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Heat Transfer Coefficients of lithium bromide (LiBr) Solution Flow inside a Horizontal Straight Smooth Tube

Shuangbo Yang[a], Suxia Ma[b], Jiangpan Xu[b]

[a]Technician, National Engineering Research Center of Green Refrigeration Equipment, Zhuhai, Guangdong, PR China
[b]*Professor, Taiyuan University of Technology, Taiyuan, Shanxi, PR China*

Abstract

The characteristic correlation of lithium bromide solution flow inside a horizontal straight smooth tube is obtained by dimensional analysis and mathematical physics based on the previous literature.

$$\mathrm{Nu}_{ex,i} = 0.020\,\mathrm{Re}^{0.800}\,\mathrm{Pr}^{0.244}\left(\frac{d}{l}\right)^{0.056}\mathrm{Rx}^{0.375}$$

The correlation represents the heat transfer mechanism which lithium bromide solution is heated. The average relative error of the correlation is 2.41%.

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Key words: Lithium bromide (LiBr) Solution, Heat transfer, Coefficients

1. Introduction

In the lithium bromide (*LiBr*) absorption heat pump design, heat transfer calculation of condenser is comparatively maturity for many year's development, but because of the complexity of heat and mass transfer, the calculated accuracy of heat transfer for other heat exchangers of heat pump is low, which has brought much trouble to academic research and engineering applying.

In many cases, heat transfer coefficients were determined by designer who select heat transfer coefficient based on their experience in the design of lithium bromide absorption heat pump [1].

The characteristic correlation of lithium bromide solution flow inside a horizontal straight smooth tube is obtained by dimensional analysis and mathematical regression based on the existing experimental data. It can provide theoretical support for the analysis of absorber and generator.

* Corresponding author. Tel.: +86-185-7824-0723.
E-mail address: yangshuangbo11@126.com.

2. Mathematical Regression of Experimental Data

Dilute solution and concentrated solution flow inside and outside tubes of solution heat exchanger. The type is usually selected as shell and tube heat exchanger.

In the heat transfer study of solution heat exchanger, Takada test and gave out the heat transfer coefficient diagram for inner surface of tube by experiment [2].

In order to obtain the quantitative relationship between heat transfer coefficient and concentration, temperature, flow rate, tube diameter and tube length, we need to discretize and digitize the original data, and get the mathematical expression of heat transfer through the fitting tool.

2.1. Discrete of Experimental Data

Lithium bromide dilute solution is heated when it flows inside tube. Inner surface heat transfer correlation was obtained by reading the original data from Fig. 1 [2], and by fitting step by step through adding some virtual coordinate.

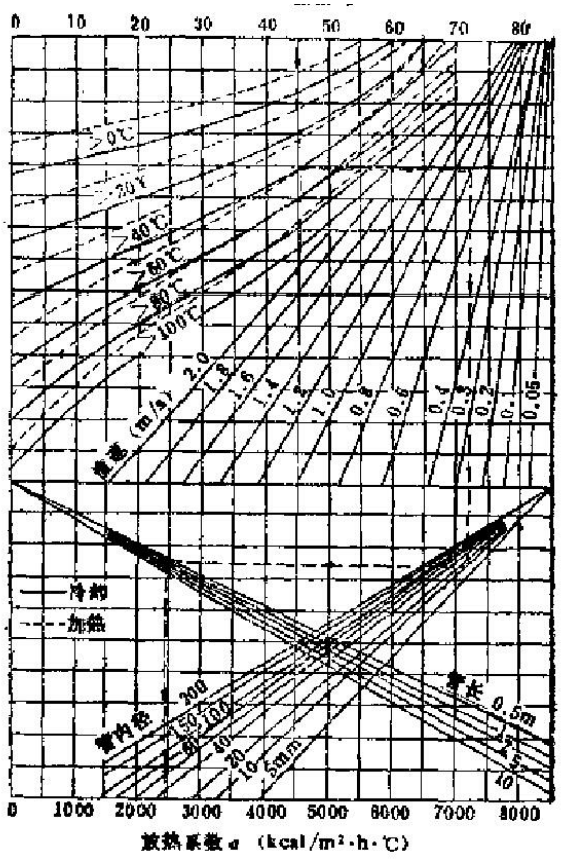


Fig. 1. Inner surface heat transfer coefficient for lithium bromide (LiBr) solution flow in tube

Firstly, the discretization process is automatically read and get through the software without the introduction of human error. Secondly, the deviation of the step-by-step fitting is concentrated in the integrated heat transfer correlation.

