

MAXIMUM AEROSOL DENSITIES FROM EVAPORATION- CONDENSATION PROCESSES

C. F. CLEMENT and I. J. FORD

Theoretical Physics Division, UKAEA Harwell Laboratory, Oxon OX11 0RA, U.K.

(Received 10 May 1988; and in final form 20 October 1988)

Abstract—The coupled equations of heat and mass transfer are used to develop a model of aerosol generation in fluid flow over liquid surfaces. Maximum aerosol densities achieved in turbulent flow of an initially saturated gas/vapour mixture along a heated or cooled pipe are calculated for water-vapour/air and for sodium-vapour/argon. The model is also applied to flows near the heated surface in free convective situations. An analysis of an experiment in which sodium aerosols were generated in a cavity over a hot sodium pool indicates that the droplets which formed grew by passing many times through the boundary layer over the pool.

NOMENCLATURE

- A Cross-sectional area of pipe
- c_s Saturated vapour concentration
- c_p Specific heat at constant pressure
- \bar{c}_p Mean specific heat of mixture
- Cn_s Surface condensation number
- dS Element of surface area
- dV Volume element
- D Vapour-gas diffusivity
- h Specific enthalpy
- j_a Diffusive aerosol current relative to gas
- j_v Diffusive vapour current relative to gas
- k Thermal conductivity of vapour/gas mixture
- l Perimeter of pipe
- L Latent heat of vaporization
- \mathcal{L} Loading
- \dot{m}_v Aerosol growth rate per unit volume
- n Outward normal from surface
- N Aerosol number density
- q Conductive heat current
- \bar{R} Mean radius of aerosol droplets
- S Saturation
- t Time
- T Temperature of bulk flow
- T_r Roof temperature of cover gas space
- T_s Temperature of sodium pool
- v Velocity
- x Distance normal to wall
- z Distance along pipe
- α Dimensionless parameter [equation (33)]
- δ_a Dimensionless ratio [equation (29)]
- ε Temperature difference between rising and falling currents in the cover gas space
- λ_a Dimensionless ratio [equation (28)]
- ξ Heat transfer quantity [equation (41)]
- ρ Total density

Subscripts

- a Pertaining to aerosol
- e Pertaining to equilibrium
- g Pertaining to gas
- v Pertaining to vapour
- w Pertaining to wall

Superscript

Derivative with respect to T

1. INTRODUCTION

There are two main areas of nuclear power technology where an understanding of aerosol physics can contribute. Firstly, in the design of the fast reactor cover gas space, where a sodium aerosol can develop, and secondly for studying the consequences of a release of radioactive material as aerosol in a hypothetical accident. Sodium aerosol in the cover gas space can affect the heat transfer properties of the cavity and can freeze in deposits on the roof. It is important to understand these phenomena, not least for reasons of safety. As for accident studies the interest lies in the processes of formation and removal of possibly dangerous suspended particles in a reactor containment atmosphere.

In practical cases the formation and growth of aerosols is complicated, although the basic physics is clear. The complications arise from the coupling together of several distinct processes: fluid dynamics, heat transfer and droplet growth. Fluid flow has an influence upon heat dissipation, which in turn is linked with mass transfer and aerosol growth dynamics. These latter processes can affect the characteristics of the flow, especially in cases of free convection. In this paper we simplify the problem by imposing a flow. We then show how maximum aerosol densities resulting from heat and mass transfer into or out of the flow can be calculated.

Much work has been done on the relevance to aerosol physics of the coupling between heat and mass transfer (Clement, 1985). There have, however, been few experiments carried out expressly to test these predictions. An exception is a study currently being performed at Harwell which is concerned with the behaviour of aerosol in a turbulent flow along a vertical pipe with cooled walls. This is a situation where to a first approximation the fluid flow is not coupled to the aerosol physics, and can be taken to be a well-mixed turbulent flow (for high enough Reynolds number) in the bulk, and a boundary layer at the wall through which heat and mass pass out of the bulk flow. The physics of the system, and that for the analogous heating case in which heat and mass pass into the flow are shown in Fig. 1. In the next section, we develop a model to describe how aerosol density changes in the flow are related to the temperature changes. In Section 3 we perform some example calculations for aerosols formed by heating and cooling water-vapour/air and sodium-vapour/argon mixtures. The results are discussed in Section 4. In Section 5 we apply the model to free flow over an open pool in a convective situation. Finally, in Section 6, we give our conclusions on the results obtained.

