EXPERIMENTAL INVESTIGATION OF AIR SIDE PRESSURE LOSS FOR WET-COOLING TOWER FILLS

by

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Original scientific paper
https://doi.org/10.2298/TSCI180709317O

The pressure loss of air-flow in the cooling tower was measured experimentally with three different type cooling tower fill materials. Air mass flux ($3.13 < G_a$, < 5.21 kg/m²s), water mass flux ($2.43 < G_w$, < 5.21 kg/m²s) and height of the fill material (0.6, 0.8, and 1 m) were used as variable parameters for experimental works. Film, curler and splash type fillings were tested in the forced draft counter flow cooling tower unit which has 0.4 × 0.4 m² cross-section area. Experimental results were presented graphically. However, these results correlated for each type cooling tower fill material. The pressure loss was increased with increasing air mass flux. The pressure loss of film type filling is 29.1% higher than splash type.

Key words: *wet-cooling towers, pressure loss, film, splash, curler, fill*

Introduction

The air side pressure loss in a cooling tower fill is one of the most important design criteria for cooling tower systems. This value is obtained by measuring pressure drop across the fill. One of the selecting parameters for optimum filling material is low air side pressure loss. The energy consumption of cooling tower fans is increased by increasing this pressure drop value. So, this value must be low for filling materials. However, the volumetric heat transfer coefficient of filling materials must be high. These two criteria and some other criteria such as water chemical composition and air cleanness are used for selecting fill material type.

The empirical equations have been published in the literature for the air side pressure loss of cooling tower fills. Goshayshi and Missenden [1] used the following form of equation to represent the pressure loss of film type fill:

$$\Delta P_{\mathrm{fi}} = c_1 (G_{\mathrm{w}})^{0.35} (G_{\mathrm{a}})^{0.55} \tag{1}$$

where c_1 is the empirical constants that depend on the fill type. Their tests were done seven types of counter flow film type fills. In these tests, the air stream values are very low for the industrial applications [2].

Milosavljevic and Heikkila [3] obtained the pressure loss values for seven types of counter flow film type fills. Their tests were conducted in a 1.44 m² counter flow cooling tower

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where G_w and G_a was varied from 2-6 kg/m^{2}s and 1.9-7 kg/m^{2}s, respectively. The range of these parameters is appropriate real industrial conditions. Their fill test data is correlated:

$$\frac{\Delta P_{fi}}{L_{fi}} = c_1\left[1+\left(G_w\right)^{c_2}\right]\left(G_a\right)^{c_3} \tag{2}$$

where c_1, c_2, and c_3 are the empirical constants that depend on the fill type.

Johnson [4] proposed an empirical eq. (3) for evaluating pressure loss coefficient of counter flow cellular type fills:

$$K_{fi} = c_1 G_w^{c_2} G_a^{c_3} L_{fi}^{c_4} \tag{3}$$

where L_{fi} is fill height. The pressure loss coefficient K_{fi} is evaluated:

$$\Delta P_{fi} = \frac{K_{fi}\rho_a \upsilon_a^2}{2} \tag{4}$$

Kloppers and Kroger [5] tested splash type, trickle type and film type counter flow fills. The heights of these fills are 3, 1.98, and 1.2 m, respectively. They suggested the more accurate empirical equation for evaluating K_{fi}. Their test data correlated:

$$K_{fi} = c_1 G_w^{c_2} G_a^{c_3} + c_4 G_w^{c_5} G_a^{c_6} \tag{5}$$

In this study, curler, film and splash type cooling tower filling materials were compared with air-flow pressure loss. There is no study about this topic in the literature. This study presents important comparison about air-flow energy consumption of towers with various filling types.

Experimental set-up

Film, curler and splash type fills were tested in the forced draft counter flow cooling tower unit shown in fig. 1. The cross-section area and the total height of the tower were 0.4 × 0.4 m^2 and 1.8 m, respectively. The three different filling material heights (0.6, 0.8, and 1 m) were used in the experiments.

Water was pumped with two centrifugal pumps. A by-pass water pipe line and by-pass valve was used to adjust water mass-flow rate. The water mass-flow rate was measured with water flowmeter which has 2" diameter. The measuring sensitivity of flowmeter was 0.7% at 30 °C water temperature. Water flow was homogeneously distributed with full-jet type nozzle and constant water temperature (±1 °C accuracy) was obtained with water depot.

