surface tension of the condensate and the mode of condensation of the materials studied by Mizushina *et al.* and by Topper and Baer are listed. It is noted that only when the surface tension of the condensate is well above the 18·5 dyn/cm critical surface tension for P.T.F.E. (which may be expected to be only slightly temperature dependent [5]) does dropwise condensation occur.

The use of adsorbed films of fluorocarbons would greatly extend the regions of interest for drop-wise condensation. In addition the adsorbed film would offer negligible additional thermal resistance. One major difficulty to be overcome is that the adsorbed layers are hydrophilic so that polar compounds will remove them; however useful heat-transfer data could be readily obtained for aromatic hydrocarbons, the higher aliphatic hydrocarbons and similar compounds.

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THE PREDICTION OF THE MECHANISM OF CONDENSATION ON CONDENSER TUBES COATED WITH TETRAFLUOROETHYLENE

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NOMENCLATURE

M = mass L = length T = time t = temperature

T, temperature [t];
θ, contact angle;
γ, surface free energy $[ML^{-2}T^{-2}]$;
γ_c, critical surface tension $[MT^{-2}]$;
π_e, equilibrium film pressure $[ML^{-2}]$;
S, spreading coefficient $[ML^{-2}T^{-2}]$.

Subscripts
L, liquid;
S, solid;
SL, solid–liquid;
V, vapour.

In a recent communication Mizushina *et al.* [1] reported data on condensation of steam and organic vapours on tubes coated with tetrafluoroethylene (T.F.E.). Previous workers [2, 3, 4] have observed that dropwise condensation of steam can be achieved on these coatings resulting in a higher heat-transfer coefficient. Topper and Baer [4] also reported dropwise condensation of ethylene glycol, nitrobenzene and aniline on this surface but noted that benzene did not exhibit this phenomenon and that film condensation occurred with a resulting lower heat-transfer coefficient. Mizushina also observed film condensation of carbon tetrachloride and methanol vapours on surfaces coated with T.F.E. These experimental findings leave some doubt on the mode of condensation exhibited by a particular system. The mechanism of condensation can however be predicted from the surface properties of the solid and liquid phases.

The conditions governing the equilibrium of a liquid droplet on a solid surface are expressed by Young's equation [5]:

$$\gamma_S - \gamma_{SL} = \gamma_L \cos\theta + \pi_e \tag{1}$$

where γ_S, γ_L and γ_{SL} are the surface free energies of the film free solid, liquid and solid–liquid interface respectively. π_e is the equilibrium film pressure and θ the contact angle. The condition for a liquid to spread on the surface is described by the spreading coefficient S defined by:

$$S = \gamma_S - \gamma_{SL} - \gamma_L. \tag{2}$$

By combining equations (1) and (2):

$$S = \pi_e + \gamma_L(\cos\theta - 1) \tag{3}$$

Dropwise condensation occurs when the surface is not wetted by the liquid, that is when S is less than zero. These conditions may be fulfilled for many liquids on low energy surfaces such as T.F.E. Furthermore Fox and Zisman [6] have shown that the value of the equilibrium film pressure is negligible for pure liquids on low energy solid surfaces. Equation (3) then reduces to

$$S = \gamma_L(\cos\theta - 1). \tag{4}$$

The condition for a liquid to wet a T.F.E. surface can now be described in terms of the surface free energy of the liquid or surface tension of the liquid at constant temperature and the contact angle of the liquid on the solid. Complete wetting of the surface will take place when the contact angle is zero. Fox and Zisman showed that, for a series of liquids at 20°C, this condition was satisfied when the surface free energy of the liquid was 18 dyn/cm. This value is defined as the critical surface tension γ_c below which spreading occurs. If this is now applied to condensation of vapour on a surface the effect of temperature and pressure on the spreading coefficient must be considered. The situation may be further complicated by the presence of non-condensible gases and by the roughness of the surface which effects the contact angle.

The effect of temperature on the contact angle under heat-transfer conditions has already been described by the authors [7].