The original data is read in sequence in Fig. 1 and the discretized data in Fig. 2 is divided into four coordinate graphs from Fig.3 to Fig.6 which are associated with the top and the bottom.

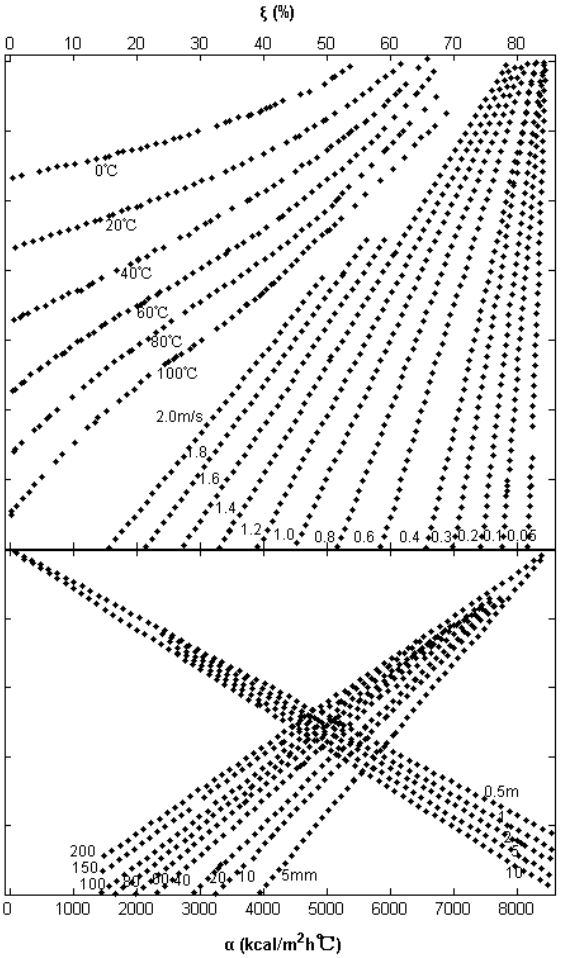


Fig. 2. Discrete inner surface heat transfer coefficient for lithium bromide (LiBr) solution flow in tube

According to the regression formulas of the graphs from Fig.3 to Fig.6, the internal heat transfer coefficient of the solution heat exchanger can be obtained according to the dependency relationship between the input quantity and the output quantity of each formula as follows.

The discrete data in Fig.2 was divided into four sections which are showed in Fig.3 to Fig.6:

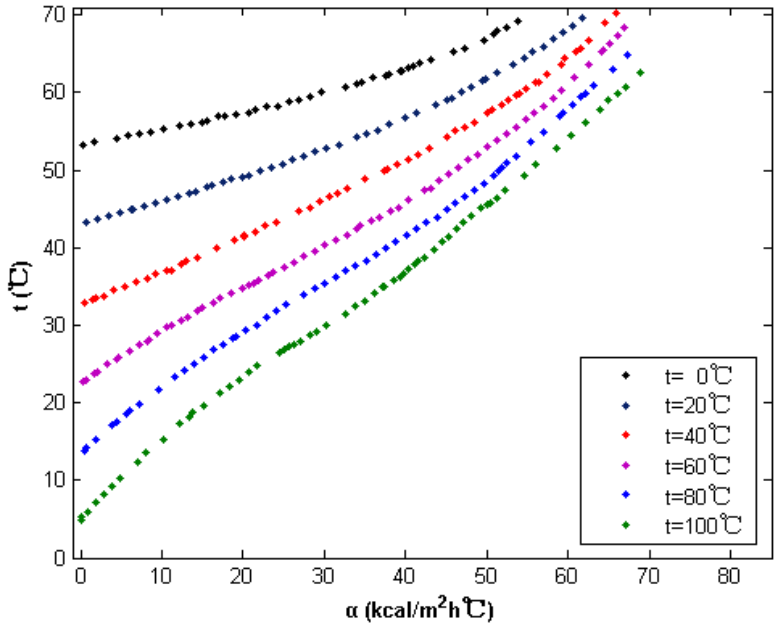


Fig. 3. Relative positions of the solution temperature and inner surface heat transfer coefficient

