioning Cooling Tower

Prashant Kumar Nayak,Radha Krushna Sahu, Biswa Bihari Rath, Milan bhusal
Department of Mechanical engineering, Gandhi Institute For Technology (GIFT), Bhubaneswar

Abstract- *60 m3/h nominal capacity cooling tower was designed, based on the required cooling water parameters in process of the adhesive production in the "Chemis d.o.o." factory. For the chosen type and capacity of the cooling tower an analysis of its operation at various operating conditions was done.*
Special attention is dedicated to the choice of the atmospheric air design parameters, so that designed (and built) tower can meet the needs of the production process in challenging summer conditions, and also to provide an opportunity for expansion of factory production in the future.
The project was carried out at the plant "Chemis d.o.o." Aleksinac and it is in operation since November 2014.
Keywords-
cooling tower, atmospheric air, design parameters.

I. INTRODUCTION

Industrial process cooling towers recirculate water to cool hot process fluids. Cooling towers are heat exchangers that are used to dissipate large heat loads to the atmosphere [1, 2]. They are used in a variety of settings, including process cooling, power generation cycles, and air conditioning cycles. All cooling towers that are used to remove heat from an industrial process or chemical reaction are referred to as industrial process cooling towers (IPCT). Cooling towers used for heating, ventilation, and air conditioning (HVAC), are referred to as comfort cooling towers (CCT). Cooling towers are classified as either wet towers or dry towers. Dry towers use a radiator like cooling unit instead of water evaporation. Dry cooling towers, HVAC, and CCT are not included in thisreport.

Most plants use indirect contact cooling (Fig. 1). Hot process fluids pass through one or more heat exchangers, condensers, etc., which allow heat to be transferred from the process fluids to the cooling tower water without any contact with the process materials. Some industries use direct contact cooling. Cooling is achieved by placing the water in direct contact with hot materials, picking up surface contaminants like oils and dirt. The warmed water is then is collected, cleaned, (e.g. sent through an oil water separator,) then returned to the coolingtower.

Cooling towers cool the warm water by contacting it with ambient air. The warm water is pumped to the top of the IPCT and is distributed across the distribution deck where it flows through a series of nozzles onto the top of the tower's fill material. Fill material is used in cooling towers to create as much water surface as possible to enhance evaporation and heat transfer. As the water flows down the fill material, it contacts air that is drawn or forced across the fill material by one or more fans at the top of the tower. A small percentage of the water evaporates, cooling the circulating water and heating the air. A smaller portion of the water is entrained in the air stream as droplets of water which are called "drift" if they leave thetower.

The warm, moist air then passes through the drift eliminator and exits the tower through the fan stack(s), carrying some residual drift out of the tower. The cooled water falls into a cold water basin, which typically is at the base of the IPCT. From there, the water in the cold water basin is pumped back to the processes served by the tower [3].

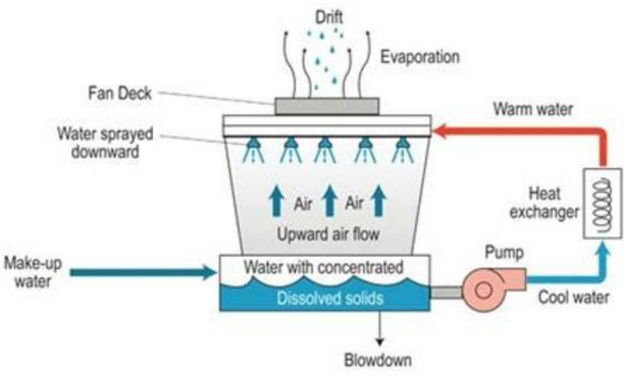

Fig. 1. Illustration of Water Flow Across a Cooling Tower

"Chemis d.o.o." is adhesive factory whit a quite complex chemical process emulsion polymerization of vinyl acetate. The modeled reaction is polymerization of vinyl acetate using potassium persulphate as initiator and polyvinyl alcohol as protective colloid. The production process is semi batch polymerization. Initial amounts of initiator and monomer are added into the system as well as the whole amount of the polyvinyl alcohol. The reactor is closed and the heating starts. When the temperature of the reactor reaches approximately 70˚C, the operator stops the hot water through the heating jacket (Fig. 2). The exothermic reaction and the heat of the remaining water filling the heating coat continue to rise the temperature over the set point. After the reactor temperature reaches a certain level, the remaining monomer starts to be pumped into the reactor.

