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Dropwise and filmwise condensation

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Abstract—.The paper reviews progress in dropwise condensation research from 1930 to the present. Particular attention is given to heat transfer measurements, theory, effect the presence of air in the condenser has on the heat flux and surface heat transfer coefficient.. This experiment would be used in any industry which is trying to increase the efficiency of heat transfer. Subsequently, more accurate measurements have shown good consistency and the theory of the dropwise and filmwise condensation have become better understood.. The balance of evidence suggests that dropwise condensation is a more effective method of heat transfer than filmwise condensation, and the presence of air insteam vapour significantly reduces the heat transfer..The paper contains the experimental steps invove in performning the experiment precautions and final result of the experiment. The exact reading and values of heat transfer coefficient in both type of condensation is still not fully understood.

Index Terms—Condenser, Dimension less numbers, Dropwise condensation,Filmwise condensation , Heat transfer coefficient , ,Water flow rate,Mass flow rate,Non condensing gases

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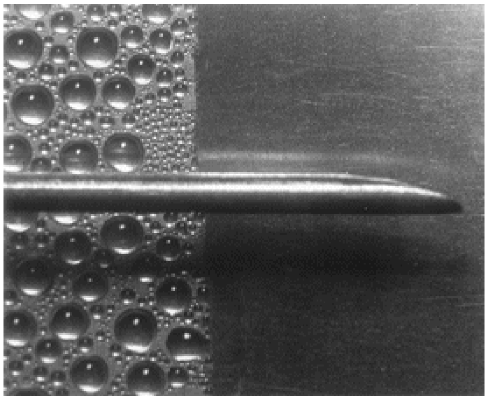
1 Introduction

T Proceedings Steam may be condense onto the surface in two distinct modes, known a “filmwise” & ” dropwise” For the same temperature difference between the steam & the surface, dropwise condensation is much more effective then filmwise condensation & for this reason the former is desirable although in practical plants it rarely occurs for prolonged periods**.** In filmwise condensation a laminar film of vapour is created upon a surface. This film can then flow downwards, increasing in thickness as additional vapour is picked up along the way .In dropwise condensation vapour droplets form at an acute angle to a surface .These droplets then flow downwards ,accumulating static droplets below them along the way. The second objective of this is to investigate the difference in heat flux between the two forms of condensation for the same set of conditions. Third objective is to investigate what effect the presence of air in the condenser has on the heat flux and surface heat transfer coefficient. This experiment would be used in any industry which is trying to increase the efficiency of heat transfer. An example of this is any vapour power cycle such as the Rankine cycle. By increasing the efficiency of the condenser, its operational pressure can be reduced and the overall efficiency of the cycle can be increased.

2 Condantion

2.1 Dropwise condensation

By specially treating the condensing surface the contact angle can be changed & the surface become ‘non – wettable’ .As the stream condenses ,a large number of generally spherical beads cover the surface. As the condensation proceeds ,the bead become larger, coalesce, and then strike downwards over the surface. The moving bead gathers all the static bead along its downward in its trail. The ‘bear’ surface offers very little resistance to the transfer of heat and very high heat fluxes therefore possible.Unfortunately, due to the nature of the material used in the construction of condensing heat exchangers, filmwise condensation is normal .(Although many bare metal surfaces are ‘non-wettable’ this not is true of the oxide film which quickly covers the bare material).



Dropwise and Filmwise condensation

2.3 Filmwise condensation

Unless specially treated, most materials are wettable as condensation occurs a film condensate spreads over the surface.The thickness of the film depends upon a numbers of factors, e.g. the rate of condensation ,the viscosity of the condensate and whether the surface is horizontal or vertical, etc.Fresh vapour condenses on to the outside of the film & heat is transfered by conduction through the film to the metal surface beneath. As the film thickness it flows downward & drips from the low points leaving the film intact & at an equilibrium thickness.The film of liquid is barrier to transfer of the heat and its resistance accounts for most of the difference between the effectiveness of filmwise and dropwise condensation.