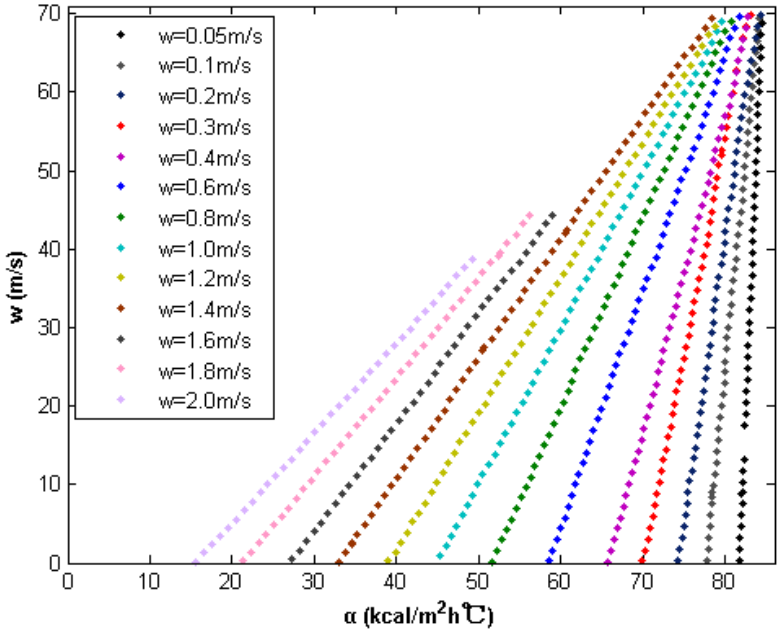


Fig. 4. Relative positions of the solution flow velocity and inner surface heat transfer coefficient

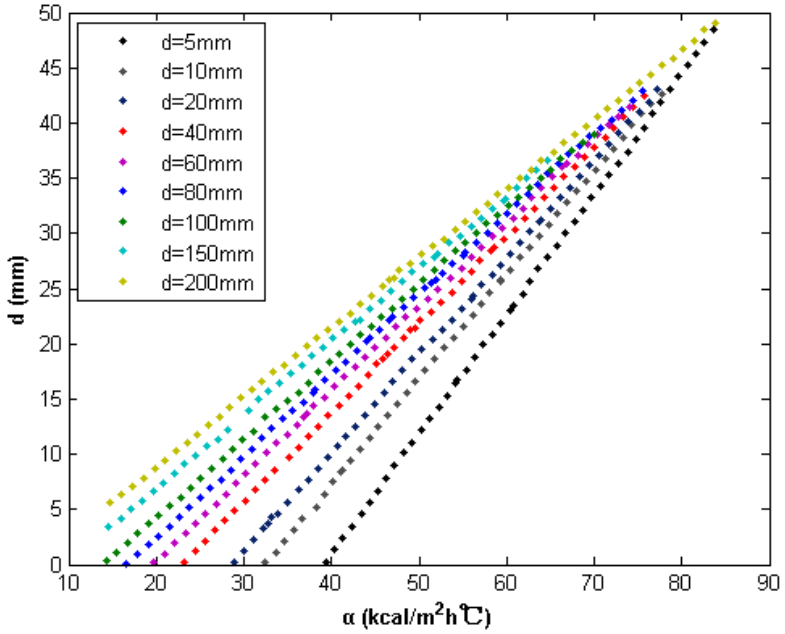


Fig. 5. Relative positions of the tube inner diameter and inner surface heat transfer coefficient

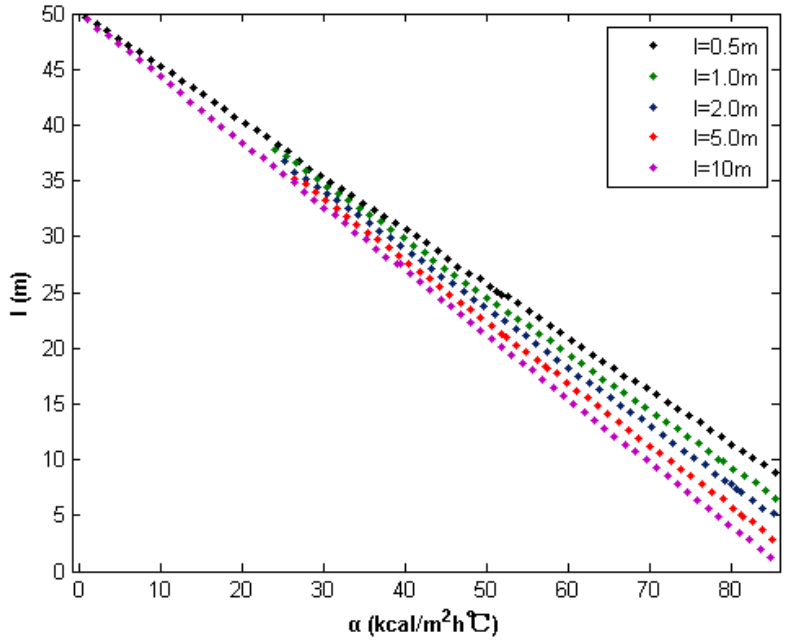


Fig. 6. Relative positions of the tube length and inner surface heat transfer coefficient

