Contribution to the Performance Computation by Enhanced Cooling Tower

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Abstract: - The present work exploits the results obtained by the authors in terms of improving the models of Merkel and Arns. Indeed, these two models were used as a basis to reduce the initial hypotheses for Merkel and made it possible to make the modeling of cooling towers against the current easier and above all robust. However, the initial hypotheses of Merkel and Arns neglected important aspects such as Drift losses and off-design simulation. These two aspects have made that the simulation of the behavior of the cooling tower is dependent on the amplitude of the two parameters. This work shows the impact that these parameters have on the calculation of the performances of cooling tower and their estimate value, from the general of the simplified method derived from Merkel's method. Recall that recent work by the authors has demonstrated the possibility of extending the Merkel model to the simplified method by adding two case studies. The results are exposed and a discussion is established.

Key-Words: - Cooling tower, modelization, simulation, evaporation, heat exchanger.

1 Introduction

The thermal production accompanying the energy production must be within the "normal" limits tolerated by the components. Otherwise, it must be provided for the evacuation of this surplus of undesirable heat as is the case of thermal or nuclear power plants, these plants use heat evacuators in the form of cooling towers.

The present work deals with the performances in the real operating conditions of these cooling towers in order to contribute to the optimization of their operation via a modeling taking into account real data by the manufacturers.

This work also contributes to pushing the limits of use of these towers by predicting the performances that these installations can have in the absence of data cataloged by the manufacturers.

The results obtained will guide designers in the dimensional optimization of equipment, and are therefore the objectives assigned to this work.

2 Problem Formulation

This part capitalizes the knowledge learned in the order of the first publication [2] and implements the recommendations made. A decisive choice has been made and consists in abandoning the standard method (StM) in favor of the simplified method (SiM). The work developed throughout stage [2] made it possible to present two major contributions that were the subject of two international publications.

In the first contribution, we took the two new cases of the extended simplified method not studied by Arns and Klenke to give the Simplified model more weight and better arguments as to its use, since it becomes universal. During the design stage, it allows the simulation of the cooling tower, whether installed or planned, to predict its behavior outside nominal operating conditions.

As generalized results, it is shown that it is possible to develop an improved method of Arns and Klenke ensuring good accuracy beyond 15% of the reference values. [2]

This success represents a substantial progress and a significant contribution of this work.

To reach this conclusion, the following checks were made:

1 - Comparison between the results of standard reference methods (StM1) and simplified heat

removed from water Qload versus air mass flow rate Ṁa [2]

2 - Comparison between the results of standard and simplified methods of heat removed from water Qload versus water mass flow rate Ṁw [2]

3 - Comparison between the results of the standard and simplified methods of the heat removed from the water Qload versus inlet air wet- bulb temperature Twbsu [2].

These checks resulted in a coincidence within acceptable limits to simulate the behavior of cooling towers beyond nominal values (up to 15%).
In this work, we continued to work on the new formulation of the simplified model proposed in [2] in order to estimate the performance of open cooling towers against the current for operating conditions different from those delivered by the manufacturers' catalogs. twex outlet water temperature, Qfan required fan power, EFFA air side effectiveness, EFFA water side effectiveness.

The numerical results were successfully compared with those obtained by the standard method.

Let's remember that:

In the simplified method, only one case was considered by Arns and Klenke: Case 2 and Case 3 were added. [2]

- Case 1: we determine the outlet water temperature knowing the water and air mass flow rates .

- Case 2: the outlet water temperature, air mass flow rate knowing the temperature of the inlet water and the water mass flow rate.

- Case 3: the outlet water temperature, water mass flow rate knowing the inlet water temperature and the air mass flow rate.

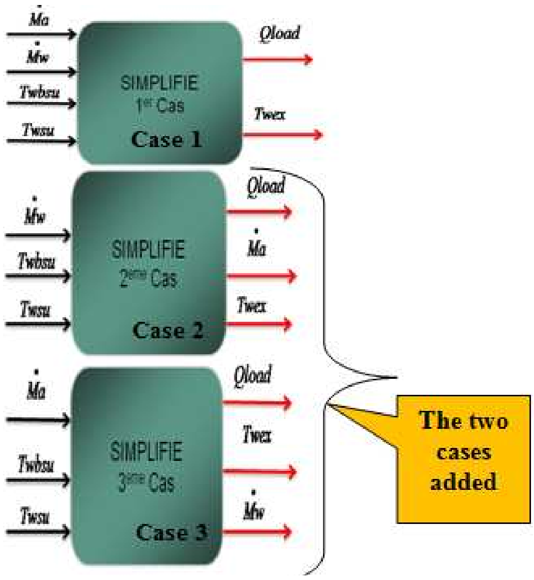

Fig.1. programming by Simulation blocks.

