The 17th Annual Conference of Mechanical Engineering Network
15-17 October 2003, Prajinburi, Thailand

Performance Prediction for Cooling Tower Eliminators

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Abstract

The risk of Legionnaires' disease can be minimized by reducing the spread of aerosols to a minimum level, Recently, many shapes of drift eliminator have been introduced into operation with cooling towers. This paper presents the prediction of pressure loss of the flow passing through the eliminators and the eliminator performance using a commercial CFD package (FLUENT version 5). Two dimensional numerical simulations are performed by injecting the number of water droplet trajectories in the air channel flow of the eliminator models and measuring the proportion of outgoing droplets relative to incoming droplets. The performance of eliminators can then be predicted. Results of pressure loss and eliminator performance obtained from the simulation are compared with those from measurements and simplified theory for three blade shapes (3-segment, zigzag, and wave plate). Wave plate eliminator profile with pitch ratio of 0.329 give the lowest pressure loss. For typical 3 m/s approach velocity of air flow through eliminators in cooling tower, the wave plate give 9.12 Pa pressure drop and 100 % eliminator performance for droplet diameter over 30 μm. The prediction; hence, suggests that the installation of wave plate eiminators in cooling towers could provide substantial reduction of Legionnaires' disease infection.

1. Introduction

Evidences show that all the outbreak of Legionnaires' disease has been associated with modest scale cooling towers having thermal capacity of around 1 MW. The transmission of Legionnaires' disease in atmospheric air occurs via water particles (aerosols) which escape from the top of cooling towers. The range of temperature associated with the risk of Legionnaires' disease is that the same range found in an operation of cooling towers (20°C to 45°C). Drift eliminator is a component in cooling tower that minimizes the droplets released from cooling tower. At the same time, it also helps to reduce the distribution of Legionnaires' disease to atmosphere.

Drift eliminators are normally designed to be efficient through a calculated range of airflow. Normal airflow velocities associated with most cooling towers are usually in the range of 2.5 to 3 m/s. Earlier generation of cooling towers usually have simple wooden slats inclined and offset to catch the larger droplets with 100 % droplet capture for above 100 μm diameter. Problem of obstruction to airflow of eliminators leads to the poor cooling performance in cooling towers. Hence, many configurations of eliminator have been experimentally investigated in order to accomplish the standard of effectiveness (the ratio of carryover amount with eliminators installed to the total amount without eliminator installed) and pressure loss. Chilton [1] suggested possible configurations with different numbers of layers of redwood louver. Results showed that the carryover and effectiveness were not significantly altered but the pressure loss was obviously changed when the louver were placed at different angles. Yao and Schorck [2] analyzed theoretically the pressure loss across the eliminator using the nondimensional parameters. The method was proposed to be the optimum design for eliminators based on aerodynamics theory and individual droplet trajectory calculation. However, it could not be applied to configurations producing flow separations due to effect of complexibility of turbulent wake regions. Chan and Golay [3] proposed numerical simulation methods in comparison with experiment techniques to analyzed the performance of standard industrial evaporative cooling tower drift eliminators, namely; zigzag eliminator, three-segment eliminator, wave plate eliminator (sinus-shaped). Conclusions drawn from their analysis are that

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both particle collection efficiency and pressure loss increased as the eliminator geometry becomes more complex, and as the flow rate through the eliminator increased. Therefore, the orders of the better performance the eliminators were ranked as follow; wave plate eliminator, three-segment eliminator, and zigzag eliminator. Notes that this information will be used in comparison in later sections of this paper. Behnia and Maclaine-cross [4] developed the simple theory for wave plate eliminator by ignoring effects of secondary flows and separations which might reduce the eliminator performance. No droplets larger than 36 μm can escape from such eliminator. In this paper, analysis of performance and pressure loss of eliminators was investigated using a commercial CFD package "FLUENT version 5 "' for finite volume simulation.