2. THE MODEL

The basic conservation equations for the separate phases of the three component vapour-gas-aerosol system and the total enthalpy are:

$$\frac{\partial \rho_g}{\partial t} + \nabla \cdot (\rho_g \mathbf{v}_g) = 0, \quad (1)$$

$$\frac{\partial \rho_v}{\partial t} + \nabla \cdot (\rho_v \mathbf{v}_g) + \nabla \cdot \mathbf{j}_s = -\dot{m}_v, \quad (2)$$

$$\frac{\partial \rho_a}{\partial t} + \nabla \cdot (\rho_a \mathbf{v}_g) + \nabla \cdot \mathbf{j}_a = \dot{m}_v, \quad (3)$$

$$\frac{\partial}{\partial t} (\rho_g h_g + \rho_v h_v + \rho_a h_a) + \nabla \cdot (\mathbf{q} + \rho_g h_g \mathbf{v}_g + \rho_v h_v \mathbf{v}_v + \rho_a h_a \mathbf{v}_a) = 0. \quad (4)$$

The subscripts g , v , and a of the density ρ , the velocity \mathbf{v} , and the specific enthalpy h , refer to the gas, vapour, and aerosol respectively. The aerosol growth rate, or mass transfer rate per unit volume from the vapour to the aerosol is \dot{m}_v , and the currents \mathbf{j}_s , \mathbf{j}_a and \mathbf{q} are defined below.

In accordance with common practice in fluid problems, any sources to the enthalpy from friction have been neglected in equation (4). The equation then applies to pipe flow even

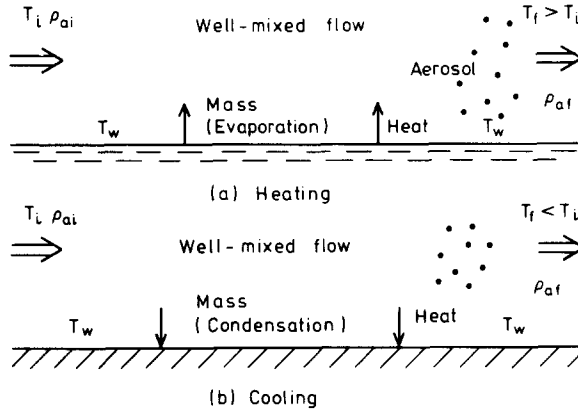


Fig. 1. Changes in the total aerosol density from ρ_{ai} to ρ_{af} produced by a well-mixed flow being (a) heated by a hot pool and (b) cooled at a wall.

when the pressure is changing moderately, the energy from this going into changes in the bulk velocity, v .

In equation (2), the vapour current has been written as

$$\rho_v v_v = \rho_v v_g + j_s, \tag{5}$$

where j_s is the vapour current relative to the gas.

Similarly, the aerosol current is written as

$$\rho_a v_a = \rho_a v_g + j_a, \tag{6}$$

where j_a is the aerosol current relative to the gas.

Finally, the conductive heat current is

$$q = -k \nabla T. \tag{7}$$

Consider the steady state flow through a pipe of cross-sectional area A . The time derivatives vanish in equations (1)–(4) and the equations can be integrated over a volume element of length dz along the flow, obtaining, for example

$$\int \nabla \cdot (\rho_g v_g) dV = \int dS \rho_g v_g \cdot n = dz \frac{d}{dz} (\rho_g v_g A), \tag{8}$$

where the outward normal n is taken to be in the gas flow direction in which there is a uniform velocity v_g . The equations are averaged over possible realizations of the flow which is taken to be turbulent. It is assumed that the streamwise turbulent fluctuations in flow velocity are much smaller than the mean velocity along the pipe, so that the contribution of fluctuations to the integrals can be neglected.

It is assumed that for a turbulent flow in the pipe the densities etc. within the bulk flow are constant across the cross-section, outside the boundary layers. Only the contribution of the vapour current against the wall is important, i.e.

$$\int j_s \cdot dS = lj_s dz, \tag{9}$$

where l is the perimeter of the area A and j_s is the magnitude of j_s . A positive j_s then indicates a loss of vapour to the wall and condensation. Since the vapour current j_s is only required at the wall, the effects of turbulent transport are irrelevant and j_s is given by (Clement, 1985)

$$j_s = -D \left(\nabla \rho_v - \frac{\rho_v}{\rho_g} \nabla \rho_g \right), \tag{10}$$

where D is the vapour-gas molecular diffusivity.

