

The Research on Local Resistance in the Box of Air Cooling Condenser in Normal Temperature CLSC Evaporative Cooling System of Large Electromagnetic Equipment

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ABSTRACT: Normal temperature close-loop-self-circulating (CLSC) evaporative cooling technology is a newly developed concept for the cooling of large electromagnetic equipment, and it can work under a quite low pressure. The local pressure drop of abrupt expansion and abrupt contraction structure in the inlet box of the condenser occupy an important proportion of the total pressure drop of the cooling system and have great impact on the cooling effect, thus it is not only important but also necessary to calculate and predict it. For this purpose, a new analytical calculation method of local resistance of inlet box of the condenser is introduced in this paper, and it can greatly improve the precision of calculation result. And then, an experiment is carried out to validate the result of calculation. The final finding shows that there is an agreement between experimental and calculation results. Thus it may be claimed that the new calculation method can be adopted in calculating the local resistance in the inlet box of the condenser. Furthermore it can do a good work in directing the design of air cooling condenser used in CLSC evaporative cooling electromagnetic equipment.

Keywords: Close-loop-self-circulation (CLSC), evaporative cooling, condenser, local resistance

NOMENCLATURE

λ	Friction factor [dimensionless]	d_i	Hydraulic diameter of the inlet box[m]
M	Coefficient of momentum (Boussinesq coefficient)[dimensionless]	v_1, v_l, v_2	Velocity of coolant at the outlet of the inlet tube, the inlet box and inlet of condensing tube[m]
N	Coefficient of kinematic energy (Coriolis coefficient) [dimensionless]	l_l	Length of the inlet box[m]
σ	Ratio between different flow sections [dimensionless]	h_f	Frictional pressure drop[Pa]
C_c	Contraction coefficient [dimensionless]	h_j	Local pressure drop[Pa]
K_e	Local loss coefficient of abrupt expansion [dimensionless]	Subscript	
K_c	Local loss coefficient of abrupt contraction [dimensionless]	l	The larger section of the flow channel
		s	The smaller section of the flow channel

1. INTRODUCTION

Normal temperature close-loop-self-circulating (CLSC) evaporative cooling is a newly developed concept for large electromagnetic equipment, and it can cool down the equipment under a quite low pressure. Air cooling condenser is widely adopted in evaporative cooling system when the equipment is running in a place where water is scarce or the water cooling can't be accepted for safe consideration [1]. In the cooling system, the local resistances of abrupt expansion and abrupt contraction structure in the inlet box of the condenser occupy an important proportion of the total pressure drop and have great impact on the cooling effect. In this paper, a new analytical calculation method of local resistance of inlet box of the condenser is introduced and it can greatly improve the precision of calculation result compared with the traditional semi-theoretical and semi-experiential equations. And then, an experiment is carried out to validate the result of calculation. The final findings show that there is an agreement between experimental and calculation results. Thus it may be claimed that the new calculation method can do a good job in directing the designation of air cooling condenser in natural temperature CLSC evaporative cooling electromagnetic equipments.

2. ANALYTICAL CALCULATION

When an incompressible fluid flows through a sudden flow area expansion, the total and irreversible pressure drop can be found in the regions nearby [2] (see Figure 1(a)). In flow through a sudden flow area contraction, up to the vena-contraction point, the fluid acceleration is approximately isentropic and mechanical energy loss take place predominantly during the deceleration and dissipation downstream of the vena-contraction point (see Figure 1(b)).

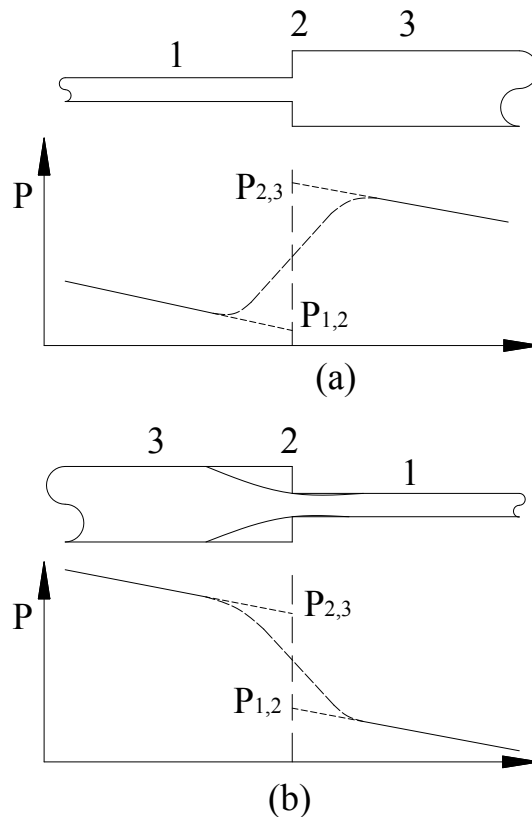


Figure 1: Schematic diagram of local pressure drop: (a) abrupt expansion; (b) abrupt contraction

In the condenser, there are sharp pressure drops caused by abrupt flow area expansion at the entrance of the inlet box and abrupt flow area contraction at the interface between the inlet box and the cooling tube.

