The influence of interaction surface structure and irrigation scheme on heat and mass transfer in direct contact condenser

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SUMMARY

The contact condensation of saturated steam on liquid spray has been studied. The mathematical model of heat and mass transfer processes between dispersed liquid and steam has been usin one-parameter drop distribution function has been worked out. The rational degree of liquid dispersing and optimal irrigation scheme has been defined.

In recent years the great interest has been paid to direct contact condensation of saturated steam on the liquid spray. The reason for this interest lies in wide possibilities of application of contact condenser in power engineering due to its advantages. However, there is still a lack of information concerning the influence of regime parameters on heat and mass transfer intensity.

The mathematical model for discribing the condensation of vapour on a spray of liquid drops is developed in this work. The process of condensation of vapour on a spray of drops is very complex. It can be assumed that the degree of spray dispersity have a great influence on the condensation process intensity. Contact surface area between steam and liquid phase increases when drops became smaller. It leads to heat absorbtion increase by drops. On the other hand the temperature of small drops almoust immediately becames equal to the temperature of saturated steam. Therefore, the small drops strike off the further heat exchange. Moreover, the less the drop size the less a time of its stay in operation zone of condenser. Large drops have a high heat lag so they need more time to warm up. Therefore, cooling effect of interaction between liquid and steam realises incompletely.

Besides when designing the direct contact condenser the irrigation scheme is also very significant. The parallel, oposite or crossing irrigation scheme in regarding the steam direction can be used.

It can be interesting to find out the rational degree of liquid dispersing and the optimal scheme of irrigation system.

The mathematical model of heat and mass exchange process between dispersed liquid and saturated steam in contact condenser includes the following principal equations.

The motion equation of single drop in moving steam-gas environment:

$$m_i dW_{di} / d\tau = m_i g - c_d \psi(d) \rho_a f_{di} |U| U / 2 \qquad (1)$$

where m_i - mass of drop,

$U = W_v - W_d$ - relative drop velocity,

W_v - vapour velocity,

W_d - drop velocity,

f_{di} - drop middle area,

$\psi(d)$ - drop deformation function,

g - acceleration due to gravity.

Index i means a number of dissection of distribution function which is discribed by equation

$$V(D_d) = \frac{2}{3\pi}\bar{\alpha}^4 D_d^3 K_1(\bar{\alpha}D_d) \tag{2}$$

where $\bar{\alpha}$ - parameter difined by experiment,

D_d - drop diameter,

V - drop volume,

K - Bessel's function.

Heat balance equation between vapour, drops, header walls and liquid film which flows down by gravity from the vertical surfaces is

$$Q_j = M_{v0}\left(i_{\chi(j-1)} - i_{\chi j}\right) = Q_{dj} + Q_{fj} + Q_{hj} \tag{3}$$

where M_{v0} - vapour flow rate

$i_{\chi(j-1)} - i_{\chi j}$ - vapour entalphy diffirence

Index j means a number of interval of condenser volume division into horizontal zone.

Heat quantity absorbed by drop during the travell from the nozzle outlet to screen is

$$Q_{dj} = \sum_{\eta}\sum_{i} m_i c_{pd} \frac{\Delta t_{d\eta}}{\Delta\tau}$$

Index η means the interval number of time integration of equation (1).

Heat absorbed by liquid film which drains off by gravity from vertical wall is

$$Q_{fj} = M_{fj} c_{pl}\left(t_j - t_{j0}\right) = \alpha_j f_{fj}\left(t_s - \bar{t}_{fj}\right) \tag{4}$$

where M_{fj} - mass of liquid film

f_{fj} - surface area of liquid film

$\bar{t}_{fj}$ - average temperature of liquid film

Heat exchange coefficient α_j can be definded from empirical dependance

$$\alpha_j = Nu\lambda_l / d_{ej},$$
$$Nu = 2.7\, Re_l^{0.6}\, Pr_l^{0.45}\, K^{0.11} We_v^{0.4} (d_e / l)$$

where λ_l - liquid heat conductivity,

d_{ej} - equivalent diameter of liquid film,

Re_l - Reynold's number of liquid,

We_v - Weber's number of steam,

K - phase transformation coefficient,

l - lengs of liquid film.

Our previous investigation has shown that the Biot number ranges from 0.8 to 1.5 for all ranges of drops and heat exchange parameters. Drop deformation coefficient ranges from 1.005 to 1.05. So it have been assumed that drops behave as rigid sphere. To calculate the drop volume average temperature the heat conductivity equation with first type boundary conditions is used:

$$\bar{\theta}_{sh} = \frac{\bar{T}_d(\tau) - T_v}{T_{d0} - T_v} = \sum_{n=1}^{\infty} B_n'' \exp\left(-\mu_n^2 Fo\right),$$

$$B_n'' = 6 / \mu_n^2; \qquad \mu_n = n\pi; \qquad Fo = a\tau_i / \left(D_{di} / 2\right)^2$$

where T_{d0}, $\bar{T}_d(\tau)$ - initial and terminal temperatures of i-range drop respectively.

The influence of noncondensables is considered by experimental dependance:

$$\alpha_m / \alpha_0 = 0.168(\varepsilon k)^{-0.1} (l / d_e)^{0.33}$$

α_0, α_m - heat exchange coefficents for pure vapour and vapour from vapour-gas mixture respectively,

k - condensation ratio

ε - air concentration in vapour-gas mixture

Heat adsorbed by header wall is

$$Q_{hj} = f_j \alpha_h (t_s - t_h)$$

where f_j - wall surface area,

t_h - wall temperature.

Heat exchange coefficient during condensation on a verticat wall is

$$\alpha_h = \left(\frac{\gamma^2 r \lambda^3}{4\mu x (t_s - t_h)} \right)^{1/4}$$

where γ, λ, μ - density, heat conductivity and viscosity of condensate,

r- heat of vaporisation,

x- distance fron the begining of film flow.

This mathematical model was solved numerically.

It finds out that the using of splash plate spray nozzles with cup reflector which provides spray spectrum with modal drop diameters ranged from 1.5 to 3 mm is the most rational from the point of reliability of spray system operation and construction simplicity.

Minimal over all dimensions of condenser can be provided in case when on the steam exit the crossing irrigation scheme is realised. The water flow rate is 2/3 of common flow rate in the upper part of condenser. The opposite irrigation scheme is used in the low part of condenser where the dryness factor is 0.3-0.4. The water flow rate is 1/3 of common flow rate in that part.

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