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Mapping of Nonconformities that Impact the Performance of Cooling Towers: Refinery Case

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The current world outlook of supply and demand for basic inputs, such as in the case of water, has created an alarming situation for all of society, especially the industrial sector. Cooling Towers are the equipment responsible for the removal of heat from a stream of hot water from an industrial process and at the same time they are the most water-consuming equipment in the industry. Their good performance is directly linked to the sustainable consumption of water present in the environment. In this context, audits for the mapping of nonconformities encountered frequently in tower operation become a useful tool to increase the efficiency of the equipment. As a step in this mapping and work objective, discussions were carried out on two irregularities commonly identified in operation, such as: (1) variation of the water feed load; (2) variation of air flow, in addition to its main causes and impacts on the operation and efficiency of the equipment. Actual data were obtained for the case study of a tower located in Petroleum Refinery in Brazil. The controlled variable chosen for the study was the outlet water temperature of the tower. The model used to identify the output temperature is based on Merkel's theory, using the Tchebeycheff method for numerical integration. Therefore, with the variations carried out, it is possible to verify the direct influence on the outlet temperature and to identify possible causes of the irregularities addressed in the study.

1. Introduction

The World Meteorological Organization (2016) states that the main causes of climate change and emissions are related to anthropogenic emissions of greenhouse gases (GHG). According to the IPCC (2007), CO_2 emissions from burning fossil fuels in industrial processes contributed approximately 78% of the increase in GHG emissions between 1970 and 2010.

With the modification of the environmental scenario, it is important to highlight the influence of climatic effects on the reduction of water availability. According to Kim et al. (2014) and Kandu et al. (2017), the temperature increase in the terrestrial troposphere is a critical factor in predicting and evaluating the future of water resources. On the other hand, it is noticed that water is the basic input more used in most industrial processes, standing out in the energy intensifying industries. The withdrawals of water for electric and electric power generation, as well as for the refining of crude oil, are active and comprise 10% of water abstractions (IEA, 2016).

Petroleum refineries represent one of the largest consumers of water in their production processes, being directly related to processed oil (Hwang et al., 2011). According to Peres (2010), the applicability of the water in the refineries is destined, mainly, for the towers of cooling, corresponding to 60-70% of all the water consumed in the sector.

Cooling towers are equipment used to control process temperatures, with greater applicability in the industrial sector. Its operation is based on the simultaneous principle of thermal exchange and mass transfer between the process hot water flow and the cold ambient air flow. Cooling systems using towers are the most found in the industry, mainly because they work at high water flows and temperature restrictions for cooling water users (Ávila et al., 2013). Its application has become a critical factor in several productive processes, raising

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its importance for research and development area, aiming to optimize its use and preserving its quality and availability in the environment (Ávila et al., 2017).

Like other industrial equipment used in production, the cooling tower also needs proper care to achieve good operating performance. Because they are not directly linked to the productive sector, but to the utilities area, which are topographically remote from production, the cooling system becomes the target of administrative negligence, reducing the operational reliability of the equipment. By factors such as this, are easily found, towers in bad working conditions, becoming a great potential for studies of improvements (Silva et al., 2016).

According to Ávila Filho et al. (2015), most of the cooling towers, especially in the industrial sector, are in a state of decay, causing large operational losses (purges, drainage, transshipment and evaporation) and requiring the constant replacement of these lost waters. However, when the replacement is frequent, it makes evident the malfunction of the equipment, generating major operating losses, economic and environmental.

In this context, a method used to optimize Cooling Towers is applying the audit in order to map the existing nonconformities to study their possible influences on the properties of the equipment. This objective can be reached from the variation of input data for later verification of its sensitivity in a given output data.

2. Methodology

Figure 1 represents the steps of applying the methodology in the present study for the identification of nonconformities in a Cooling Tower and the simulation of the main influencers in its performance. This procedure will allow an increase in the operational reliability of countercurrent type cooling towers, reducing frequent abnormalities and operating costs with utilities and energy wastage, in addition to combating the performance problems of other process equipment and environmental impacts, as in the case of water scarcity.

In the initial part, a cooling tower was chosen for the development of the study. Such equipment can be characterized as large and is located in an oil refining industry in Brazil. In the second step, the main nonconformities in the operation of cooling towers were identified. This mapping was proposed through the bibliographic research and application of questionnaires to the staff responsible in the study area, besides research with professionals with expertise in the subject. In the third step, the tower design data was collected for the application of the necessary calculations. In the fourth stage, the audit is carried out to identify and dimension the nonconformities present in the equipment operation.