2.4 Methods and Procedure

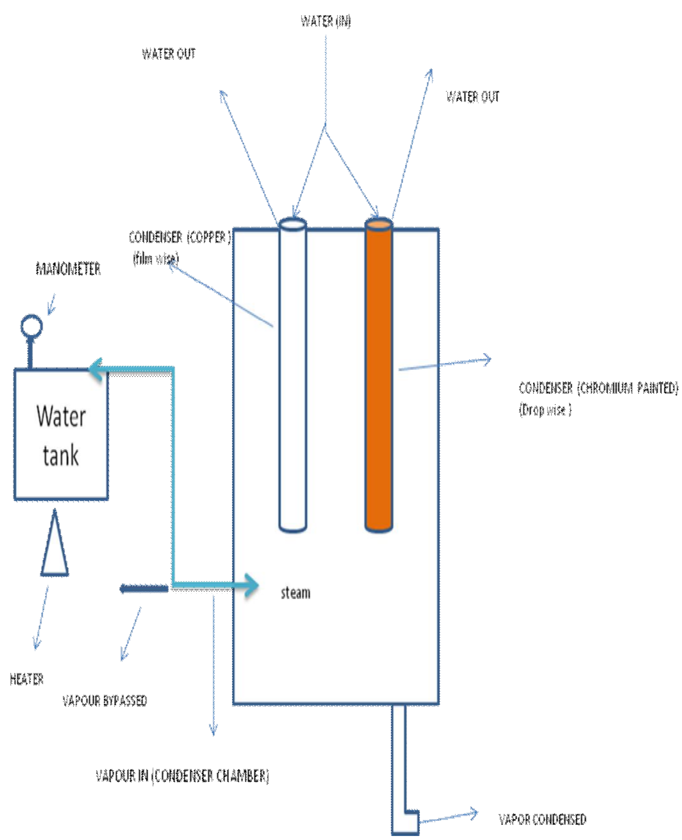
Fill up the 5 litre distilled water in main unite by opening the valve.After filling the water close the valve. Start water flow through one of the condensers which is to be tested and note down water flow rate in rotameter.Ensure that during measurement, water is flowing only through the condenser under test and second valve is closed.

Connect supply socket to mains and switch ON the heater switch

$1/u = 1/h_i + 1/h_o \times D/D_o$ kcal/hr-m^2-°C

Same procedure can be repeated for other condenser.Except for same exceptional cases overall heat transfer coefficient for dropwise condensation will be higher than that of filmwise condensation.

Result may vary from theory in some degree due to unavoidable heat losses.



The water level should be up to ¾ th of container.Do not start the heat supply unless water is fillked in test tube unit.Operate gently the sector switch of temperature indicator to read various temperature.Slowly generation will be start in stream generation of the unite and the stream rises to the test section, gets condensed on the tubes and fall down in the cylindrical space. Record the the temperature of painted condenser ,plane condenser ,water inlet to condenser and water out let to condenser.Depending upon the condenser dropwise and filmwise condensation can be visualized,If the water flow rate is low the steam pressure will rise in cylindrical region and pressure gauge will read the pressure. If the water flow rate is matched then condensation will occur at more or less atmospheric or upto 1 kg/cm^2 pressure.Observation like water flow temperature of painted condenser ,plane condenser ,water inlet to condenser and water out let to condenser.Depending upon the condenser dropwise and filmwise condensation can be visualized rates, pressure and noted down in the observation table at the end of each set.

Steam pressure kg/cm^2		0.65	0.60		0.50	
Water flow rate LPH		156	54.6		14.1	
Condenser under test		Filmwise	Filmwise		Dropwise	
Painted condenser outer surface	T_1	79.3	91.00	90.60		
Plane condenser outer surface	T_2	78.3	88.00	94.3		
Steam	T_3	125	124.1	124.4		
Water inlet to condenser	T_4	30	28.3	28.6		
Water outlet plane condenser	T_5	32.7	32.2	-		
Water outlet painted condenser	T_6	-	-	33.4		
Ambient	T_7	32	32	32		

Analysis Normally steam will not be pressurized. But if the pressure gauge reads some pressure then properties of steam should

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be taken at that pressure or otherwise atmospheric pressure will be taken.

We will first find the heat transfer coefficient inside the condenser under test.for this properties of water are taken at the bulk mean temperature of water e.g. $(T_{wi} + T_{wo})/2$ where T_{wi} and T_{wo} are water inlet & outlet temperature.

Following properties are required:
ρ_1 = density of water (kg/m³)
p_r = Prandtl number

Now calculation for Reynold'number
$R_{ed} = 4\,m/(\pi \times \rho_1 \times \mu_1 \times D_1)$

Where
Di =Inner diameter of condenser. = 1.75 cms
If this vale of R_{ed}=2100 then flow will be turbulent in pipe.