2.2. Fitting of Experimental Data

According to Fig.3 to Fig.6, four regression equations were obtained, the inner surface heat transfer coefficient correlation was established by following the dependencies of each input and output variables of the four equations:

$$\alpha_{ex,i} = C(\sum_{0}^{5} A_n t^n + \xi \sum_{0}^{5} B_n t^n + \xi^2 \sum_{0}^{5} C_n t^n + + \xi^3 \sum_{0}^{5} D_n t^n + E) w^{0.8002} d^{-0.1417} l^{-0.05607} \quad (1)$$

The coefficient C is -154.6728 and the coefficient E is -79.606. The range of application for formula is $0<\xi\leq70$, $0℃\leq t\leq100℃$, $0.05m/s\leq w\leq2m/s$, $5mm\leq d\leq200mm$, $0.5m\leq l\leq10m$. The regression coefficients were listed in Table 1 below:

Table. 1 Regression coefficients of inner surface heat transfer coefficient calculation equation

n	An	Bn	Cn	Dn
0	5.325E1	2.133E1	1.188E1	5.030E1
1	-4.68E-1	8.958E-1	3.4674	4.233
2	-3.476E-3	-3.991E-2	-3.126E-1	-3.801E-1
3	7.484E-5	1.385E-3	9.456E-3	1.134E-2
4	-5.911E-7	-1.538E-5	-1.045E-4	-1.271E-4
5	1.797E-9	5.461E-8	3.876E-7	4.811E-7

The formula has a high calculation accuracy, which can satisfy the design requirement, especially in the range of $0.4<\xi\leq0.65$, the average relative deviation is 2.41%. Table 2 gives the deviation data for individual data.

Table. 2 Error data of inner surface heat transfer coefficient of solution heat exchanger.

Concentration/ (%)	Temperature/(℃)	Velocity of flow/(m /s)	Inner diameter of tube/(mm)	Length of tube/(m)	Inner surface heat transfer coefficient		
					Calculated value/(W/(m²· K))	Measured value/(W/(m²· K))	Relative error/ (%)
0	0	0.2	5	0.5	930.70	944.44	1.45
10	10	0.3	10	0.5	1272.25	1240.74	2.54
20	20	0.4	20	1	1477.12	1370.37	7.79
30	30	0.6	40	1	1848.20	1777.78	3.96
40	40	0.8	60	2	1980.02	1851.85	6.92
50	50	1.0	80	2	1980.37	1833.33	8.02
60	60	1.2	100	5	1600.56	1481.48	8.04
70	70	1.4	150	5	885.32	870.37	1.72

3. Dimensionalization of Heat Transfer Coefficient Formula

The formula of equation (1) is obtained as follows by the similarity principle and dimensional analysis:

$$Nu_{ex,i} = C\,\mathrm{Re}^a\,\mathrm{Pr}^b\left(\frac{d}{l}\right)^c Rx^d \quad (2)$$

Re: characterization of the fluid inertia force and viscous force ratio;
Pr : characterization of the momentum diffusion and thermal diffusion ratio;
Rx: characterization of the concentration ratio of the two working fluids in the binary solution;
Nu: characterization of the dimensionless temperature gradient of the fluid;

The Nusselt number of the inner surface heat transfer process can be calculated by linear regression using MATLAB software. The fitting results are shown below:

$$Nu_{ex,i} = 0.020\,\mathrm{Re}^{0.800}\,\mathrm{Pr}^{0.244}\left(\frac{d}{l}\right)^{0.056} Rx^{0.375} \tag{3}$$

4. Conclusion

The heat transfer coefficient of the solution heat exchanger is obtained through the analysis of the original data, and the calculation formula has a high precision. It provides an efficient and practical tool for accurate design of lithium bromide (LiBr) absorption heat pump. The correlation is also important to the further study of the thermodynamic calculation accuracy of absorber and generator.

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