Enhancement of Dropwise Condensation Heat Transfer of Steam by Oleic Acid

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ABSTRACT

This study compares the heat transfer coefficients for film and dropwise condensation of steam. Copper tube was coated with oleic acid to promote dropwise condensation of steam rather than a continuous film. Excellent dropwise condensation was observed when the cooling surface was coated with oleic acid, and this helps to enhance droplet formation without wetting the surface. The experimental results show that the value of overall heat transfer coefficient is 50000 W/m²K in dropwise and 125000 W/m²K in filmwise condensation. Thus, the overall heat transfer coefficients during dropwise condensation are approximately four times greater than those during filmwise condensation at the same surface subcooling degrees.

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The simplest form of equation which represents these forms of heat transfer is written as:

\[ Q = UA\Delta T \]  \hspace{1cm} (1)

Where \( U \) is the proportionality constant known as overall heat transfer coefficient (W/m²K).

The steam condenses on the outside of the tube, through which water is passed at various velocities. If the transfer area on each side of the tube is approximately the same then the overall and film transfer coefficients is given as:

\[ \frac{1}{U} = \frac{1}{h_o} + \frac{x_w}{K_w} + R_{i} + \frac{1}{h_f} \]  \hspace{1cm} (2)

For conditions of turbulent flow the transfer coefficient for the water side \( h_f = \alpha u^{0.8} \), where \( u \) is the fluid velocity, the scale resistance \( R_{i} \) is constant, the coefficient of the condensate film \( h_o \) is almost independent of the water velocity. \( K_w \) and \( x_w \) are the thermal conductivity and thickness of the wall (we assume that the wall resistance is negligible) equation (3) reduces to:

\[ \frac{1}{U} = \text{(constant)} + \frac{1}{\alpha u^{0.8}} \]  \hspace{1cm} (4)

A plot of \( 1/U \) against \( 1/u^{0.8} \) gives a straight line with slope of \( 1/\alpha \) and intercept equals to the value of the constant, \( \alpha \) is the film coefficient \( h_f \) for unit water velocity \( (h_o = \alpha) \). For a clean tube \( R_{i} = 0 \), thus the heat transfer coefficient \( h_o \) can be found directly from the intercept[4].

\section*{Results}

The results shows variations of overall heat transfer coefficient as a function of water flow rate at atmospheric pressure. The heat flux and overall heat transfer coefficient decrease as the water flow rate decrease. Wilson plot shown in Figures 2 and 3 below provides the means of determining the individual film heat transfer coefficient for films and dropwise condensation at atmospheric pressure.

\begin{figure}[h]
\centering
\includegraphics[width=0.4	extwidth]{figure1.png}
\caption{Schematic diagram of experiment set-up}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.4	extwidth]{figure2.png}
\caption{Plot of \( \frac{1}{U} \) vs \( \frac{1}{u^{0.8}} \) (filmwise condensation)}
\end{figure}

Heat transfer coefficient \( h_o \) was calculated from the intercept, i.e.,

\[ \frac{1}{h_o} = 8 \times 10^{3}, h_o = 12500 \text{W/m}^2\text{K} \]

\begin{figure}[h]
\centering
\includegraphics[width=0.4	extwidth]{figure3.png}
\caption{Plot of \( \frac{1}{U} \) vs \( \frac{1}{u^{0.8}} \) (dropwise condensation)}
\end{figure}

Heat transfer coefficient was calculated from the intercept, i.e.,

\[ \frac{1}{h_o} = 2 \times 10^{3}, h_o = 50000 \text{W/m}^2\text{K} \]

\section*{Discussion}

The value of heat transfer coefficient is 50000 W/m²K in dropwise and 12500W/m²K in filmwise condensation. The temperature driving force \( \Delta T \), was significantly lower in dropwise compared to filmwise condensation at the same value of heat flux; this may be due to the presence of numerous microscopic sized droplets on the hydrophobic surfaces in dropwise which do not exist in filmwise condensation[2].

In similar experiments, steady dropwise condensation of steam was observed on a plate coated with polyethylenefluoroethylene (PTFE), the condensation heat transfer was increased by 30 to 47 times at the same surface subcooling degrees compared to filmwise condensation[5]. Hydrophobic coatings created through self-assembled monolayer of n-octadecyl mercaptan on copper alloy surfaces increased the condensation heat transfer rate by about eight times when compared with film condensation[2]. The overall heat transfer coefficient during dropwise condensation of ethyl alcohol, methyl alcohol, and acetone on a PTFE-coated condensing surface were approximately 30 percent for ethyl alcohol, 45 percent greater for methyl alcohol, and 65 percent for acetone than those during filmwise condensation on a bare iron tube[1].

Marto et al. and Holden et al. [6, 7] independently examined the effectiveness of several organic coatings to promote the dropwise condensation of steam. The results indicated that the steam dropwise condensation heat transfer coefficients for the
surfaces coated with organic films are 3-8 times larger than those during filmwise condensation value for bare surface. Similarly, [8] employed thin film of polyvinylidene chloride to promote dropwise condensation of steam; the condensation heat transfer coefficient was more than 20 times than that for film condensation on bare surface.

Conclusions

The effect of coating the condensing surface with oleic acid on the condensation heat transfer characteristics was studied. Excellent dropwise condensation was observed on the pipe coated with oleic acid, it enables condensation of the steam in drops without wetting the condensing surface. On the other hand, continuous stream lines were flowing during film condensation. The heat transfer coefficient during dropwise condensation was found to be four times higher than those during filmwise condensation.

References

1. C.E. Kirby, promotion of dropwise condensation of ethyl alcohol, methyl alcohol, and acetone by polytetrafluoroethylene, Nasa Tn D-6302 1971.