Air-flow was adjusted with frequency controlled centrifugal fan. The air mass-flow rate was measured at end of the air channel (point 1) shown in fig. 1. The length of air channel was calculated for obtaining fully developed air-flow. In air channel, flow type is turbulent. At this flow type, the air-flow can be assumed as fully developed after critical length. This critical length can be assumed as ten times the hydraulic diameter of air channel. In this study the cooling tower type is an induced draft model. So, air-flow in the tower, designed for induced draft operation and the air-flow could be accepted as *homogenous*. The air-flow was measured with 16 mm diameter Testo Vane type probe. This has ±%1 measuring accuracy. This probe was connected to data logging system. The measuring values were digitally monitored and logged.

The pressure loss of air-flow was measured in the system between point 2 and point 3 shown in fig. 1. The pressure loss measuring cables' ends were closely located to the centers

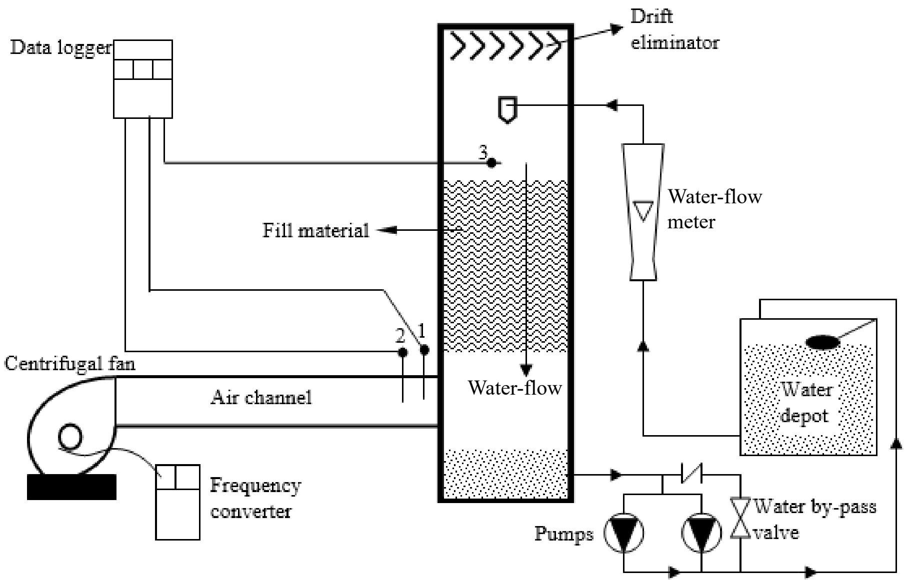
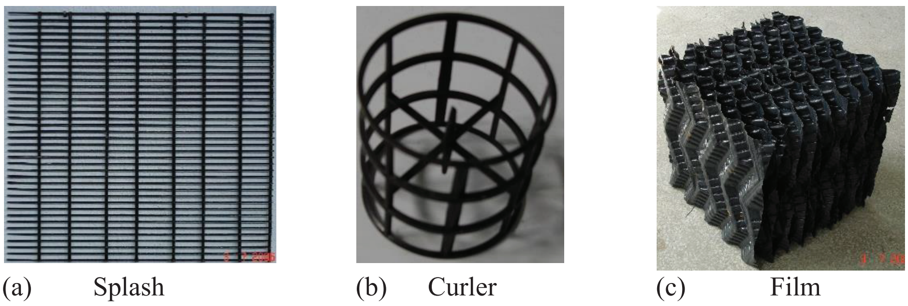


Figure 1. Schematic diagram of the experimental set-up

of the air channel and the tower for obtaining accurate measurement values. This condition is important at rectangular channels [6]. The measuring cables were connected to Testo 454 digital data logging system. The measuring values were monitored and saved during the experiments. Differential pressure gauge accuracy is ±0.5% [7].

The filling materials used for the experimental works can be shown in fig. 2. The splash fill had 39 horizontal metal rods which has 3 mm diameter and eight vertical metal rods which has 5 mm diameter shown in fig. 2(a). The splash fill layers were located with 90° rotation angle and 0.1 m. vertical spacing shown in fig. 3. The diameter of each curler filling material was 63 mm. However, each curler filling shown fig. 2(b) has 24 rectangular spacing. Film fill model was mixed fluted plates with corrugated pattern shown in fig. 2(c). This film fill model has the best volumetric heat transfer coefficient [3].