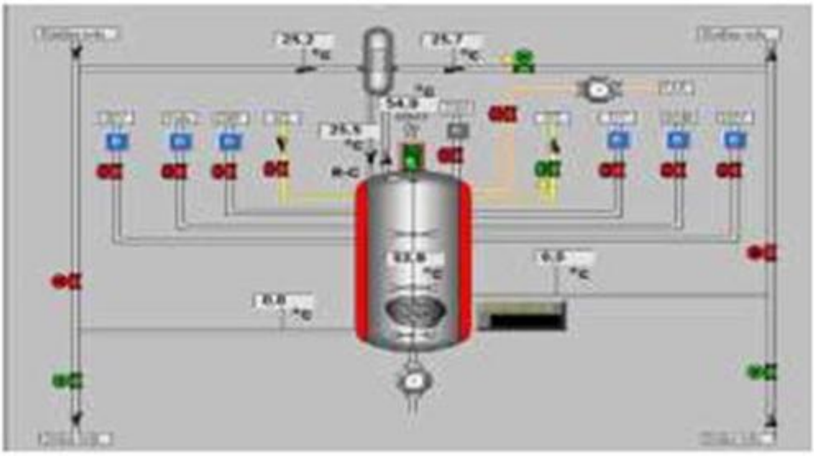

Fig. 2. Scheme of polymerization process

In order to provide continual polymerisation process, significant amount of cooling water is required. In this industrial plant, with its location change, the lack of fresh cooling water became a problem. To ensure undisturbed adhesive production, the wet cooling tower with mechanical draft was designed and built.

Based on the known parameters obtained from the adhesive factory, the following parameters are obtained: cooling tower filling height for the known cooling capacity and temperature difference, air flow rate, fan power consumption.

In the design are especially taken into account the requirements for increased production capacity in the near future, and climate parameters of the area in which the company was built. Due to the continuity of the production process throughout the year, required temperature level of the cooling water must be ensured in all weather conditions. At the same time, we avoided superfluous consumption of energy in the climate less intensive period. In the (Fig. 3) cooling tower designed and built in the "Chemis d.o.o." adhesive factory is presented.

Fig. 3. Cooling tower in factory "Chemis d.o.o"

II. MATHEMATICALMODEL

Evaporative water cooling decreases its temperature during simultaneous execution of two physical processes [4, 5, 6]: heat convection due to temperature difference of water and air, and the evaporation of water in atmospheric air due to differences of concentrations. Since a cooling tower is based on evaporative cooling the maximum cooling tower efficiency is limited by the wet bulb temperature of the cooling air. In practice, the actual temperature of water cooling is higher than wet bulb temperature for (5 - 10) K.

The cooling characteristic of the cooling tower is represented by the Merkel Equation[7]:

$$\frac{BV_{xv}}{G} = \int_{t_1}^{t_2} \frac{c\,dt_w}{h'' - h} \qquad (1)$$

The Merkel Equation primarily says that at any point in the tower, heat and water vapor are transferred into the air due (approximately) to the difference in the enthalpy of the air at the surface of the water and the main stream of the air. Thus, the driving force at any point is the vertical distance between the two operating lines. And therefore, the performance demanded from the cooling tower is the inverse of thisdifference. For technical calculations can be considered with sufficient accuracy that unsaturated moist air obeys the laws of a mixture of ideal gases.