As in [2], we have taken the case 1 of the Merkel method as a reference to validate the results obtained because it reproduces very well the data of the manufacturers' documents according to HVAC, this contribution assumes, as hypothesis, that the case 1 is correctly simulated is its results obtained are consistent with those obtained by the builders The 13 parameters of Case 1 are the operating parameters of the cooling tower and describe a characteristic state of its performance.

Table 1
The13 parameters of STM

N°	Names of variables	Reference Value
1	Air mass flow rate	2.5 m^3/s = 2.98 k_g/s
2	Water mass flow rate	6.38 E-3 m^3/s = 6.37 k_g/s
3	Inlet wet-bulb temperature	17°C
4	Inlet water temperature	35.7 °C
5	Heat removed from water	188.1KW
6	Outlet water temperature	28.6°C
7	Required fan power	2.2 KW
8	[water / air] mass flow ratio	2.134
9	Water side effectiveness	0.378
10	Air side effectiveness	0.622
11	Number of transfer Units	2.001
12	Effectiveness relating to NTU	0.477
13	Approximated Effectiveness	0.549

In fact, the difference between cases 1, 2 and 3 resides, therefore, in the inputs and outputs available for carrying out the simulation (see Fig.1). [4]

Case1 of the simplified method: in this case the inputs are 1, 2, 3,4 and the outputs are 1,5,6,7,8,9,10 (see tab1)

Cas2 of the simplified method: in this case the inputs are 2, 3,4 and the outputs are 1,5,6,7,8,9,10 (see tab1)

Case 3 of the simplified method: in this case the inputs are 1, 3,4 and the outputs are 2,5,6,7,8,9,10 (see tab1)

Reference [4], we find as results that the values obtained in output are very close to the values taken as reference.

The methodology adopted to determine the values of the parameters in Table 2: we used all the ranges of values of the different outputs and inputs for the outlet water temperature, the required fan power, the water side efficiency and the air side efficiency and observe the results obtained and trends.

Table 2
The situations adopted

Situation	Standard method	simplified method	observ ation
	Reference case 1		
Qload			
1-Qload = f(V̇a)	(+)	(+)	Référence [2]
2-Qload = f(V̇w)		(-)	Référence [2]
3-Qload = f(Twsu)		(+)	Référence [2]
Twex			
3-Twex = f(Twbsu)		(+)	Fig.2
4-Twex = f(Twsu)		(+)	Fig.3
Qfan			
1-Qfan = f(V̇a)		(+)	Fig.4
EFFA			
3-EFFA=f(Twbsu)		(+)	Fig.5
4-EFFA=f(Twsu)		(+)	Fig.6
EFFW			
3-EFFW=f(Twbsu)		(+)	Fig.7
4-EFFW=f(Twsu)		(+)	Fig.8

3 Results Obtained

For clarity, all the graphs obtained have been reported in the following:

3.1 The heat removed from water for situations 1,2,3 of reference [2]

For the heat removed from water versus air mass flow rate, versus input air wet bulb temperature and versus inlet water temperature the method could be extended up to 15% beyond the operating value given by the nominal operating condition.

These checks resulted in a coincidence within acceptable limits to simulate the behavior of cooling towers beyond nominal values (up to 15%).

3.2 Outlet water temperature for 3, 4 situations will be shown below:

3.2.1 Situation 3:

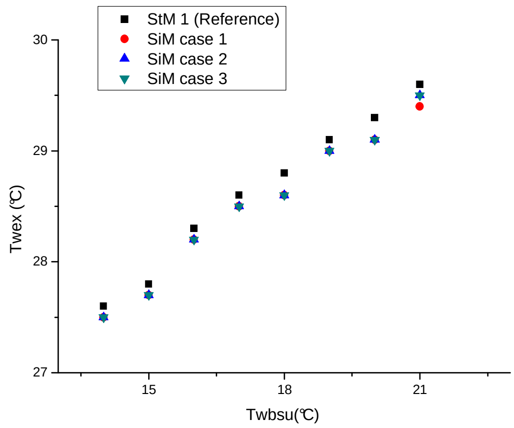

Fig.2. Comparing StM1 and SiM Case1/Case2 / Case3 results relating to the outlet water temperature versus inlet air wet- bulb temperature

By comparing the standard reference StM1 with Case 1, 2 and Case3 of SiM, acceptable results are obtained.