2. Calculation and Modeling

2.1 Pressure loss

Total pressure loss taken into account the different up-stream and down-stream airflow velocities can be expressed as:

$$\Delta P_t = \left[P_1 + \rho g h_1 + \rho \frac{\upsilon_1^2}{2} \right] - \left[P_2 + \rho g h_2 + \rho \frac{\upsilon_2^2}{2} \right] \quad (1)$$

In this paper, to make a comparison of pressure loss as a function of Reynolds number between simulation results and other previous results, the parameter "K", Pressure loss coefficient, is introduced. The pressure loss coefficient can be expressed as;

$$K = \frac{2\Delta P_t}{\rho \upsilon^2} \quad (2)$$

These following assumptions must be made in order to perform the theoretical solution:

- The flow is assumed to be the two dimensional incompressible flow.
- The airflow is laminar (ignore any turbulence effect).
- Droplet density is very low (less than 10 % of air density).
- There is no interaction between droplets.
- Wall boundary condition is assumed to be non-slipped (ignore the effect of liquid film on blade surface).
- The airflow is not altered by the presence of droplets.

2.2 Eliminator performance

For the wave plate eliminator, theoretical calculation procedure of eliminator performance applied in this paper was derived by Maclaine-cross [5]. A significant parameter introduced to comparative study of eliminator performance is known as the inertial parameter (P').

$$P' = \frac{\rho_w D^2 \upsilon}{\mu_a L} \quad (3)$$

Eliminator performance prediction by this simulation approach is the droplet collection efficiency (η) that can be determined as following;

$$\eta = 1 - \frac{\dot{m}_o}{\dot{m}_i} \quad (4)$$

where,

$\dot{m}_o$ = mass flow rate of escaping droplets

$\dot{m}_i$ = mass flow rate of droplets at the entrance of elominator

The droplet mass flow rates are kept constant for all droplet diameters, hence;

$$\eta = \frac{N_{trap}}{N_{\text{int}}} \quad (5)$$

where,

N_{trap} = number of trapped droplet trajectories

N_{int} = number of droplet injections

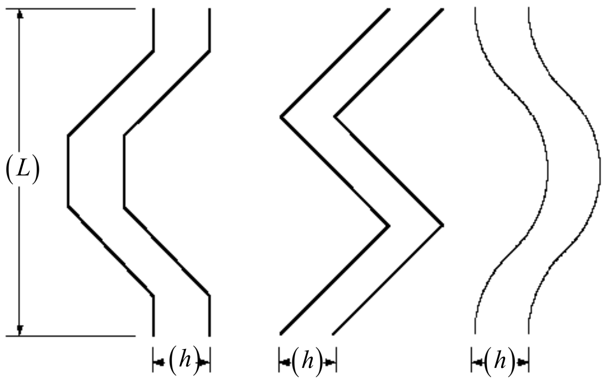
High performance eliminators do not only reduce the amount of droplets, but they also significantly absorb incident light. By fitting numbers of eliminators at the top of cooling towers, no light would be transmitted inside the towers; hence, the growth of the Legionella bacteria within the tower will be reduced. The amount of light that falls on to the circulating water inside towers is a function of eliminator geometry and surface condition. All eliminators discussed in this paper reduce light transmission. If the eliminators were coated with a perfect matte black, no light could be reflected and transmitted through the eliminators.

2.3 Modeling

In order to compare the relative eliminator performance in terms of droplet collection efficiency between different models, shown in Fig.1, the two parameters are set to be equal.

1) The characteristics or pitch length of the channel flow (h) = 12.5 mm.
2) The vertical height of the eliminators (L) = 76 mm.

By ignoring the heat transfer in the calculation, the wall simply set to be non-conducting wall. Normal inlet and outlet conditions were applied to the entrance and exit of the models. In fact, the arrangement of eliminators in cooling tower could be more than one bank in order to achieve the minimum possible of escaping droplets. However, only one bank of eliminator will be investigated due to the fact that cyclic boundary condition cannot be applied to the models, especially when the droplet trajectory calculations are performed.