The local pressure drop at the inlet of the condenser occupies a great proportion of the total pressure drop of the whole loop of the CLSC evaporative cooling system. To insure the evaporative cooling system of large electromagnetic equipment works, the resistance of coolant in the CLSC system must be thoroughly studied, and each resistance should be reduced as low as possible.

2.1 Reasonable Assumption and Theory of Calculation

The saturated gas of coolant is pushed through the inlet pipe into the air cooling condenser by the self circulating head. The velocity of the coolant is u_0 , and the radius

of the inlet pipe is R . The running pressure of the CLSC evaporative cooling system is fairly low, so the fluid of coolant can be assumed to be incompressible. As the length of the inlet box is comparatively short, the heat exchange between the coolant and the box wall is comparatively weak, and the phase change can rarely happen. Thus the coolant in the inlet box can be simply treated as pure fluid with certain dryness.

The gas of the coolant flows into the inlet box and is redistributed in it, and then into the condensing tube bundle of the condenser. For the purpose of simplification, some presumptions are made: (1) The physical properties of the coolant are constant; (2) The gas is under the state of saturation with certain dryness; (3) The wall of the inlet pipe and the inlet box is hydraulically smooth; (4) No heat exchange takes place in the inlet box, and the whole condensing process is carried out in the condensing tube; (5) The coolant flows in an equivalent state; (6) The flow media is incompressible. So the corresponding governing equations can be got:

Mass conservation equation:

$$\frac{d[\rho_l u_l (1-a)]}{dx} + \frac{d(\rho_g u_g a)}{dx} = 0$$

Momentum conservation equation:

$$\frac{d[\rho_l u_l^2 (1-a)]}{dx} + \frac{d(\rho_g u_g^2 a)}{dx} = -\frac{dp}{dx} + \frac{\tau_w U_w}{A}$$

Energy conservation equation:

$$\frac{d[\rho_l (1-a) u_l e_l]}{dx} + \frac{d(\rho_g a u_g e_g)}{dx} + \frac{a_x \Delta t U_w}{A} = 0$$

2.2 Analytical Calculation of the Abrupt Expansion and Abrupt Contraction

As the effect of gravity is much smaller than that of the flow head, it is ignored as the coolant runs through the inlet box. The geometry model of the research is showed in Figure 2.

In the figure, the model is in a cylindrical coordination(x, r); the X axis of the coordination is the axis of the model. For the tangential component of the velocity is

comparatively small and it can be ignored, the vector of speed can be described by (u, v) . The calculating region is the part of the model between the line 1-1 and 2-2.

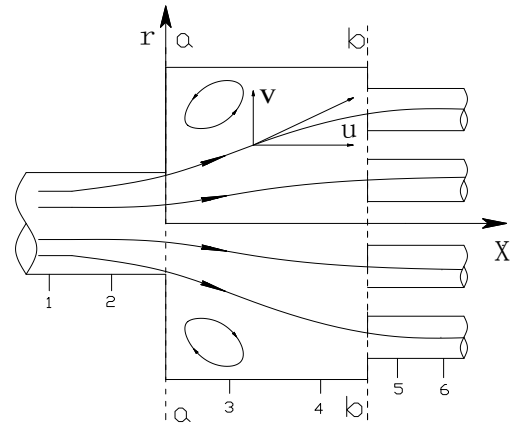


Figure 2: Schematic diagram of inlet structure of the condenser for calculation

The reasons for the local loss can be concluded as below: (1) The collision effect due to redistribution of coolant velocity; (2) The work of viscous force in the vortex due to the redistribution; (3) The variety of momentum caused by the mixing of fluid particles[3]. Traditionally, the local resistance produced in the region of the abrupt expansion is calculated by the

formula $h_j = \xi \frac{v^2}{2g}$. Bernoulli Equation,

momentum equation and continuous equation are all adopted in the deduction. The total pressure in the self circulation system is very low, so it's necessary to take the pressure caused by abrupt flow area changes into consideration.

A sudden pressure drop occurs in the region near the entering section of the inlet box due to abrupt expansion of the flow way. The loss coefficient of abrupt expansion [4] K_e can be attained by applying one-dimensional momentum and mechanical energy conservation equations:

$$K_e = 1 - 2M_s \sigma + \sigma^2 (2M_l - 1)$$

In this equation: M is the flow momentum coefficient (the Boussinesq

coefficient) $(M = (1/F_0) \int_{F_0} (w/w_0)^2 dF)$, and N is the coefficient of kinetic energy of the flow (the Coriolis coefficient) $(N = (1/F_0) \int_{F_0} (w/w_0)^3 dF)$; σ is the flow area contraction ratio, $\sigma = A_s/A_l$. The subscript l is the larger flow area and s shows the smaller flow area. M and N are determined by the flow regime in the tube: (1) for laminar flow ($Re < 2300$), the fully developed velocity profile are assumed ($M=1.33$, $N=2$); (2) for turbulent flow ($Re \geq 2300$), uniform velocity profiles are assumed ($M=N=1$). An approximation $N=3M-2$ can be made. The approximation is more correct the nearer M and N are to unity [5].