The method can extended at 13% beyond the maximum nominal operating value.

3.2.2 Situation 4:

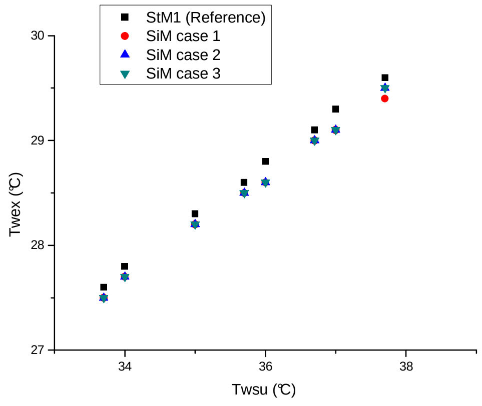

Fig.3. Comparing StM1 and SiM Case1/Case2 / Case3 results relating to the outlet water temperature versus inlet water temperature

By comparing the standard reference StM1 with Case 1, 2 and Case 3 of the SiM, acceptable results are obtained , we could use the method to predict the outlet water temperature until 20% more than the maximal real value limit given manufacturer's data.

3.3 The fan power required for situation 1 will be shown below:

3.3.1 Situation 1:

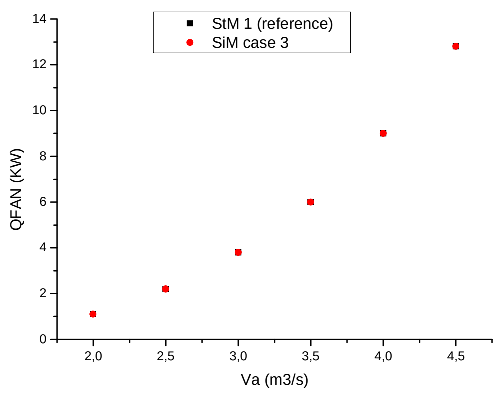

Fig.4. Comparing StM1 and SiM Case 3 results relating to the required fan power versus air mass flow rate

By comparing the standard reference StM1 with Case 3 of the SiM, acceptable results are obtained.

The developed method applies with 100% of the reference value of air mass flow rate in (figure 3).

3.4 The air side efficiency for situations 3, 4 will be shown below:

3.4.1 Situation 3:

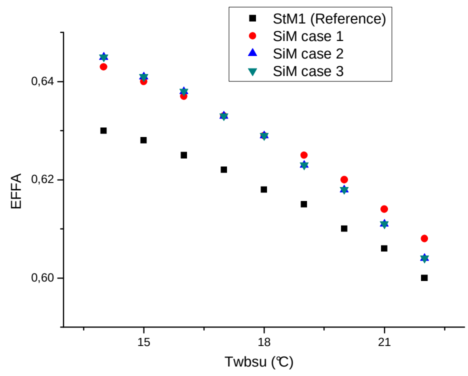

Fig.5. Comparing StM1 and SiM Case1/Case2 / Case3 results relating to the air side effectiveness versus inlet air wet- bulb temperature

By comparing the standard reference StM1 with Case 1, Case 2 and Case 3 of the SiM, acceptable results are obtained under the following observation:

Situation 3 for air side effectiveness, both methods give acceptable results.

3.4.2 Situation 4:

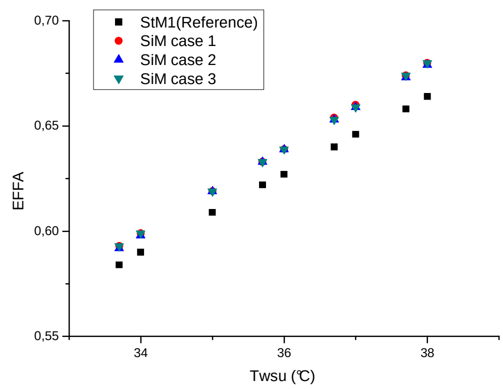

Fig.6. Comparing StM1 and SiM Case1/Case2 / Case3 results relating to the air side effectiveness versus inlet water temperature

By comparing the standard reference StM1 with Case 1, Case 2 and Case 3 of the SiM, acceptable results are obtained under the following observation:

Both methods give acceptable results. The considerable differences between the two methods are obvious.