(a) (b) (c)

Fig. 1 Eliminator blade profile for (a) 3-segment, (b) zigzag and (c) wave plate eliminator. Blade chord and pitch are the same for all profiles.

The program FLUENT allows users to predict the trajectory of a dispersed phase droplet by integrating the force balance on droplet. This force balance equation can be expressed as;

$$\frac{du_p}{dt} = F_d\left(u_d - u_P\right) + \frac{g_Z\left(\rho_P - \rho\right)}{\rho_P} + F_Z \quad (6)$$

where $F_d\left(u_d - u_P\right)$ is the drag force per unit particle mass

and;
$$F_d = \frac{18\mu}{\rho_P D_P^2}\frac{C_D \mathrm{Re}}{24} \quad (7)$$

The relative Reynolds number is defined as:

$$\mathrm{Re} = \rho D_P \frac{\left|u_P - u\right|}{\mu} \quad (8)$$

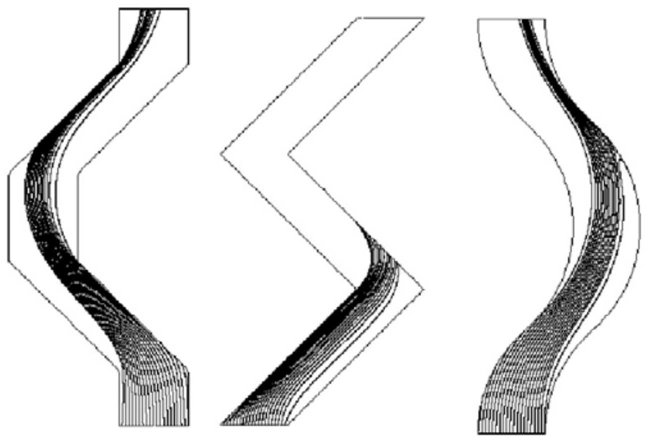
The drag coefficient, C_d, is expressed as a function of Reynolds number;

$$C_d = a_1 + \frac{a_2}{\mathrm{Re}} + \frac{a_3}{\mathrm{Re}^2} \quad (9)$$

From the above equation, all values of "a" are constants that apply over several ranges of the relative Reynolds number. As being mentioned before, heat transfer was ignored in this investigation; hence, the effect of temperature was not a concern. At the starting point of calculation, initial conditions of droplet trajectories must be provided. These initial conditions are droplet velocity, position of droplet injections, numbers of droplet injection, droplet diameter, and droplets' mass flow. In this investigation, 20 droplet trajectories were injected into the airflow field. Boundary conditions at the eliminators' walls were set to trap the droplets; hence, ignore the effect of ``bounce''.

3. Results and Discussion

The simulation results of each geometrical model were obtained at various inlet air velocities range from 1.5 to 3 m/s. The results of 25-micron droplet trajectories simulation at the specified airflow velocity of 1.5 m/s are presented graphically for each eliminator models (Fig. 2), while, the others are represented in the chart forms.



(a) (b) (c)

Fig. 2 Simulation result of 25 µm droplet trajectories at 1.5 m/s inlet air for (a) 3-segment, (b) Zigzag and (c) Wave plate eliminator.

Simulation results from the charts in Fig. 3, Fig. 4 and Fig. 5 indicate that the zigzag eliminator is the best profile in term of the highest eliminator performance. Moreover, results also indicate that the higher the velocities of the airflow the better the performance that the eliminator could be obtained. On the contrary, results of the pressure loss across inlet and outlet of the eliminators show that the best eliminator in term of the minimum possible pressure loss is the wave plate eliminator. Comparisons of the results of pressure loss for various velocities are illustrated in table 1.