Under these particular conditions, equations (1)–(3) become

$$\frac{d}{dz}(\rho_g v_g A) = 0, \quad (11)$$

$$\frac{d}{dz}(\rho_v v_g A) = -lj_s - A\dot{m}_v, \quad (12)$$

$$\frac{d}{dz}(\rho_a v_g A) = -lj_a + A\dot{m}_v. \quad (13)$$

Likewise the enthalpy equation (4) becomes

$$\frac{d}{dz}(\rho_g h_g v_g A + \rho_v h_v v_g A + \rho_a h_a v_g A) = -lh_{vw}j_s - lh_{aw}j_a - lq, \quad (14)$$

where the subscript *w* denotes wall value.

The enthalpies are functions of temperature and pressure and if the temperature is changing along the tube, then for the flow conditions considered here

$$\frac{dh_g}{dz} = c_{pg} \frac{dT}{dz}, \quad (15)$$

etc., where c_{pg} is the specific heat at constant pressure, and T is the bulk flow temperature.

Using equations (11)–(13), equation (14) can be rewritten as

$$\rho \bar{c}_p v_g A \frac{dT}{dz} = lj_s(h_v - h_{vw}) + lj_a(h_a - h_{aw}) + A\dot{m}_v(h_v - h_a) - lq, \quad (16)$$

where the mean specific heat \bar{c}_p is given by

$$\rho \bar{c}_p = \rho_g c_{pg} + \rho_v c_{pv} + \rho_a c_{pa}. \quad (17)$$

The first two terms on the right-hand side of equation (16) are correction terms arising from any change in temperature of the vapour or aerosol in going from the bulk flow to the wall. They will generally be small in comparison to the conductive flux (fourth term) and the aerosol condensation term (third term), which is specified by the latent heat of vaporization

$$L(T) = h_v - h_a. \quad (18)$$

Using the definitions of h , etc., equation (16) can be rewritten as

$$\rho \bar{c}_p v_g A \frac{dT}{dz} = AL\dot{m}_v - lq + l(T - T_w)(c_{pv}j_s + c_{pa}j_a), \quad (19)$$

where T_w is the wall temperature.

The heat current at the wall can be related to the mass current using a surface condensation number (Clement, 1985)

$$Cn_s = q/(L(T_w)j_s). \quad (20)$$

From equation (11), the rate of change of ρ_g is related to that of Av_g by

$$\frac{d}{dz}(Av_g) = -v_g A \frac{1}{\rho_g} \frac{d\rho_g}{dz}, \quad (21)$$

and so equations (12) and (13) reduce to

$$v_g A \left(\frac{d\rho_v}{dz} - \frac{\rho_v}{\rho_g} \frac{d\rho_g}{dz} \right) = -lj_s - A\dot{m}_v, \quad (22)$$

$$v_g A \left(\frac{d\rho_a}{dz} - \frac{\rho_a}{\rho_g} \frac{d\rho_g}{dz} \right) = -lj_a + A\dot{m}_v. \quad (23)$$

Next \dot{m}_v can be eliminated between equations (22) and (23) and between equations (19) and (22) to obtain

$$v_g A \left[\frac{d}{dz} (\rho_v + \rho_a) - \frac{(\rho_v + \rho_a) d\rho_g}{\rho_g dz} \right] = -l(j_s + j_a), \quad (24)$$

and

$$\begin{aligned} v_g A \left[L(T) \frac{d\rho_v}{dz} + \rho \bar{c}_p \frac{dT}{dz} - L(T) \frac{\rho_v d\rho_g}{\rho_g dz} \right] &= -lL(T_w) Cn_s j_s - lL(T) j_s + l(T - T_w)(c_{pv} j_s + c_{pa} j_a) \\ &= -lL(T_w) j_s (1 + Cn_s) + l(T - T_w) c_{pa} (j_a + j_s), \end{aligned} \quad (25)$$

where equation (20) has been used and also the relation between the latent heats at different temperatures:

$$L(T) - L(T_w) = (c_{pv} - c_{pa})(T - T_w). \quad (26)$$

Finally, the ratio of equation (24) to (25) provides an expression for the rates of change along the path:

$$\begin{aligned} L(T_w) [1 + Cn_s - \delta_a] \frac{d}{dz} (\rho_v + \rho_a) &= (1 + \lambda_a) \left[L(T) \frac{d\rho_v}{dz} + \rho \bar{c}_p \frac{dT}{dz} \right] \\ &+ \frac{1}{\rho_g} \frac{d\rho_g}{dz} \{ L(T_w) (\rho_v + \rho_a) [1 + Cn_s - \delta_a] - L(T) (1 + \lambda_a) \rho_v \}, \end{aligned} \quad (27)$$

where

$$\lambda_a = j_a / j_s, \quad (28)$$

and δ_a is a small correction term that can often be neglected:

$$\delta_a = c_{pa} (1 + \lambda_a) (T - T_w) / L(T_w). \quad (29)$$

If it is assumed that the vapour density in the main flow is kept close to saturation by aerosol formation or evaporation, ρ_v takes on its equilibrium value, $\rho_{ve}(T)$, so that

$$\frac{d\rho_v}{dz} = \rho'_{ve}(T) \frac{dT}{dz}. \quad (30)$$

If this were true for the boundary layer as well, then the surface condensation number would be given by

$$Cn_s = \frac{k(1 - c_e(T))}{DL\rho c'_e(T)}, \quad (31)$$

where k is the thermal conductivity of the mixture and the equilibrium vapour concentration is

$$c_e(T) = \rho_{ve}(T) / (\rho_{ve}(T) + \rho_g), \quad (32)$$

i.e. the vapour concentration is defined as the mass fraction of aerosol. The derivative of c_e with respect to T is taken at constant pressure.

Otherwise, an amended value should be used (Clement, 1987), corresponding to a maximum supersaturation ($S - 1$) in the boundary layer

$$Cn_s(S) = \frac{Cn_s(1)}{(1 \pm \alpha(S - 1)^\pm)} = \frac{Cn_s(1)}{\left(1 + \frac{1}{(4\pi N \bar{R})^\pm} \frac{c'_e}{c'_e} \frac{dT}{dx} \right)}, \quad (33)$$

where $\alpha = (c'_e c_e)^\pm / c'_e \approx 1$ and the plus and minus signs refer to the cooling and heating cases, respectively. In the second expression $S - 1$ has been replaced by a quantity specified by the aerosol number density, N , its mean radius, \bar{R} , and the temperature gradient dT/dx normal to the wall at the surface of the tube (Clement, 1987). All spatially dependent quantities are evaluated at the surface.

With the neglect of δ_a and any aerosol current at the wall the first term on the RHS of equation (27) reduces to the previous result (Clement and Julien Dolias, 1987)

$$\frac{d}{dz}(\rho_v + \rho_a) = \frac{1}{1 + Cn_s} \left[\rho'_{ve}(T) + \frac{\rho \bar{c}_p}{L(T_w)} \right] \frac{dT}{dz}, \quad (34)$$

which can easily be integrated using equation (30) to obtain changes in density as a function of temperature, i.e.

$$\rho_{af} - \rho_{ai} = \frac{1}{1 + Cn_s} \left[-Cn_s(\rho_{ve}(T_f) - \rho_{ve}(T_i)) + \frac{\rho \bar{c}_p}{L(T_w)} (T_f - T_i) \right]. \quad (35)$$

Here, the density ρ and the surface condensation number Cn_s are taken at some representative bulk temperature, e.g. $\frac{1}{2}(T_i + T_f)$.

The size of the final term in equation (27) depends upon the physics of the situation which determines $d\rho_g/dz$. In terms of the total pressure p , the gas density is, assuming an ideal gas law,

$$\rho_g = \frac{\mu_g p_g}{R_G T} = \frac{\mu_g}{R_G T} (p - p_{ve}(T)), \quad (36)$$

where μ_g is the molar mass of the gas, p_g and p_{ve} the gas and equilibrium vapour pressures respectively, and R_G the gas constant. From this expression, and using an ideal gas law for the vapour density,