3.5 The water side efficiency for situations 3, 4 will be shown below:

3.5.1 Situation 3:

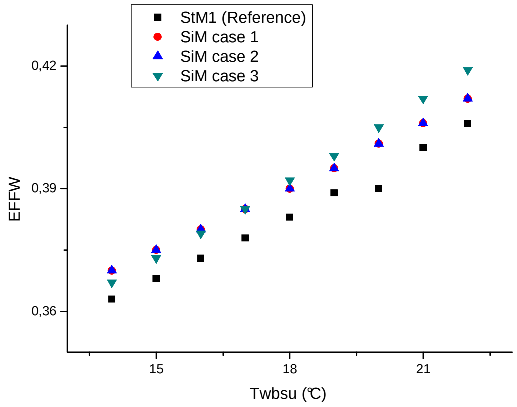

Fig.7. Comparing StM1 and SiM Case1/Case2 / Case3 results relating to the water side effectiveness versus inlet air wet- bulb temperature

By comparing the standard reference StM1 with Case 1, Case 2 and Case 3 of the SiM, acceptable results are obtained under the following observation:

Situation 3 for water side effectiveness, both methods give acceptable results.

3.5.2 Situation 4:

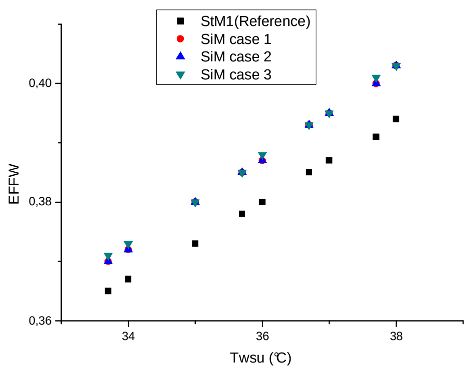

Fig.8. Comparing StM1 and SiM Case1/Case2 / Case3 results relating to the water side effectiveness versus inlet water temperature

By comparing the standard reference StM1 with Case 1, Case 2 and Case 3 of the SiM, acceptable results are obtained under the following observation:

Both methods must result in almost the same result, but the second gives more acceptable results. It is good to note that the three simplified cases are more stable and acceptable to near-calculate errors than those of the standard method.

4 Discussions of the Results

The results obtained for the first case of the standard method and the simplified method, for an open counterflow cooling tower, and for a given design operating condition, are shown in the figures above.

We compared the first case of the standard method (reference case) against the first, second and third cases of the simplified method for the outlet water temperature, the required fan power, and the water and air side effectiveness.

It emerges that the two simulation cases (case 1, case 2 and case 3 of the simplified method) give stable and acceptable results in the Simplified method compared to the standard case1 taken as a reference.

However, a generalized observation is an important result of this work after the treatment of the seven graphs considered.

The following results must be underlined:

- For the water temperature versus air temperature wet- bulb temperature, the method could be extended to 13 percent beyond the operating value given by the nominal operating condition
- For the water temperature versus inlet water temperature, the method could be extended to 20 percent beyond the operating value given by the nominal operating condition.
- For the required fan power versus air mass flow rate, the method may be extended to 100 percent of the operating value given by the nominal operating condition.

The method gives acceptable results (the three simplified cases are more stable and acceptable to errors of calculation than those of the first one using the standard method).

As a generalized discussion result, we can readmit that the developed extended method ensures accuracy with acceptable results with reference values provided by the constructor at 20%

(substitute the simplified method by the Standard method).

5 Conclusion

The main objective of this work was to continue to contribute to Industrial Cooling System Models, in the case of open counterflow cooling tower.

This contribution is a logical conclusion of the preliminary studies carried out during the subsequent course. [4-5]
A modeling was carried out during this work and a calculation code substituting the standard method by the simplified method applied in order to estimate the performances of the operational cooling towers. We abandon the standard method in favor of the simplified method which considers that the tower is a simple heat exchanger.

This is the starting point for starting this work which was to continue the simulation. An improved method of Arns and Klenke has been developed ensuring good accuracy beyond 15% of the reference values .[2]

We are going further by increasing the extension of the simplified model, by studying the remaining benchmark performance, such as input water temperature, fan power required, air side and water side effectiveness of the Open counterflow cooling tower.

This attempt has succeeded and represents a substantial progress and a contribution of this work; it can be proposed that the developed extended method ensures good accuracy beyond 20% of the reference values.

This work reinforces the tendency to replace Merkel's method by the simplified method, and increases the performances of the simplified model

However, the results obtained encourage an approach to validate models with in-situ results.

References:

[1] P.ARNEODO, V.GIARTO, A.MAZZA, *System simulation*, International Energy Agency, 1990,Annex 10.