(a) Splash (b) Curler (c) Film

Figure 2. The filling materials used in experimental works

Results

Film fill

Figures 4-6 represents the air pressure loss values for film fills which have 0.6, 0.8, and 1 m height, respectively.

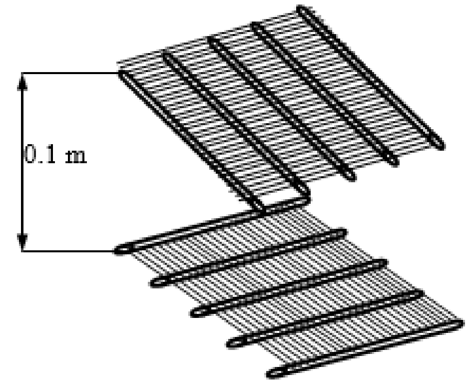


Figure 3. Schematic diagram of splash fill arrangement

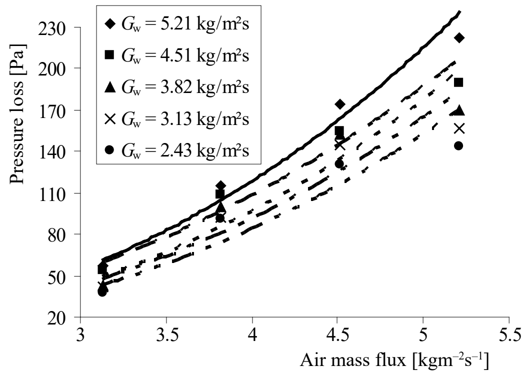


Figure 4. Pressure loss values obtained with film type fill for 0.6 m fill height

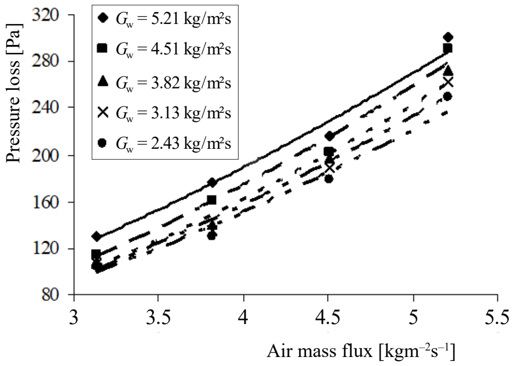


Figure 5. Pressure loss values obtained with film type fill for 0.8 m fill height

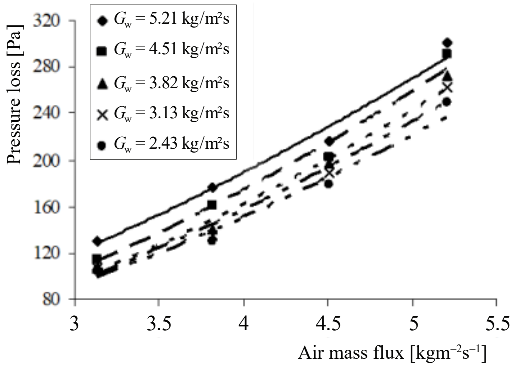


Figure 6. Pressure loss values obtained with film type fill for 1 m fill height

Equation (6) presents an empirical equation derived with the experimental results for all heights of the film fill ($r^2 = 0.96$):

$$\Delta P = 0.0217G_{\mathrm{w}} + 0.124G_{\mathrm{a}} + 161.151H - 320.692K_{\mathrm{fi}} = c_1 G_{\mathrm{w}}^{c_2} G_{\mathrm{a}}^{c_3} + c_4 G_{\mathrm{w}}^{c_5} G_{\mathrm{a}}^{c_6} \tag{6}$$

Curler fill

Figures 7-9 represents the air pressure loss values for curler fills which have 0.6, 0.8, and 1 m height, respectively.

It can be seen that the pressure loss for curler type filling nearly linear increases with increasing fill height. Also this pressure loss increases with the cooling tower water mass flux. The eq. (7) presents an empirical equation derived with the experimental results for all heights of the curler fill ($r^2 = 0.955$):

$$\Delta P = 0.0314G_{\mathrm{w}} + 0.106G_{\mathrm{a}} + 194.625H - 317.605 \tag{7}$$

Splash fill

Figures 10-12 represents the air pressure loss values for splash fills which have 0.6, 0.8, and 1 m height, respectively.