$$\begin{aligned} \frac{1}{\rho_g} \frac{d\rho_g}{dT} &= -\frac{1}{T} - \frac{p'_{ve}(T)}{p - p_{ve}(T)} \\ &= -\frac{1}{T} \left[1 + \frac{\mu_g \rho_{ve}}{\mu_v \rho_g} \right] - \frac{\mu_g \rho'_{ve}}{\mu_v \rho_g}, \end{aligned} \quad (37)$$

where μ_v is the molar mass of the vapour. It is therefore possible to cast equation (27) in the form of a differential equation in T :

$$\begin{aligned} \frac{d}{dT}(\rho_v + \rho_a) &= \frac{1 + \lambda_a}{1 + Cn_s - \delta_a} \left[\frac{L(T)}{L(T_w)} \rho'_{ve}(T) + \frac{\rho \bar{c}_p}{L(T_w)} \right] \\ &\quad - \left[\frac{1}{T} \left(1 + \frac{\mu_g \rho_{ve}}{\mu_v \rho_v} \right) + \frac{\mu_g \rho'_{ve}}{\mu_v \rho_g} \right] \left[\rho_{ve} + \rho_a - \frac{L(T)}{L(T_w)} \frac{(1 + \lambda_a) \rho_{ve}}{1 + Cn_s - \delta_a} \right]. \end{aligned} \quad (38)$$

With a knowledge of Cn_s and λ_a , equation (38) can be integrated to determine the aerosol density change along the path from an initial temperature T_i to a final temperature T_f .

3. EXAMPLE CALCULATIONS

The integration of equation (38) is easy to perform numerically with backward Euler extrapolation over a temperature step which is small enough such that the results do not depend upon its size. Calculations have been performed for water-vapour/air and sodium-vapour/argon mixtures using the data specified in Appendix A.

Any differences between the results of integrating equations (38) and (34) arise from a feedback from the vapour and aerosol already present in the mixture, corresponding to the second term on the RHS of equation (38). This term tends to enhance aerosol growth for a cooling case, and to reduce it in the case of heating, relative to the results of equation (34). This is shown clearly in Fig. 2 which gives the final aerosol densities obtained, starting with $\rho_{ai} = 0$, for a heating and a cooling case of a saturated water-vapour/air mixture. Note that as maximum densities are being considered here, it is assumed that the mixture reaches the temperature of the walls before emerging from the tube. Also, it is assumed that the boundary layers are saturated, and that no aerosol is lost by deposition onto the walls, i.e. $\lambda_a = 0$. Although easily calculable and for this reason attractive, the expression in equation (34) does not yield a result very close to the exact behaviour for this mixture (shown as a

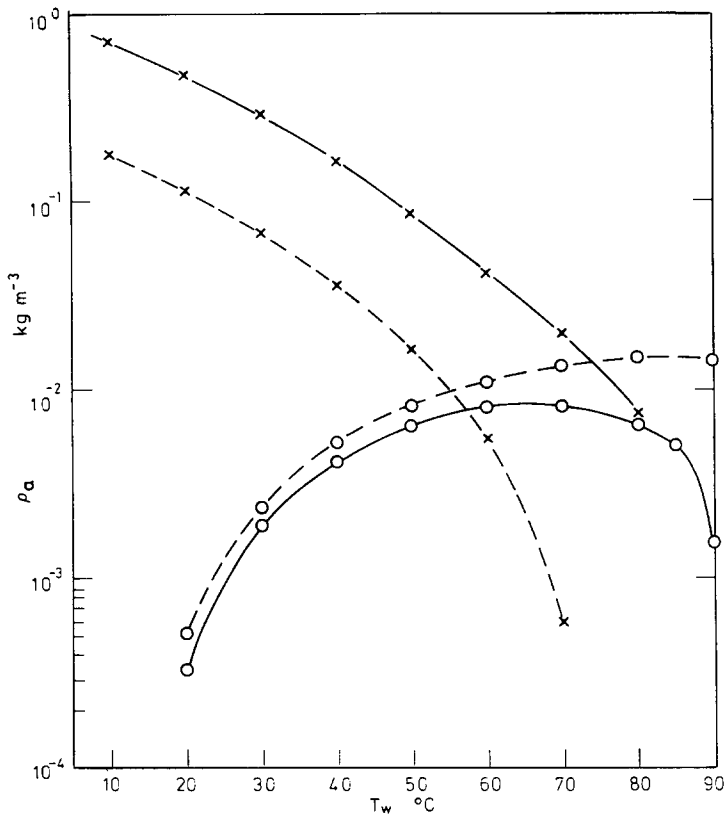


Fig. 2. Exact (solid lines) and approximate (dashed lines) increases ρ_a in water aerosol density on heating a well-mixed water-vapour/air mixture at 1 atm pressure from 10°C to T_w (circles) and cooling from 90°C to T_w (crosses).

continuous line) for all choices of initial and final temperatures. However, for a sodium/argon mixture similar example calculations display much closer agreement, as shown in Fig. 3.