[2] G. ABDI, T. BENABDALLAH, New Extended Simulation Method at Out-Design Operating Conditions for Cooling Towers. *International Review of Mechanical Engineering (I.RE.M.E.), Vol. 9, n. 1 , January 2015*

[3] T. BENABDALLAH , G. ABDI, Mohamed ait Hamadouche, New Enhanced Cooling Towers Models bu Implementation of Drift Losses Calculations. *International Review of Mechanical Engineering (I.RE.M.E.), Vol. 9, n. 3 May 2015*

[4] Abdi Ghezail, *Contribution aux modèles derefroidissement Industriels, cas des tours de refroidissement*, mémoire de Doctorat (Phd thesis), Dept. Mecanique, Ecole NationalePolytechnique d'Oran (ENP D'Oran), Algeria, Nov 2015.

[5] Abdi Ghezail, *Simulation du fonctionnement d'une tour de refroidissement par la méthode standard et simplifiée*, mémoire de magister(Master thesis), Dept. Mecanique, Ecole Nationale Polytechnique d'Oran (ENP D'Oran), Algeria, Juin 2011.

[6] Ch. ARNS, *Zur Beurteilung von Prospekt-und Angebotsangaben überkühltörme*, Kältetechnik-Klimatisierung, 10/1970, pp.335-339.

[7] W. KLENKE, *Zur Einheitlichen Beurteilung und Berechnung von Gegenstrom und Kreuzstrom Kühltömen*, Kältetechnik-Klimatisierung, 10/1970, pp.322-330.

[8] KERN, D.Q, Process Heat Transfer (Mc Graw Hill, New York, 1950, pp.563-623).

[9] ASHARE, Refrigerating and Air Conditioning Engineers, *Handbook Fundamentals*, (American Society of Heating, Atlanta,1981, pp. 3.1-3.16)

[10] J.W. Sutherland, Analysis of Mechanical Draught Counterflow Air/Water cooling towers, *Journal of heat transfer*, Vol. 105, pp. 576-583, 1983.

[11] R.L. Webb, A. Villacres, Algorithms for Performance Simulation of Cooling Towers, Evaporative Condensers and Fluid Coolers, (ASHARE Transactions, Vol. 90, Part 2, 1984)

[12] R.L. Webb, A Unified theoretical treatment for Thermal Analysis of Cooling Towers, Evaporative Condensers, and Fluid Coolers, (ASHRAE Transactions, Vol. 90 , Part2, 1984)

[13] H.C. Peitsman, U.J. Nicolas, *System simulation 'Liquid chilling system'*(TNO Institude of Applied Physics, April 19,1988)

[14] Medardo Serna-Gonzalez, José M. Ponce-Ortega, Arturo Jiménez-Gutiérrez, MINLP optimization of mechanical draft counter flow wet-cooling tower, *Chemical Enginnering Research And Design* ,pp614-625, 88(2010).

[15] Jean Lebrun, *Thermodynamique Appliquée* (Liège, Janvier 1989)

[16] JC. Kloppers, DG. Kroger, A critical investigation into the heat and Mass Transfer analysis of counterflow wet-cooling towers, *International journal of heat and mass transfer*, Vol. 48, n. 1, pp.765-777, 2005c.

[17] JC. Kloppers, DG. Kroger, Cooling tower performance evaluation:Merkel, Poppe and e-NTU methods of analysis, *Journal of engineering for Gas Trubines and Power* ,Vol. 127, n. 1, pp.1-7, 2005b.

[18] Medardo Serna-Gonzalez, José M. Ponce-Ortega, Arturo Jiménez-Gutiérrez, MINLP of mechanical draft counter flow wet-cooling towers, *Chemical Engineering Resarch and Design*, Vol. 88, pp.614-625, 2010.

[19] ASHRAE, Systems and Equipment Cooling Towers, *Handbook CD-HVAC* , (Chapter 36, 2005)

[20] ASHRAE, Systems and Equipment Cooling Towers, *Handbook CD-HVAC*, (Chapter 38, 2008)

[21] J.R. Picardo, J.E. Variyar, The Merkel equation revisited: a novel method to compute the packed height of a cooling tower , *Energy Conversion and Management* , Vol. 57, pp.167-172, 2012.

[22] J.R. Singham, *Heat Exchanger Design Handbook* (Hemisphere Publishing Corporation, New York , USA,1983).

[23] A. Mohier, *Thermodynamique*(Édit. DELAGRAVE, Paris, 1965).

[24] Lemouari.M, Boumaza.M, Experimental investigation of the performance characteristics of a counter flow wet cooling tower, *International Journal of Thermal Sciences*, Vol.49, pp.2049-2056, 2010.