Finally, in the fifth stage, the simulation was performed with information obtained in previous stages, to understand the influence of nonconformities with the performance of the cooling tower studied.

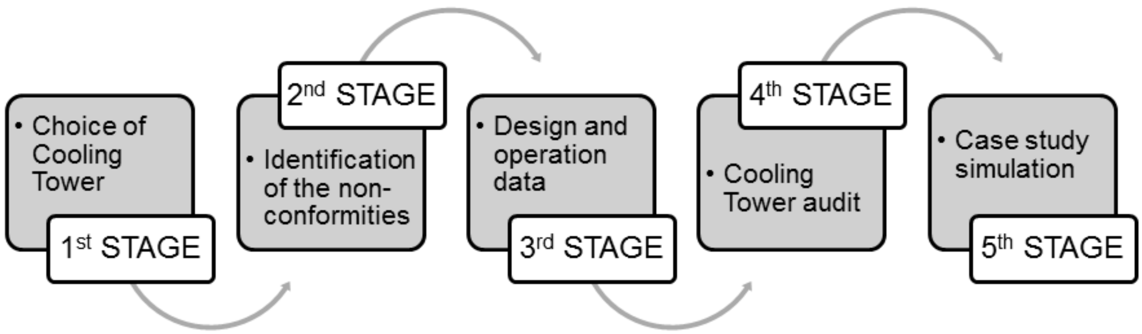

Figure 1: Proposed methodology for the mapping of nonconformities

2.1 Procedure for Determining the Outlet Water Temperature

From the integrated form of the Merkel equation Eq(1), and using the Tchebeycheff method (Casseta, 2003) for numerical integration, the number of transfer units (NTU) is defined for corresponding values of mass flows of water streams (L) and air (G) circulating in the counter current tower. However, for the development of the study, variations of water and air flow were performed separately, with objective to simulate problems related to operational variations and their respective impacts on the outlet water temperature (T_{UF}).

$$\frac{K.a.V}{L} = \int_{T_{UF}}^{T_{UQ}} \frac{C_p\,dT}{h_V - h_A} \qquad (1)$$

From the NTU calculation method (Casseta, 2003; Silva, 2015) and adaptations, the proposed procedure for determining the temperature of the tower outlet water can be seen in Figure 2.

In the first step we should input project data involved, like ratio L/G, input temperature, output temperature, filling data and water flow test data. The water flow is variable and for each value we can find one the new output temperature.
After of input data is calculated the number of transfer units (NTU) using the Equation Merkel (1). For this calculation it’s necessary to determine the water temperature inside the tower using the Tchebycheff Method, step 3. Then partial pressure, absolute humidity, dew temperature, latent heat using the trivial equations must be determined, steps 4, 5, 6 and 7.
After that, is calculated the enthalpy of air at wet bulb temperature, enthalpy of unsatured air and enthalpy of the air film through psychrometric charts, steps 8, 10 and 11.
And finally is determinate an objective function using Merkel equation and is applyed hypothesis test (solver) to determine the cold real temperature, step 12.