The behaviour of ρ_{af} for different wall temperatures in the heating case is explained in terms of competing effects. The rise in temperature of the mixture tends to thin out the aerosol as the carrier gas expands; against this has to be set the increased rate of evaporation into the flow from the walls for larger temperature differences. This can be seen in another way by considering the evolution of ρ_a with temperature along a pipe, an example of which is given in Fig. 4. The increase of mass of airborne water in this case is reflected in the plot of loading \mathcal{L} , which is defined as

$$\mathcal{L} = \frac{\rho_a + \rho_{ve}(T)}{\rho_g(T)}. \quad (39)$$

This quantity rises approximately exponentially.

4. DISCUSSION

The results make it clear that it is physically possible to produce quite dense aerosols by heating or cooling a saturated vapour, especially for large coolings in the water example. The densities that have been calculated, however, are upper limits to those which would be produced in less than ideal experimental conditions. Unless the tube is very long, it is unlikely that the mixture would emerge from it with a bulk temperature equal to that of the walls. This poses no difficulty for the model, and only requires a different upper limit to the integration of equation (33), for instance. The experimental results are more likely to differ

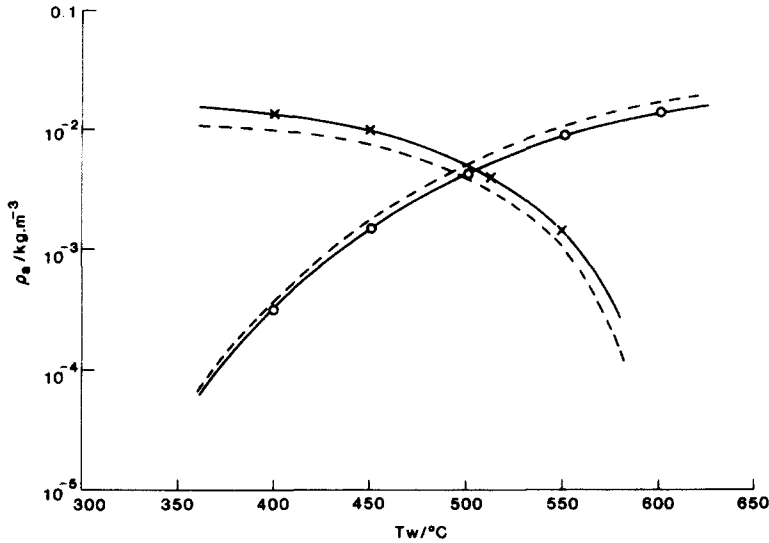


Fig. 3. As for Fig. 2, but for sodium-vapour/argon. The initial temperatures for the heating (○) and cooling (×) cases are 300 and 600°C, respectively.