The absolute air humidity (ω) can be calculated as:

$$\omega = 0.622\frac{p_{wp}(t)}{p_{ap}} = 0.622\frac{p_{wp}(t)}{p_a - p_{wp}(t)} \qquad (2)$$

The relative humidity (φ) of an air-water mixture can be calculated as:

$$\varphi = \frac{p_{wp}(t)}{p_{ws}(t)} = \frac{\omega}{(0.622+\omega)}\frac{p_a}{p_{ws}(t)} \qquad (3)$$

Moist air is a mixture of dry air and water vapor. The enthalpy of moist and humid air includes the enthalpy of the dry air - the sensible heat – and the enthalpy of the evaporated water - the latent heat. Specific enthalpy of moist air on the tower inlet can be expressedas:

$$h = h_a + xh_w = 1.006t + \frac{0.622p_{ws}(t)\varphi}{p - p_{ws}(t)\varphi}(2500 + 1.86t) \qquad (4)$$

where

h - specific enthalpy of moist air (kJ/kg) ha - specific enthalpy of dry air (kJ/kg) x - humidity ratio (kg/kg)

hw - specific enthalpy of water vapor (kJ/kg) t - air temperature (◦C)

The saturated vapor pressure can be calculated by different methods. In this paper, the IAPWS-97 method is used [8, 9].

Determination of the volumetric heat and mass transfer coefficients is done for the cooling devices in which water is sprayed through nozzles (Fig. 4) or in the form of drops is flowing on the grid. Size of surface cooling, which refers to the active volume unit is changed in this case, depending on the amount of water entering the cooler and air speed, which is reflected in the value of the heat and mass transfercoefficients.

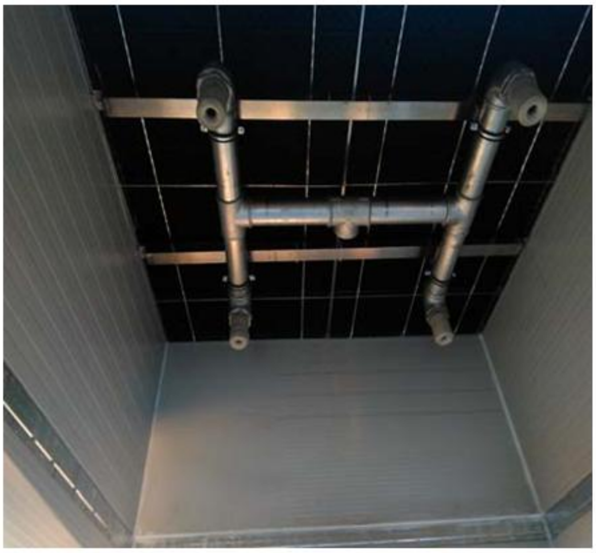

Fig. 4. Nozzles

Criteria equations do not include changing the surface of liquid, so in the absence of exact methods it is common use of the purely empirical formulation. In [7] empirical formula is given as

$$\beta_{xx} = A(w\rho)^m q_1^n \,[kg/m^3 h(kg/kg)] \qquad (5)$$

Where

q_1 - specific mass flow rate [kg/ m^{2}s], w – air velocity

A, m, n are constants and value of this constants are:

A = 1050,

m = 0.53 and n = 0.39

For the analytical solution of this integral, it is necessary to find appropriate dependence of specific enthalpy of saturated air and temperature. The parabolic dependence is chosen:

$$h'' = 0.019t^2 - 1.575t + 40, [kJ/kg] \qquad (6)$$

Solving the Merkel integral and using geometrical parameters of the cooling tower, the following equation can be written:

$$H_i = \frac{Gc_w \otimes t}{\beta_{xw} \otimes_m F_{ppi}} \qquad (7)$$

Fan power consumption

$$P = \frac{dp \cdot V_i}{\eta}$$

$$dp = \frac{\xi \cdot H_i \cdot \rho \cdot w^2}{1.4} \qquad (8)$$

III. RESULTS AND DISCUSSION

Fill material is TYPE MBV-312 from manufacturers and characteristics of this type of material are:

- Dimension:1200x300x300mm
- The contact surface for heat exchange: 240 m^2/m^3
- Maximum capacity (furthe hydraulic load of fill): 30t /m^2h

Technical specifications offered cooling towers EWK 441:

- Water flow: 36-132m^3/h
- Air flow: 17,4m^3/s

The fan with an electric motor:	HWD 150/10	HWD 150/10/20
Fanspeed:	580min^{-1}	290/580 min^{-}
^{1}Shaftpower:	4.9kW	0.8/4.9 kW
Nominalpower:	5.5kW	1.2/5.5kW