The results of Topper and Baer and Mizushina are summarized in Table 1. The surface tensions of the liquids at the condensation temperatures have been calculated from the surface tensions of the pure liquids at 0°C and the temperature coefficient of surface tension ($\partial\gamma/\partial T$) [8]. The observations on ethylene glycol, nitrobenzene and aniline were recorded at temperatures below the normal boiling points of these liquids and therefore must have been carried out under reduced pressure. The pressures corresponding to the operating temperatures are shown in Table 1. Reducing the pressure of the system will in general increase the surface tension of a liquid [5], thus the actual surface tension of these liquids may be greater than the calculated values. It can be seen that the calculated values of surface tensions of all the liquids exhibiting dropwise condensation are much greater than the critical surface tension of T.F.E., γ_c, whereas values of γ for carbon tetrachloride, benzene and methanol are very close to γ_c. It is also evident that γ_c is not effected appreciably by temperature.

From this reasoning we suggest that dropwise condensation of pure vapours of benzene, carbon tetrachloride and methanol could be achieved on T.F.E. under reduced pressure conditions and that by observing the transition from a dropwise to film mechanism the effect of operating conditions on the critical surface tension could be assessed. In this way the mechanism of condensation of pure vapours on low energy surfaces can be predicted.

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Table 1. Condensation on tetrafluoroethylene-coated surfaces

Substance	Mechanism of condensation	Reference	Normal boiling point (°C)	Measurement temperature T (°C)	Pressure (mm Hg)	$\gamma_{0°C}$ (dyn/cm)	$\partial\gamma/\partial T$	γ_T
ethylene glycol	dropwise	[4]	197·4	120	43·0	49·34	−0·0935	38·14
nitrobenzene	dropwise	[4]	210	110	33·0	45·83	−0·114	33·33
aniline	dropwise	[4]	184·4	110	68·0	45·30	−0·106	33·75
water	dropwise	[1–4]	100	100	760	75·87	−0·1511	60·76
CCl_4	film	[1]	76·8	76·8	760	29·35	−0·120	20·15
benzene	film	[4]	80·1	80·0	760	31·7	−0·140	20·50
methanol	film	[1]	64·7	64·7	760	23·5	−0·071	18·90

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RADIATING, CONVECTING AND CONDUCTING FINS: NUMERICAL AND LINEARIZED SOLUTIONS

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NOMENCLATURE

A, area of fin cross section;
C, circumference of fin cross section;
h, heat-transfer coefficient;
k, thermal conductivity of fin;
L, fin length;
N_{cv}, convection parameter, equation (1a);
N_r, radiation parameter, equation (1a);
Q, rate of heat loss from fin;
T, temperature;
X, dimensionless coordinate, x/L;
x, coordinate measuring axial distance along fin ($x = 0$ is fin base).

Greek symbols
ϵ, emittance of fin surface;
η, fin effectiveness, equation (2);
θ, temperature ratio, T/T_b;
σ, Stefan–Boltzmann constant.

Subscripts
b, fin base;
∞, fluid bulk.

Superscript
$*$, effective radiation environment.

INTRODUCTION

The purpose of this note is to provide representative results for one-dimensional heat conduction in fins of axially unchanging cross section, the surface heat transfer involving both convection and radiation. The governing energy equation is

$$d^2\theta/dX^2 = N_r(\theta^4 - \theta^{*4}) + N_{cv}(\theta - \theta_\infty) \qquad (1)$$

$$\theta = \frac{T}{T_b}, \quad X = \frac{x}{L}, \quad N_r = \frac{\epsilon\sigma T_b^3 CL^2}{kA}, \quad N_{cv} = \frac{hCL^2}{kA},$$

$$\theta^* = \frac{T^*}{T_b}, \quad \theta_\infty = \frac{T_\infty}{T_b} \qquad (1a)$$

in which T_b, T_∞, and T^* are, respectively, the temperatures at the fin base, in the adjacent fluid, and of the effective radiation environment.‡ The area and circumference of the cross section are A and C; while L is the length of the fin. Equation (1) is to be solved subject to the boundary conditions $\theta(0) = 1$ and $(d\theta/dX)_1 = 0$, and for specified values of the four independent parameters N_r, N_{cv}, θ^*, and θ_∞.

In addition to direct numerical solutions, linearized

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‡ The absorbed radiant energy per unit time and area is $\epsilon\sigma T^{*4}$.