Now Nusselt number.

$$N_{ul} = 0.023(R_{ed})^{0.8}.(P_r)^{0.4}$$

And $h_i = N_{ul}.k/L$ kcal/hr.m³ (w/m²)

Now calculate the heat transfer coefficient on the outer surface of the condenser (h_o). For this properties of water taken at bulk mean temperature of condenser e.g.
$(T_S + T_W)/2$
Where T_s = Temperature of steam
T_W = Temperature of condenser wall
Properties needed are
K_2 = Thermal conductivity kcal/ hr-m °C (w/m- °C)
ϱ = density of water (kg/m³)
μ= Viscosity of condensate kgf-sec/m² (kg/m.s)
h_{fg} = Heat of evaporation kcal/kg. (540 Kcal/kg)

$$h_o = \{ (h_{fg} \times g \times \varrho^2{}_2 \times k_2{}^3)/((T_S - T_W) \times \mu \times L)\}^{0.25}$$

where g = acceleration due to gravity =9.8 m/sec² =1.27 × 10⁸ m/hr²
L = Length of condenser =160 mm

From this value overall heat transfer coefficient (U) can be calculated in

3 Sample Calculation

AREA

Outer diameter of heat transfer surface, d = 19 mm
Length of heat transfer surface,L = 175 mm
Heat transfer area π.d.L = $\pi.(19\times10^{-3}).(175\times10^{-3})$
= 0.010445 m²

Temperatures:

All temperatures are taken in
Steam temperature, T_∞ = 124.1
Condenser surface temperature,
Copper condenser, T_{cu} = 88.4
Chromium temperature,T_{cr} = 91.4

Flow Rate:

Flow rate = 455ml/30sec
= 0.0546 m³/hr
Rate of steam condensed = 780 ml/hr
= 3.12kg/hr
At temperature $= (T_s + T_{steam})/2$
= (124.1+88.4)/2
= 106.25
Pressure gauge = 0.5 kg/cm²
Density of steam condensed at
Temperature $(T_{in}+ T_{out})/2$ = 995.6 Kg/m³
Now parameters used,
H_{fg} = 533.3 kcal/kg
P = 954.3 kg/m³
μ = 274.4×10^{-6} N-s/m³
P_r = I.75
K = 0.5860 kcal/h-m-
= 276.3×10^{-6} N-s/m³
Heat flux = $U (T_\infty - T_s)$
Q = $UA (T_\infty - T_s)$

Over all heat transfer coefficient $= m_s \times h_{fg}/(A \times \Delta T)$

$$U = 3.12\times533.3/((0.010445\times(124.1-88.4))$$
= 4462.2 Kcal/h-m-

For filmwise condensation
$$h_o = 0.943\{(H_{FG} \times \varrho^2 \times g \times k^3)/((T_\infty - T_s) \times \mu \times L)\}^{0.25}$$

$$h=0.943\{(553.3\times(954.3)^2\times9.81\times(0.586)^3)/((124.1-88.40)\times276.3\times10^6\times0.175)\}^{0.25}$$

h_0 = 6304.209 kcal/h-m-

Calculation For hi:

$R_{ed} = 4 \times m_w/(\pi \times D_i \times \varrho_1 \times \mu_1) = v \times \varrho \times D/\mu$
m_w = 54.3kg/hr
volume flow rate
Q = 0.0546 m³/hr

velocity Q/A = 0.0546/(3600×0.000227)m/s
= 0.0668m/s

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$R_{ed} = 0.0668\times994.5\times0.017/(8.01\times10^{-6})$
$= 1410605$

$R_{ed}>2100$

$Nu = 0.023(R_{ed})^{0.8}\times(P_r)^{0.4}$

Here, $P_r = 5.204$ at $T_{avg} = (29 + 34)/2 = 31.5$

$Nu = 0.023(1410605)^{0.8}\times(5.204)^{0.4}$
$= 3696.469$

$h_i = Nu\times k/L$
$= 3696.469\times0.609/1.6$
$= 1360.76117$

$T_{steam} = 125$
$T_S = 78.3$
$T_{avg} = (125+78.3)/2$
$= 101.68$
$P_{gauge} = 0.6$ kg/cm^3
Density = 958.4 kg/m^3
$H_{fg} = 533.4$ kcal/kg
K = 0.5883 kcal/h-m-
$P_r = 1.75$

$H_o = 0.943\{(h_{fg}\times\rho^2\times g\times k^3)/((T_\infty - T_S)\times\mu\times L)\}^{0.25}$

$= 0.943\{(533.4\times(958.40)^2\times9.81\times(0.58830)^3/(125-78.30)\times282.4\times10^{-6})\}$
$= 5885.32$