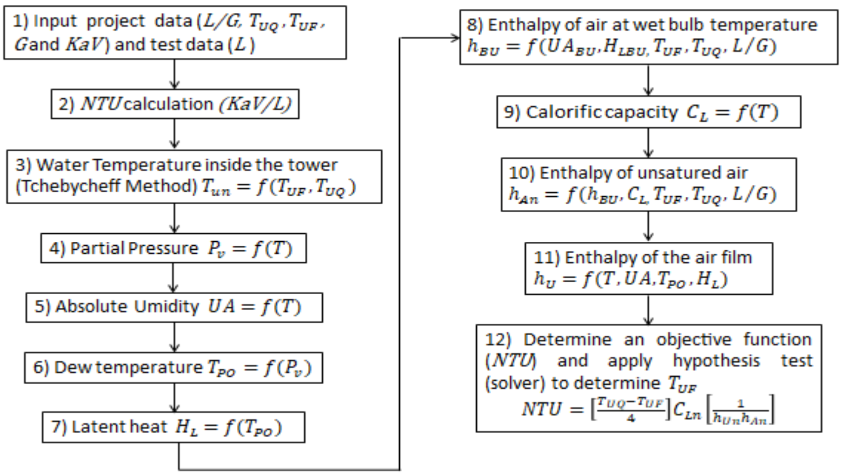

Figure 2: Procedure for determining the water flow temperature at the outlet

3. Case Study in a Cooling Tower – Brazilian Refinery

In 2017, Brazil faced some problems of water scarcity, caused by the long periods of drought during the year. Consequently, the levels of the reservoirs have been reduced, making it a warning signal for possible cuts in the water supply to industrial facilities, in order to prioritize the water supply to the population. These events caused the industry to prioritize the search for alternatives that would reduce the consumption of this input in the productive processes.
In the fight against water waste, the Cooling Tower is considered the main target of study in an industrial unit. In oil refineries, where the demand for cooling water is high, it is evident the presence of a good management of this equipment for a significant reduction in water consumption. Good equipment performance can be achieved through good practice and human reliability. There are some situations that may interfere with the proper functioning of a cooling tower, such as: (1) uneven distribution of water in the upper basin; (2) fan problems; (3) concentration cycle; (4) damage to tower structure; (5) plant load.
However, for the development of this study, only influences on the performance of the equipment involving the variation of hot water and air currents in the tower were analyzed. These choices were prioritized based on the applied methodology and for being the more impactant situations found in the tower. Figure 3 shows the Cooling Tower selected for study development.

Figure 3: Cooling Tower studied from a Brazilian Refinery (Ávila et al., 2017)

In the final step of the methodology, the tower design data were used as reference for validation of the model and can be visualized in Table 1.

Table 1: Design and calculated data for model validation

Properties	Values	Units
Water flow (L) project	12,000	kg/s
Air flow (G) project	10,000	kg/s
Hot Temperature (T_{UQ})	315.15	K
Wet Bulb Temperature (T_{BU})	300.25	K
$NUT_{project}$	2.495	
$NUT_{calculated}$	2.497	
Cold Temperature ($T_{UF\ project}$)	303.15	K
Cold Temperature ($T_{UF\ calculated}$)	303.13	K
Relative Error	0,007	%

4. Results and Discussions

To simulate the influence of the water flow (L) on the water flow temperature at the tower outlet (T_{UF}), design values were set for G, T_{UQ} and T_{BU}, varying the values of L, demonstrated in Table 1. From the application of the procedure described in Figure 2, the results were obtained according to Table 2.

Table 2: Project and calculated data for model validation

Water flow (kg/s)	$T_{UF\ calculated}$(K)	Range (K)	$NUT_{calculated}$	Efficiency (%)	Relative Error
10,400	302.39	12.76	2.881	85.64	0.251
10,600	302.48	12.67	2.826	85.01	0.220
10,800	302.57	12.57	2.774	84.39	0.198
11,000	302.67	12.48	2.723	83.77	0.159
11,200	302.76	12.39	2.675	83.15	0.128
11,400	302.85	12.30	2.628	82.53	0.098
11,600	302.94	12.20	2.583	81.91	0.067
11,800	303.04	12.11	2.539	81.29	0.037
12,000	303.13	12.02	2.497	80.68	0.007
12,200	303.22	11.93	2.456	80.06	0.023
12,400	303.31	11.84	2.417	79.46	0.053
12,600	303.40	11.75	2.378	78.85	0.083
12,800	303.49	11.66	2.341	78.25	0.112
13,000	303.58	11.57	2.305	77.65	0.142
13,200	303.67	11.48	2.271	77.06	0.171
13,400	303.76	11.39	2.237	76.47	0.200
13,600	303.84	11.30	2.204	75.88	0.229

The efficiency of the tower can be calculated from Eq (2).

$$\eta = \frac{Range}{T_{UQ} - T_{BU}} = \frac{T_{UQ} - T_{UF}}{T_{UQ} - T_{BU}} \qquad (2)$$

For the calculation of the relative error we considered the variations of $T_{UF\ project}$ in relation to the $T_{UF\ calculated}$ of the estimated flows. According to Hensley (1985), are suggested limit variations of ± 10% of the design value for the water flow.

Analyzing Table 2, it is noticed that the variation of the water flow is directly proportional to the temperature of the water at the exit of the tower and inversely proportional to the efficiency of the equipment. However, the comparison between $T_{UF\ project}$ and $T_{UF\ calculated}$ shows that the higher the L variation, the greater the relative error, making it evident that not necessarily the increased efficiency will imply acceptable values of the cold water temperature. Cooling towers are designed to obtain T_{UF} according to the needs of the process, always requiring the lowest relative error possible. Another important issue to note is that T_{UF} values close to or equal to T_{BU} (representing a high efficiency) is impossible to occur, because it would be necessary for the entire water stream to come into contact with the air and remain in contact for as long as possible, the which in fact does not occur in practice (Ávila et al., 2017).