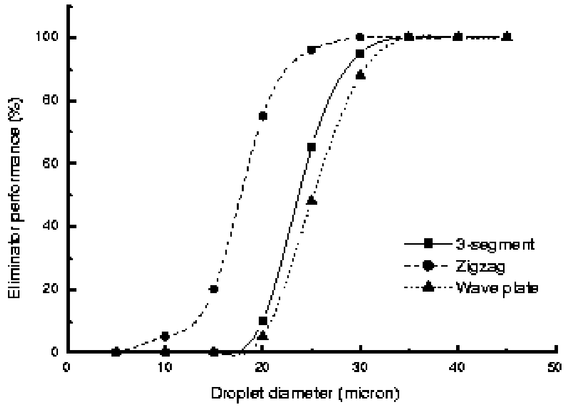


Fig. 3 Eliminator performance at 1.5 m/s airflow for various droplet sizes

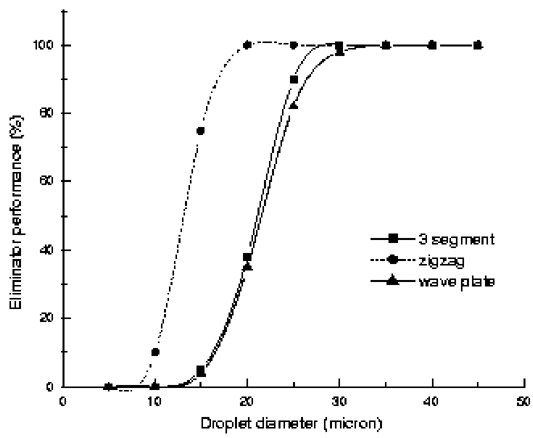


Fig. 4 Eliminator performance at 2.5 m/s airflow for various droplet sizes

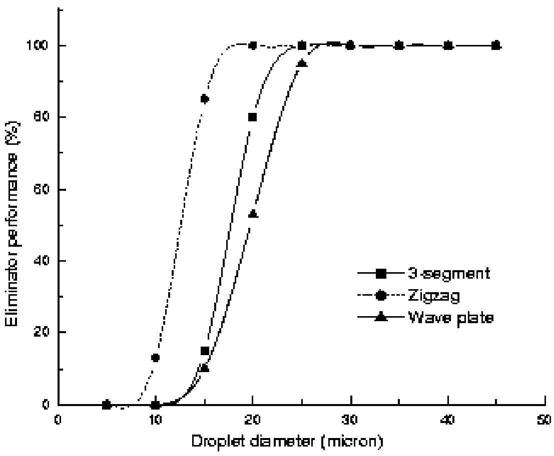


Fig. 5 Eliminator performance at 3.0 m/s airflow for various droplet sizes

Table 1

Comparison of simulated pressure loss across eliminators

Air flow velocity (m/s)	Pressure loss across eliminators (Pa)		
	3-segment	Zigzag	Wave plate
1.5	4.01	11.92	2.46
2.0	7.04	22.54	4.15
2.5	10.76	34.27	6.44
3.0	15.00	48.04	9.12

Simulated pressure loss across eliminator profiles is compared with prior measurements performed by Chan and Golay [6] which had the pitch ratio $\left(2h/L\right)$ of all blade profiles about twice of that used in this paper. The pressure loss coefficient, K , as a function of pitch Reynolds number (Re) is, then, considered as a comparative parameter. The comparison tables of pressure loss for each eliminator types with the previous works are shown in Table 2. Where, pitch Reynolds number is defined as;

$$\mathrm{Re}=\frac{2h\upsilon_1}{\nu} \qquad (10)$$

Table 2

Comparison of simulated pressure loss across the eliminators with prior experiment

Eliminator	Re	3-segment		Zigzag		Wave plate	
		$2h/L$	K	$2h/L$	K	$2h/L$	K
Chan & Golay	10000	0.714	3.68	0.573	7.31	0.562	3.00
Current CFD Results	5000	0.329	2.71	0.329	8.62	0.329	1.65

The simulation results of pressure loss and the measurement of Chan and Golay [6] for all eliminator profiles show that the minimum pressure loss is occured in the wave plate profile. To make a fair comparison of eliminator performance for the wave plate profile, the following chart (Fig. 6) was plotted by consider the non-dimensional parameter, "P'", inertial parameter, suggested by Maclaine-cross [5] rather than droplet diameter. Comparison graph of eliminator performance versus the inertial parameter $\left(P'\right)$ are shown in Fig. 6., indicated that the theoretical calculation suggested by Maclaine-cross [5] is closed to the results obtained from an experiment made by Chan and Golay [6].

