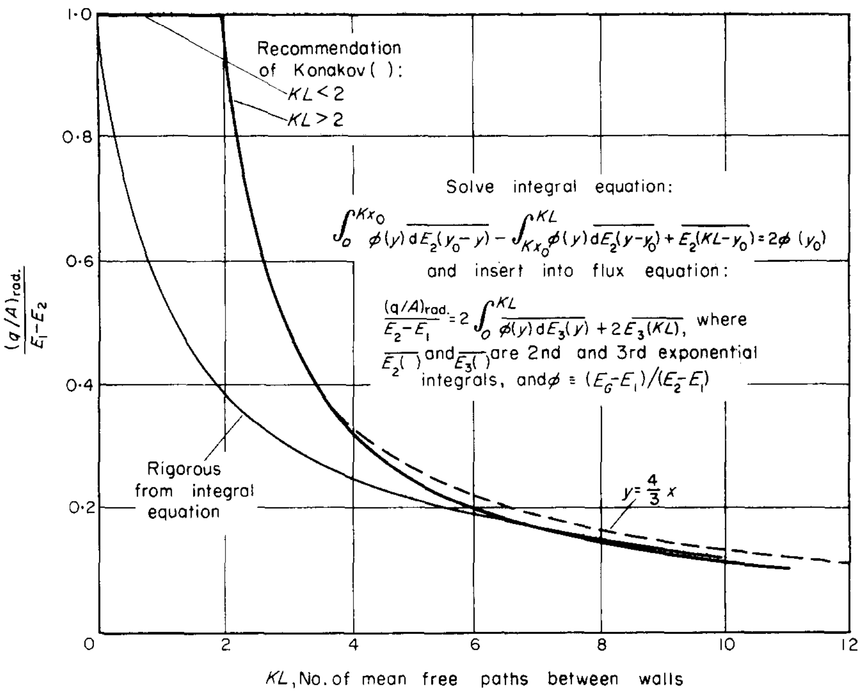

FIG. 1.

This difference is discussed by the present author in the referenced paper.

Many problems of practical interest lie in the KL range 0 to 3 where, as the figure indicates, the proposed approximation has negligible value. When KL is large the technique of adding λ_c and $16\sigma T_{AV}^3/3K$ to obtain λ_T, where λ_c is the true thermal conductivity and λ_T is the effective or "total" conductivity due to conduction plus radiation, is well known.

FREE CONVECTION FROM A SPHERE IN AIR

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PRINCIPAL MEASUREMENTS AND RESULTS

EXPERIMENTS were carried out to measure overall convection heat transfer from a sphere. The aluminium sphere, 4 in external diameter and $\frac{3}{8}$ in thick, was heated internally by an electric element. It was suspended in air, with all heating and thermocouple wires entering at the top, and protected from draughts by a large polythene "tent".

Temperatures were measured with calibrated copper–constantan thermocouples and a Tinsley portable otentiometer. Power input was found with a Cambridge dynamometer wattmeter. Radiation losses were determined separately by measurement in a vacuum chamber (better than 10^{-4} mm Hg).

The approximate ranges covered in the experiments were:

temperature difference between surface and air	$43 < \theta_w < 312°F$
heat input	$4 < q < 50$ W
Grashof number	$3 \times 10^6 < G_d < 8 \times 10^6$

The worst non-uniformity of θ_w over the surface was

7 per cent, but this was almost entirely confined to small areas at the bottom and top which contributed little to the total heat loss.

The results are based on 12 carefully measured equilibrium states, with all properties taken at the film temperature $t_f = t_w - \frac{1}{2}\theta_w$. The average Nusselt number was found to be

$$N_d = 0{\cdot}513(G_d \times P)^{1/4}.$$

When the coefficient of cubical expansion is taken at the free stream temperature the appropriate coefficient becomes 0·491.

SUBSIDIARY MEASUREMENTS AND RESULTS

(a) *Smoke tests*

Ammonium-chloride smoke was introduced into the boundary layer near the bottom of the sphere. Observations showed that the boundary layer remained laminar throughout, but separation occurred near the top. It was difficult to establish a definite position for separation of the smoke, since this depended somewhat on the point at which the smoke was introduced into the boundary layer.

(b) *Shadowgraph*

The boundary layer was observed qualitatively by means of shadowgraph technique. As expected the boundary layer thickness δ did not vary markedly over the lower half of the sphere; it increased rapidly over the upper half up to the point of separation to accommodate the flow in the boundary layer with reduced horizontal perimeter around the sphere.

(c) *Temperature traverses*

Radial temperature traverses were carried out with a manganin–constantan thermocouple probe at several "latitudes", and the dimensionless temperature θ/θ_w (relative to the free stream) was plotted against the dimensionless wall distance y/δ. There was no marked change in the profiles up to the point of separation, and the profile $\theta/\theta_w = (1 - y/\delta)^2$, assumed in the solution of Ref. 1, fitted the results well.

(d) *Local heat transfer coefficients*

Attempts were made to measure local values of heat transfer with a JLC-Hatfield Heatflow Meter Disk inserted and clamped into the inner surface of the sphere. The results indicated a heat transfer distribution bearing little resemblance to that predicted by theory; the transfer appeared to be almost uniform over the bottom half of the sphere and then increased rapidly over the top half. For several reasons, however, notably the pressure sensitivity of the disk assembly and the distortion of the heat flow pattern near the disk, these results must be suspect until further investigations have been carried out.

COMPARISON WITH OTHER WORK

In Ref. 2 Shell gives a theoretical solution

$$N_d = 0{\cdot}429(G_d)^{1/4} = 0{\cdot}469(G_d \times P)^{1/4},$$

which is based on an incorrect form of the continuity equation. His experimental results, based on a rather crude transient method and covering a range of $1{\cdot}1 \times 10^6 < G_d < 3{\cdot}2 \times 10^6$, agree well with his equation (the coefficient of cubical expansion was taken at free steam temperature).

Merk and Prins in Ref. 1 give an approximate solution for $P = 0{\cdot}7$

$$N_d = 0{\cdot}474(G_d \times P)^{1/4}$$

for a fluid with properties that are independent of temperature. The solution does not take account of the plume at the top of the sphere, but since the area affected by it represents only about 6 per cent of the total surface area, reasonable agreement with experimental results should be expected.

REFERENCES

1. H. J. Merk and J. A. Prins, Thermal convection in laminar boundary layers III, *Appl. Sci. Res.*, **A4**, 207–21 (1954).
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