Over all heat transfer coefficient

$Q = m_s\times h_{fg}$
$Q = 4.77$ kg/hr
$Q = UA(T_\infty - T_S)$
$U = m_s\times h_{fg}/A(T_\infty - T_S)$
$= 4.77\times5.33.4/(128-78.3)\times0.010445$
$= 5216$ kcal/h-m-

CALCULATION FOR DROPWISE CONDENSATION

Dropwise condensation

Heat transfer area = 0.010445 m^2

$T_{steam} = 118.3$
$T_{chromum} = 83.2$
$T_{w\ in} = 28.6$
$T_{w\ out} = 36.5$

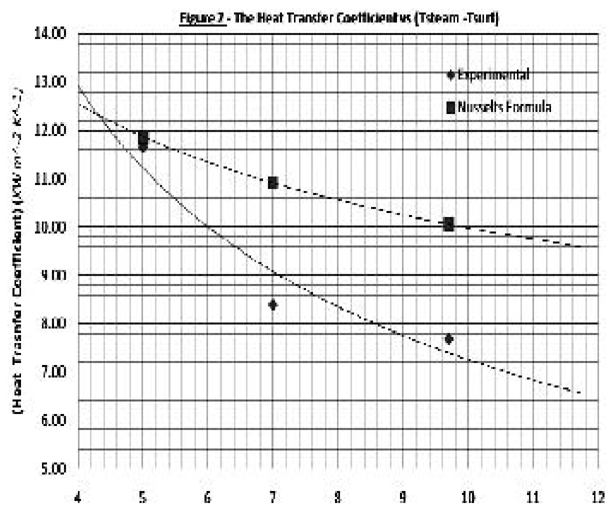
Pressure gauge 0.6kg/cm^2
Mass of steam condensed = m_s
Mass of coolded water = m_w
Mass flow rate of cooling water = 220 kg/hr

Steam condensation = 4.27 kg/hr
Where U is heat transfer coefficient

$Q = UA\Delta T$
$U = Q/A\Delta T$
$U = 4.27\times533.5/(0.010445\times(118.3-83.20))$
$U = 6213.65$ Kcal/hr

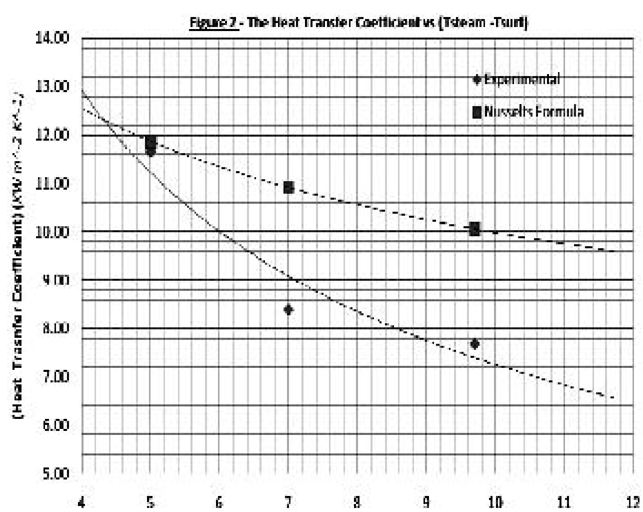
4 CONCLUSION

The final observation is confirmed in the Handbook of Phase Change (2) which quotes that at atmospheric pressure, the Heat Flux in dropwise condensation can be more than filmwise. This can be explained in terms of how the condensation forms on the



condenser.

The vapour drops in dropwise condensation are discrete and are continually formed and released which means that the surface of the condenser is alsocontinually exposed. In comparison, the film created in filmwise condensation always covers the surface of the



condenser (3). As a relatively poor conductor of heat, this film creates a thermal resistance which is the reason why the value for Heat Flux is lower for filmwise in comparison to dropwise condensation (3)

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To check the accuracy of the experiment, the values for the Heat Transfer Coefficient in the filmwise condenser were compared tothe values which are obtained theoretically using the Nusselt equation (3). Figure 2 shows that the results derived experimentally were of a lower value than of those derived theoretically.

One explanation for this is the presence of non-condensable gases in the steam vapour (1).It shows that for a certaintemperature difference, the Heat Flux for a condenser using steammixed with 5% of air is significantly smaller than pure steam, and the magnitude of this difference increases with temperaturedifference. In the case of Heat Transfer Coefficients, the value for both steam and steam with air approaches zero, but when the steamis mixed with air it is consistently low.

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