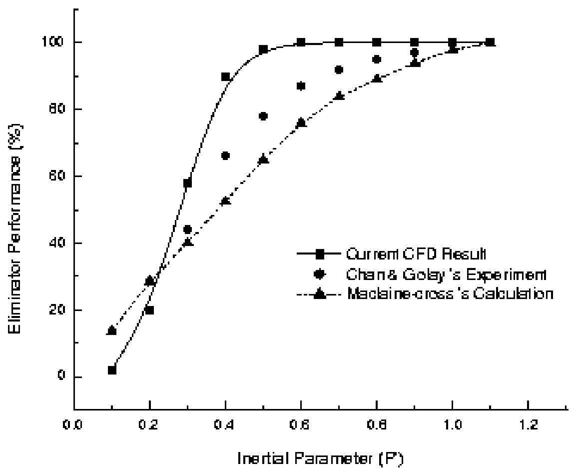


Fig. 6 Graph of comparison of eliminator performance versus the inertial parameter $\left(P'\right)$ for the wave plate profile

The results obtained from the simulation predict the highest eliminator performance when the inertial parameter $\left(P'\right)$ is over 0.23 and the lowest performance when the inertial parameter is lower than 0.23.

4. Concluding Remarks

Simulation results of the three blade profiles (Fig. 1) with the same pitch ratio of 0.329 indicates that wave profile eliminator gives the lowest pressure loss (Table 1). The pressure loss measurement of Chan and Golay [6] is also expressed that the wave profile gives minimum pressure loss.

For eliminator performance, the zigzag eliminator has the best eliminator performance but produce the highest pressure loss. Obviously, as the geometry of the eliminator becomes more complex the pressure loss increases. Since the eliminator performance also increases with increasing geometrical complexity (see Figs. 3, 4 and 5), both low pressure loss and high eliminator performance are to be compromised in selection of eliminator profile. Simulations for various droplet diameters indicate that no droplet larger than 30 µm could escape from the wave plate eliminator. The droplet collection efficiency as a function of droplet diameter of wave plate profile for the range of airflow velocity from 1.5 to 3 m/s are very closed to the results of the 3-segment profile. Hence, wave profile eliminator is suggested to be used with the minimum pressure loss.

Since, the eliminator performance or droplet collection efficiency is depend on various factors such as, droplet size, droplet density, location of droplet injections, droplet distribution inside the flow, etc., it is difficult to measure or predict accurate values for eliminator performance. However at least attempt to predict eliminator efficiency make useful results for determining the relative performance for various shapes of eliminators. Therefore, manufacturers and consumers can select appropriate eliminators for their applications. The author's attempt to investigate the flow in the three dimensional wave plate eliminator is not yet successfully achieved the appropriate results, since the pressure drop results are far from the results obtained from the two dimensional simulation. Such errors probably occur due to significant effect of the second re-flow presence in the third dimension and the effects of turbulence wake regions that cannot be negligible.

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Nomenclature

K= pressure loss coefficient	P_t= total relative pressure, kPa
P'= inertial parameter	$\dot{m}$= mass flow rate, kg/s
Re = Reynold number	η= eliminator performance
ρ= density, kg/m^3	ν= kinematic viscosity, m^2/s
μ= viscosity, $kg.m/s$	g= gravity, m/s^2
D= droplet diameter, m	υ= normal airflow velocity, m/s
L= eliminator depth, m	h= pitch length of eliminator, m
C_D = drag coefficient	p= particle
a= air	N= number of droplet trajectories
w= water	