The manufacturer of the cooling tower equipment has given information for 900 mm height of the fill at full speed. This data is valid for 15 t/m2/h hydraulic load, which is half of the given maximumload. The density of the air in the tower is under this calculation 12.1 kg/m3, which corresponds to the average air temperature in the tower 38ºC. According to the data provided by the supplier of the equipment and user demands, after the preliminary calculation of operation cooling towers for factory "Chemis d.o.o." from Aleksinac (further 'Client'), were obtained the following conclusions: For the cross-sectional fill 1.8x1.8m and 0.9m fill height, manufacturer proposes air flow approximately 70 000 m3/h, or about 20 m3/s. This air flow, according to the calculation, is corresponding to air velocity of 5.5 m/s. For the cooling towers of this type and capacity and the cooling zone width (i.e. the water temperature difference on inlet and outlet of the tower), the recommended values of air speed amounts to 2-5 m/s. These recommendations by the standards meet the requirements of stability in work and efficiency of the cooling process in the tower.

Fig. 5. Fan of presented cooling tower

The higher air velocity leads to following problems: higher power consumption for fan operation, greater vibration and possible instability of construction, increased noise levels. Also, leads to turbulent air flow, increased flow resistance and significantly higher amount of water drops taken by air stream. This increases the amount of water needed for compensation of losses, as well as the costs for the necessary chemical preparation of additional water.

In our opinion, the speed of air flow in a given tower should not exceed 3m/s in order to avoid the problems mentioned above. Increase of speed should exist only in case of extreme weather conditions.

Air flow velocity of 3 m/s corresponding cooling air flow of approximately 10 m^3/s, for a cross-section filling area of 3.6m^2.

Based on empirical equations for calculating the coefficient of resistance fill [7] further report table showing the dependence of the resistance of airflow in the fill and the tower (fan effort) for the proposed air velocity 5.5 m/s and recommended 3 m/s, for different fill hydraulic load from 15 to 30 t/m2h, in the range proposed by the manufacturer of the cooling tower fills.

TABLE I. AIR VELOCITY 5.5 M/S

Hydraulicload fill (kg/m^2s)	Coefficientof resistance fill (m^{-1})	Resistance od fill (Pa)	Other resistances (Pa)
4	18.5	289.6	124.4
6	26.5	414.8	178
8	34.5	540	231.5

TABLE II. AIR VELOCITY 5.5M/S

Hydraulicload fill (kg/m^2s)	The total resistance of tower(Pa)
4	414
6	592.6
8	771.5

TABLE III. AIR VELOCITY 3M/S

Hydraulicload fill (kg/m^2s)	Coefficientof resistance fill (m^{-1})	Resistance od fill (Pa)	Other resistances (Pa)
4	18.5	86.2	36.8
6	26.5	123.4	53
8	34.5	160.7	68.8

TABLE IV. AIR VELOCITY 3 M/S

Hydraulicload fill (kg/m^2s)	The total resistance of tower (Pa)
4	123
6	176.3
8	230

Based on the results of the calculation, it is obviously significantly lower airflow resistance at the recommended speed, and there for fan effort and thus its power consumption is reduced. This conclusion leads to savings in energy consumption for fan drive with a satisfactory coolingeffect. If we compare Table II and Table IV, where are presented the total resistance of tower, can be noted that regardless of the hydraulic load fill the total resistance of tower is lower when air flow is lower. We can also notice that with increasing of hydraulic load, the difference in the total resistance of towerincreases. Taking into account that for the given capacity the use of an axial type of fans is recommended.

Efficiency of those fans is up to 0.6. Table V shows the comparative relationship of forces at a given fan and a suggested speed airflow.

TABLE V. FAN POWER, BASED ON CALCULATION AT THE DEGREE OF UTILIZATION 0.6 , FOR AIR VELOCITY 5.5 M / S

Hydraulic load fill (kg/m²s)		**4**	**6**	**8**
Flow (kg/s)	20	13.8	19.7	23.3
Power (kW)	11	2.3	3.23	4.23

The results presented here confirm the savings on drive fan at the recommended velocity.