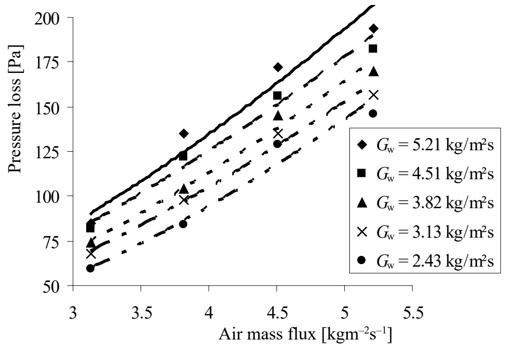


Figure 7. Pressure loss values obtained with curler type fill for 0.6 m fill height

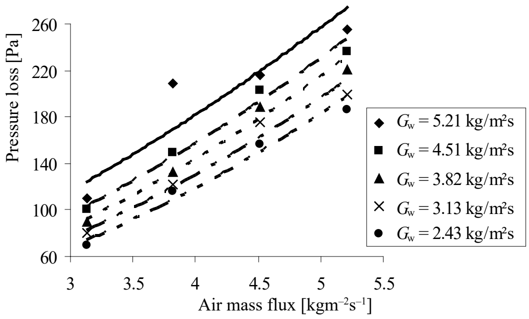


Figure 8. Pressure loss values obtained with curler type fill for 0.8 m fill height

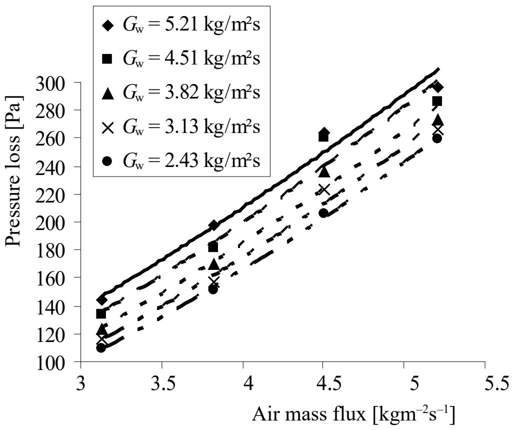


Figure 9. Pressure loss values obtained with curler type fill for 1 m fill height

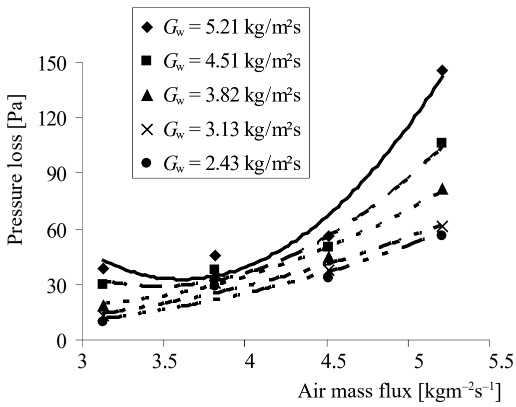


Figure 10. Pressure loss values obtained with splash type fill for 0.6 m fill height

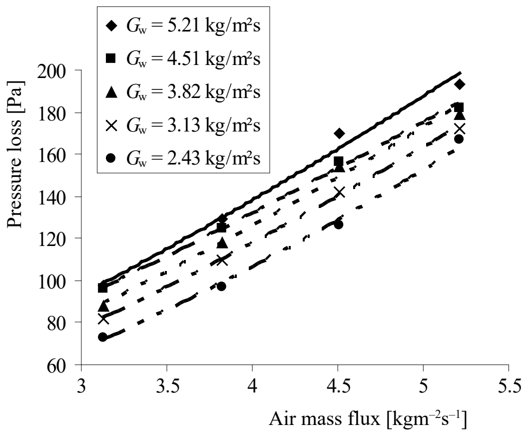


Figure 11. Pressure loss values obtained with splash type fill for 0.8 m fill height

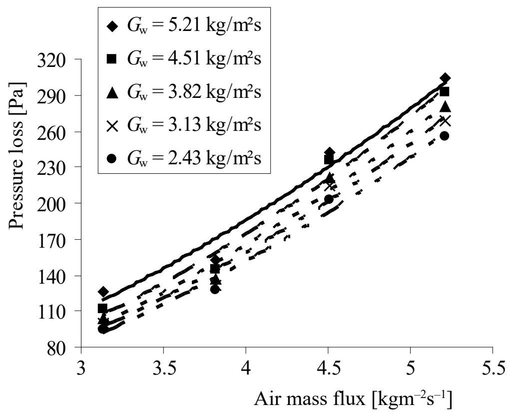


Figure 12. Pressure loss values obtained with splash type fill for 1 m fill height