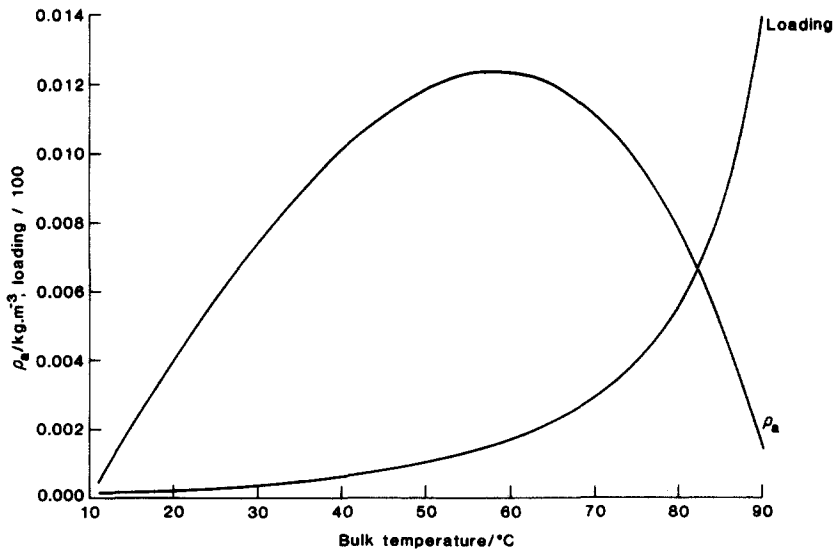


Fig. 4. Evolution of water aerosol density ρ_a and loading due to heating of a saturated water-vapour/air mixture, initially at 10°C, in a flow along a pipe with walls at 90°C.

from the predictions given above due to deviations of the vapour density in the boundary layers from saturation. An exact theoretical description of the development of such deviations would have to incorporate the dynamics of fluid exchange between the boundary layer and the bulk flow, as well as droplet growth kinetics to determine \bar{R} in equation (33). The essential ingredient of such a treatment would be the timescale of residence of a fluid packet within the boundary layer before ejection into the main flow, but such complications are beyond the scope of the simple picture being drawn here.

The calculations described above have neglected aerosol deposition upon the walls, in accordance with the expressed intention to predict maximum aerosol densities. If it is desired to extend the model to include the effects of turbulent or thermophoretic deposition then it would be necessary to estimate the parameter λ_a .

5. CONVECTIVE FLOW SITUATIONS

It is instructive to apply the aerosol growth model to convective flow situations which develop within the cover gas space. A passage of a packet of gas/vapour mixture over the hot sodium pool is analogous to the pipe flow situation considered in this paper, except that the packet is in contact with the liquid surface only over a portion of its surface. Consider an incremental slice of the packet, perpendicular to the overall flow direction, with a perimeter l and length dz . Vapour enters diffusively only through a portion of the area $l dz$; that part which contacts the hot pool. To a first approximation it is possible to neglect the loss of vapour through the remaining portion as the packet warms. This remaining portion resides in the turbulently mixed region of the cavity, where gradients of concentration and temperature are small. The density of aerosol in the packet increases according to equation (38), where λ_a is largely due to a gravitationally settling aerosol current. The temperature to which the packet is heated is determined by the fluid dynamics of free convection. It is then carried away as a thermal plume into the bulk mixture. Similar cooling processes occur on the roof of the cover gas space, which also result in aerosol formation.

This picture of the mechanism of loading the cover space with aerosol can provide an estimate of the number of circuits of the cavity taken by a particular droplet before falling out. This in turn can give an indication of the distribution of aerosol density within the cavity. Figure 5 shows the maximum fractional increase in aerosol density to be expected from one passage of a packet of gas close to the surface of a sodium pool at temperature T_s with a roof temperature T_r of 120°C. Steady state bulk aerosol densities as a function of T_s are taken from Japanese experimental work (Himeno and Takahashi, 1978). The boundary layer is assumed to be saturated. The calculations are for an initial packet temperature of $T_b - \varepsilon/2$, and a final temperature of $T_b + \varepsilon/2$, using two typical values of ε . T_b is the average bulk temperature and is determined (Clement, 1985) by the relation:

$$\xi(T_b) = \frac{1}{2}(\xi(T_s) + \xi(T_r)), \quad (40)$$

where

$$\xi(T) = T + \frac{L(T)c_e(T)}{\bar{c}_p}. \quad (41)$$

At the wall and roof

$$-k\nabla\xi = q_{\text{tot}}, \quad (42)$$

where q_{tot} is the total heat transfer rate due to conduction and evaporation/condensation