When the coolant flows from the inlet box into the condensing tube, great losses occur due to the contraction between the two parts of the condenser, which is basically similar to the local losses during the abrupt expansion. The losses occur mainly during the entry from the broad cross section of fluid in the box into the narrow channel of the condensing tube, expands until it fills the entire section of the condensing tube. The loss coefficient of abrupt contraction K_c can also be calculated through one dimensional Momentum conservation equation and Energy conservation equation:

$$K_c = \frac{1 - (N_l \sigma^2 - 2M_s + 1 - \sigma^2) C_c^2 - 2C_c}{C_c^2}$$

The contraction coefficient [6] C_c can be calculated by the formula:

$$C_c = A_l/A_s = 1 - \frac{1 - \sigma}{2.08(1 - \sigma) + 0.5371}$$

The frictional pressure drop in the tube can be calculated with Darcy-Weisbach Formula:

$$h_f = \lambda \frac{l}{d} \frac{v_l^2}{2g}$$

In this formula: λ is dimensionless friction factor, $\lambda = 64/Re$ when the flow is

in laminar condition ($Re < 2000$), and $\lambda = 0.3164/Re^{0.25}$ in turbulent condition, while when the flow is in transitional state ($2320 < Re < 4000$), there is no determinate way to decide the value of λ . But, the flow can't maintain this state for the very condition is instantaneous. In engineering, the value of λ can also be obtained through Moody chart.

So the total pressure drop of the coolant flow through the inlet box of the condenser is the sum of local resistance of abrupt expansion, abrupt contraction and the friction in the inlet box:

$$h_w = \sum h_f + \sum h_j = \lambda \frac{l_l}{d_l} \frac{v_l^2}{2g} + k_e \frac{v_1^2}{2g} + k_c \frac{v_2^2}{2g}$$

In this equation: v_1 , v_l , v_2 stand for respectively the velocities of coolant at the outlets of the inlet tube, the inlet box and inlet of condensing tube; while l_l stands for the length of the inlet box, and d_l is the hydraulic diameter of it.

3. EXPERIMENT FOR VALITATION FOR CALCULATION RESULTS

In order to validate the result of the calculation, an experiment is conducted in the laboratory. The experiment apparatuses used in the experiment are shown in Figure3.

In the device a heater is designed to simulate the electromagnetic equipment which is cooled down by CLSC evaporative cooling system. The liquid coolant is heated to gas state in the heater and flows upward through the pipe to the condenser to be condensed. The valve can control the velocity of coolant when it flows from the heater to the condenser. The condensed coolant in liquid state flows down back to the heater to cool it and then another circle starts in the close loop. The driving power of the flow is the gravity difference of the liquid coolant in the downward pipe and gas in the upward pipe. All parameters of temperature, pressure and velocity are

acquired by measuring structure and then transmitted to the data acquiring system (see Figure 3).

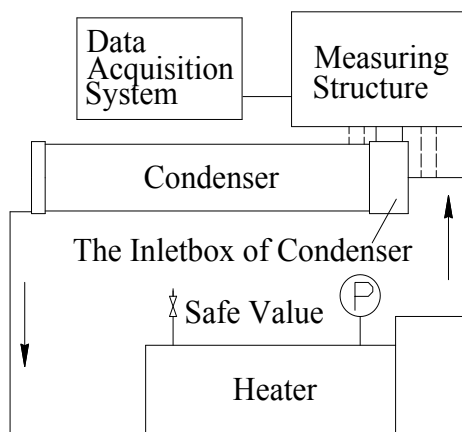


Figure 3 Flow chart of CLSC experimental device

The results of analytical calculation and the pressure drop acquired from experiment are shown in figure 4. It indicates that there is an agreement between the analytical calculation results and the experimental ones. Experimental pressure drops are slightly larger than theoretical results when the flow is in laminar state. As most CLSC evaporative cooling system runs at a rather low pressure, the flow in the system is generally in laminar state. Turbulence rarely happens in self circulation evaporative cooling systems.

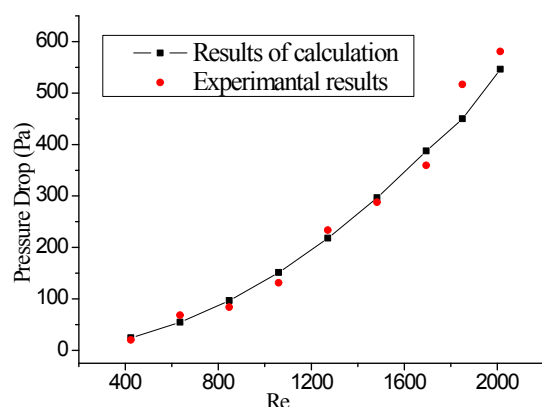


Figure 4: comparison between calculation results and experimental results

5. CONCLUSION

A calculation method for the local resistance is provided in this paper, and then experiments are conducted to validate the correctness of the method. The calculation results agree with the experimental ones very well. So, the method can be adopted in calculating the local resistance in the inlet box of the condenser. Furthermore it can do a good work in directing the design of air cooling condenser used in CLSC evaporative cooling electromagnetic equipment.

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