Equation (8) presents an empirical equation derived with the experimental results for all heights of the splash fill (r^2 = 0.903):

$$\Delta P = 0.022G_{\mathrm{w}} + 0.0936G_{\mathrm{a}} + 348H - 428.935 \tag{8}$$

Comparison for pressure loss values obtained with all fill types

Figure 13 represents the comparison of pressure loss values obtained with all fills for 3.13 kg/m^{2}s water mass flux and 0.8 m fill height conditions. The same trends were observed for 0.8 m and 0.6 m fill heights and other water mass flux conditions. But pressure loss values obtained with all fills were nearly same for 1 m fill height condition shown in fig. 14. However, pressure loss values obtained with curler fill are higher than others and pressure loss values obtained with splash fill increase with more rapidly with increasing air mass flux.

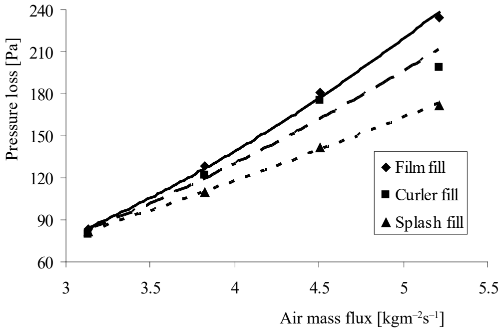


Figure 13. Comparison of pressure loss values for G_{w} = 3.13 kg/m^{2}s and L = 0.8 m

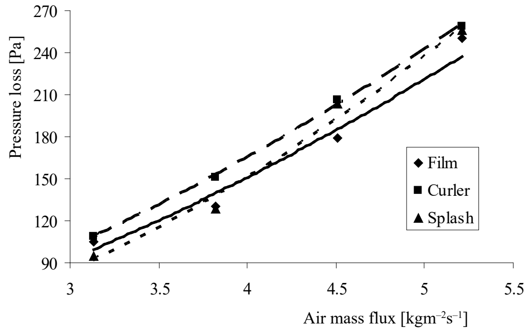


Figure 14. Comparison of pressure loss values for G_{w} = 2.43 kg/m^{2}s and L = 1 m

Conclusions

Equations (6)-(8) will accurately correlate measured pressure loss values for film, curler and splash type fills, respectively. Influence of the air-flow rate on the heat transfer coefficient is neglected because it is not topic of this study. Only pressure loss of the fillings has been investigated in this study. The lower pressure loss values were obtained with splash fill for 0.6 m and 0.8 m fill heights than others. However, the pressure loss values for all fill types were similar values at 1 m fill height condition. The pressure loss values obtained with splash fill increase more rapidly with increasing air mass flux.

It was concluded that: the most effective parameter is the air mass flux and the least effective parameter is the water mass flux for cooling tower air-side pressure loss. However, the fill height parameter can be assumed the second most effective variable for air pressure loss. The pressure loss of film type filling is 29.1% higher than splash type.

These results give useful information to the cooling tower designers for calculating the pressure loss values of cooling tower air-flow. Especially there is no sufficient works about the pressure loss values of air-flow obtained with the curler type fills. This fill type can be used widely in industrial applications such as dirty and limy water cooling, dusty ambient air-flow and higher than 60 °C inlet water temperature applications.

Acknowledgment

The authors gratefully acknowledge Niba Ltd. for supplying the fill materials and Suleyman Demirel University Technical Education Faculty for supplying laboratory devices.

Nomenclature

A – area, [m^2]
G_a – air mass flux, [kgm^{-2}s^{-1}]
G_w – water mass flux, [kgm^{-2}s^{-1}]
H – vertical distance between splash fill layers, [m]
K – loss coefficient
L – height, [m]
P – pressure, [Pa]

Greek symbols

Δ – differential
ρ – density, [kgm^{-3}]
υ – velocity, [ms^{-1}]

Subscripts

a – air
cs – cross-section
fi – fill
w – water

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Paper submitted: July 9, 2018
Paper revised: November 2, 2018
Paper accepted: November 14, 2018