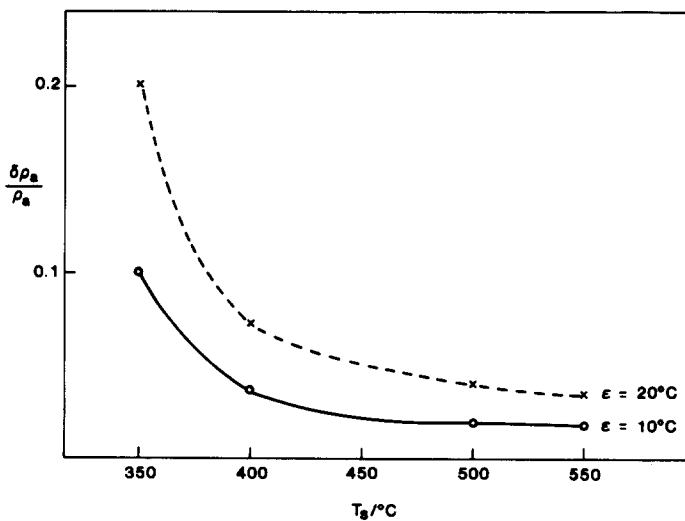


Fig. 5. The maximum fractional increase in sodium aerosol density achieved on heating a packet of a saturated mixture of sodium-vapour/argon from a temperature $T_b - \varepsilon/2$ to $T_b + \varepsilon/2$. T_b is the convective mean temperature for each pool temperature T_s , with a roof temperature of 120°C. The bulk aerosol densities are taken from Himeno and Takahashi (1978).

between the pool and the roof. Equations (40)–(42) are not general relations, but hold for this case since the Lewis number for sodium-vapour in argon is close to unity.

The temperature difference ε would increase as T_s increases, so that a more accurate treatment would produce a plot flatter than those shown in Fig. 5. A greater accuracy in the consideration of this problem is unnecessary however, since it is clear that the bulk aerosol density in the cavity is insensitive to a passage of a constituent packet of mixture close to the heated pool. About 10–50 such passages are required to grow aerosol in the packet to the observed steady state density.

These explicit calculations confirm a common supposition; that aerosol growth can be averaged out over the cover gas cavity (due to the fast turbulent mixing) and smoothed out over time (due to the small change possible from a pass over the pool). Aerosol generated by evaporation/condensation in the boundary layer above a hot sodium pool will pass into the bulk cavity virtually undepleted by immediate fallout.

6. CONCLUSIONS

A model of the generation of an aerosol density in well-mixed fluid flow situations close to heated or cooled liquid surfaces has been presented. The evolution proceeds simply by solution of the coupled equations of heat and mass transfer. Certain ideal conditions allow a calculation of the maximum possible aerosol density generated. The most important of these conditions is the saturation of the boundary layer between the well-mixed bulk flow and the walls. A better understanding of the development of deviations from saturation would be required in order to calculate realistic generation rates of aerosol in pipe flows, but ideal case calculations have been presented which give upper limits to these rates for various conditions.

Convective flow in the fast reactor cover gas space has been considered in terms of the passage of packets of argon gas over a hot sodium pool, during which they are heated through a small temperature difference. Calculated maximum densities of sodium aerosol generated in such packets provide lower limits to the number of circuits around the cavity made by a droplet before growing sufficiently to fall out. This number is fairly large for a range of typical sodium pool temperatures suggesting that aerosol growth can indeed be viewed as being averaged out over the whole cavity.

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APPENDIX A

Water-vapour/air data:	summarized in Barrett and Clement (1985)
Sodium-vapour/argon data:	(T in Kelvin)
Latent heat:	$L = 4.1993 \times 10^6 - 985.58 T \text{ J kg}^{-1}$
Equilibrium vapour pressure:	$p_{ve} = 1.01325 \times 10^5$ $\times \exp\left(\frac{-12818}{T} - 0.5 \ln T + 14.6306\right) \text{ Pa}$
Specific heat capacities:	$c_{pa} = 521 \text{ J kg}^{-1} \text{ K}^{-1}$ $c_{pv} = 900 \text{ J kg}^{-1} \text{ K}^{-1}$
Equilibrium vapour density:	$\rho_{ve} = 10^3 \exp(-1/z) \text{ kg m}^{-3}$ $z = 1.91711 \times 10^{-8} T^2 + 8.4563 \times 10^{-5} T - 7.3053 \times 10^{-4}$
Sodium-vapour diffusion coefficient (at 1 atm. pressure)	$D = 7.215 \times 10^{-9} (T - 149)^{3/2} \text{ m}^2 \text{ s}^{-1}$
Thermal conductivity	$k \approx k_g = 2.378 \times 10^{-3} + 5.561 \times 10^{-5} T - 1.558 \times 10^{-8} T^2 \text{ W m}^{-1} \text{ K}^{-1}$

These fits are sufficient for the range of temperatures relevant to the cover gas space.