In practice, such equipment is often found below ideal operating capacity and in many cases directly affected by non-conformities encountered in operation. In the case of an operation where a flow variation is identified above or below the ideal, it is possible to identify some causes as shown in Figure 4.

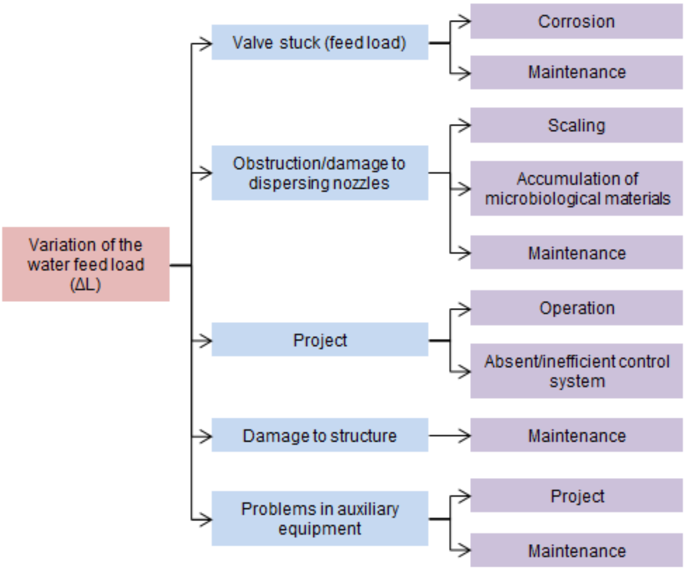

Figure 4: Cause and effect tree for variation in feed load water

Some of these irregularities are associated with: (1) valve stuck of the upper basin (corrosion of the material, low periodic preventive maintenance); (2) obstruction of dispersing nozzles (formation and accumulation of scaling and microbiological materials, low periodic preventive maintenance); (3) cooling tower project (out-of-specification operation data with design data, missing or inefficient control system for supplying operation data); (4) damage to the structure generating leakage of water to the outside (low periodic preventive maintenance); (5) problems in auxiliary equipment (pumps, motors / turbines poorly dimensioned or selected, low periodic preventive maintenance).
Another non-compliance found in towers neglected by poor management is related to the variation of air flow. According to Figure 5, some of these irregularities are associated with: (1) problems in auxiliary equipment (ventilators, poorly dimensioned or selected motors, low periodic preventive maintenance); (2) damage to the structure generating air leaks (low periodic preventive maintenance); (3) load loss (ΔP) inside the tower (poorly projection of the equipment and internal parts); (4) local climate (poor projection of equipment, location).

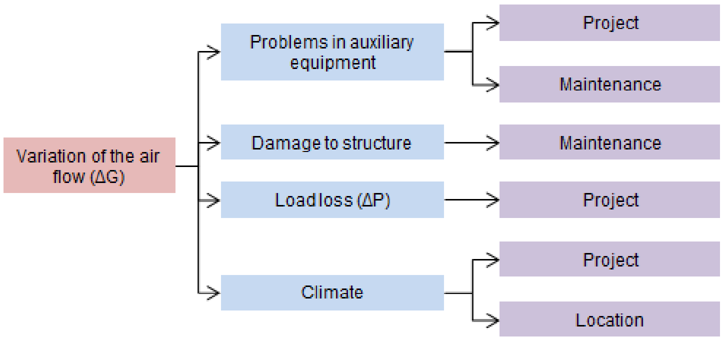

Figure 5: Cause and effect tree for variation of air flow

Such irregularities can lead to T_{UF} variation, directly influencing the performance of heat exchangers present in the process. It is important to point out that the study carried out shows the importance of periodic auditing to identify operational problems that can be found in cooling towers.
In addition to the two irregularities addressed in this study, another cause that is very worrying and found in the operation of a tower is related to the treatment of cooling water. Low quality water can lead to an

environment conducive to the formation of scaling and microbiological materials, damaging thermal exchange and L variation, negatively impacting the efficiency of the equipment.

5. Conclusions

This work aimed to show the importance of the methodology applied to the mapping of nonconformities in cooling towers of the countercurrent type, as well as to discuss the main and secondary causes of two of the main irregularities found in operation. This is preliminary work that seeks to analyze and indicate opportunities for improvements in an oil refinery tower.
The field visit, acquired data, the discussion with area experts and responsible for the operational routine of the refining unit, besides the management involvement with the construction of the study, can indicate a good performance in the quality of the work. The implementation of periodic audit / maintenance actions in energy and water intensifying industries has a positive impact on the performance of these equipments, leading to reductions in operational costs and solutions to achieve sustainability.

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