Based on the present, the conclusion is that it does not pay to install the fan with 70000 m3/h air flow, which are recommended by equipment manufacturer for cooling this production line, nor on the side of working expenses or on the side of safety. If on a given volume of fill is not possible to provide adequate security in the cooling operation at any atmospheric conditions and requirements of production, the greater savings will be achieved through greater investment costs in height of fill than the increase in capacity and fan effort, especially taking into account old and relatively unsafe (unaudited) building infrastructure at the location.

The calculation with a speed of 3 m /s, the volume mass transfer calculated by Berman, , and design temperature of ambient air 33ºC, gives the result of 0.99m fill height, higher than 0.9m proposed by fill manufacturer. However, this difference has no significant impact on the operation, and 0.9m fill height is chosen as best solution, meeting the requirements in all operating modes. Next standard value of the fill height 1.2 m would be cost effective in case of increasing the amount of cooling water (as a result of increased demand for cooling water in case of significant increasing in adhesive production capacity). Finally, for the current situation, dimensions of fill are 1.8x1.8x0.9 m, air velocity of 3 m /s, the air flow corresponds to the speed of10m3/s.

IV. CONCLUSION

With increased cooling water demand for any industrial process, building the cooling tower is right solution. For any particular industrial process, it is necessary to take into account many factors in order to design appropriate cooling tower. In this paper, the design of the mechanical draught wet cooling tower for the adhesive factory "Chemis d.o.o." is shown, together with analysis of different parameters affecting the stable and efficient operating of the designed cooling system. Although it seems that this is the standardized selection of the industrial cooling tower, this paper introduces an important innovation. That innovation is a choice of the higher design atmospheric air temperature compared with usual recommended values. Using this higher temperature in the design, it is achieved to have proper cooling capacity during the summer. By analysing the operation of the cooling tower under differentconditions,theproperequipmentis selected, to ensure adequate investment and operating costs. Designed cooling tower is built and put into operation in November 2014. The energy efficiency of the cooling system in the adhesive factory is tested during the winter and especially during the very hot summer in 2015. Required cooling water parameters, necessary for undisturbed production process are provided in any season, together with savings in energy demand during the seasons with lower ambient air temperature.

REFERENCES

[1]. Book: Mihajlov J., Thermal power plants, design and building, (in Serbian), Tehnicka knjiga, Zagreb,1965.

[2]. Journal Article: H. John, Cooling Towers System Guidance for Energy Operations, Kelcroft E & M Limited, 1988, pp.1- 6.

[3]. Journal Article: Zhao Bin, Liu Ling, Zhang W., Optimization Of Cold End System Of Steam Turbine, Frontiers of Energy and Power Engineering in China 2008, 2 (3), pp. 348-353

[4]. Study: Benton, D, J.: A Numerical Simulation Of Heat Transfer In Evaporative Cooling Towers, Tennessee Valer Authority Report WR 28-1-900- 110, 1983.

[5]. Book: Zemanek, I.: Heat and Mass Transfer in Cooling Tower Packing, National Research Institute for Machine Design, Praha,1989.

[6]. Journal Article: D.Golubović, D. Golubović, One Dimensional Model of Cooling Water in Counter flow Cooling Tower, Proceedings of 15th Symposium on Thermal Science and Engineering of Serbia, ISBN 978-86-6055-018-9,pp, Sokobanja, Serbia, October 18–21, 2011

[7]. Book: Berman, Evaporative Cooling of Circulating Water, 2nd edition, Henrych Stawistowshi, Pergamon Press, 1961

[8]. Book: Wagner W., Kruse A., „Properties of Water and Steam, the industrial Standard IAPWS-IF97 for the Thermodynamic Properties and Supplementary Equations for Other Properties“, Springer-Verlag, Berlin Heidelberg,1998.

[9]. Journal Article: Laković Mirjana., et.al. Impact of the Cold End Operating Conditions on Energy Efficiency of the steam power plants, THERMAL SCIENCE: Year 2010, Vol. 14, Suppl., pp. S53- S66