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Heat Transfer in Pulsating Flow

When pulsations are imposed on a flowing fluid, it may normally be expected that heat transfer to or from it would be changed because the pulsations would alter the thickness of the boundary layer and hence the thermal resistance. In the laminar region, this view is also supported by the fact shown by Richardson[1] that the velocity profile for pulsating flow is steeper near the wall than for smooth flow. It follows from a consideration of the Reynolds analogy that the heat transfer should increase under such conditions. A similar process might occur for turbulent flow also, but the equations are too cumbersome for analytical solution.

Experimental information about the process, however, is meagre and sometimes conflicting. In the turbulent region, Martinelli *et al.*[2,3] and Marchant[4] found no difference in heat transfer between steady unidirectional flow and pulsating flow, but West and Taylor[5] reported an increase of 60–70 per cent. In the laminar region, Marchant[4] noted a slight increase, whereas Morris[6] and Webb[7] found no change. All these investigations were carried out at low pulsation frequencies by heating flowing water. Working with oil, Linke[8] found an increase in heat transfer of up to 4 times in the laminar region and up to 1·35 times in the turbulent region. In air, Stanton *et al.*[9] found no difference between a static and a vibrating finned engine-cylinder, whereas Kubanskii[10] obtained an increase of 50 per cent at acoustic frequencies. Andreas[11] advocated the mechanical vibration of the entire heat exchanger to improve heat transfer.

We have carried out investigations under the auspices of the Council for Scientific and Industrial Research, New Delhi, on the heat transfer to pulsating air. These investigations have been carried out by the external heating, by steam, of air at or near atmospheric pressure, flowing in a horizontal pipe of 1 in. inside diameter and 6 ft. 10 in. effective heating length. The heat transfer coefficients were measured first with steady unidirectional flow and then with pulsations imposed on the flow by means of a poppet valve operating in the path of the air. The wave-form and amplitude were measured by an instrument based on an idea of Schweitzer[12]. Reynolds number was varied from 5,000 to 35,000 and frequency of pressure pulsations from 5 to 33 c./s. The experiments were repeated with different wave-forms and amplitudes.

The Reynolds and Nusselt numbers were calculated at the mean temperature of the air, and the velocity used was that obtained by dividing the total volume flow by the cross-sectional area of the pipe. It was found that the Nusselt number changed up to about 30 per cent in a rather uneven but defined manner under different conditions of frequency, amplitude, wave-form and Reynolds number. In general, the change was negative below a certain frequency and positive above it, in the range of frequencies investigated. This critical frequency was a function of the wave-form and to a lesser extent of the Reynolds number. The magnitude of the change increased slightly with Reynolds number, the negative part of the curve increasing at lower Reynolds numbers and the positive part at higher Reynolds numbers. Only a negligible change could be detected when the amplitude of the pulsation was very low, thus corroborating the negative results of Stanton[9]. With higher amplitudes, the change was not directly proportional to the amplitude but depended on a function which combined the frequency, amplitude and Reynolds number. The exact nature of this function is now being investigated. It seems likely that not only the total magnitude of the pressure amplitude but also the steepness of the wave (or the rate of change of pressure in the wave) plays an important part in the mechanism of forced convective heat transfer under pulsating flow conditions.

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Ageing of Quartz Crystal Vibrators

It is probable that in the field of use of quartz crystal vibrators there are no requirements more exacting than those imposed on the quartz vibrator which is used to control the time-keeping of a quartz clock. The British Post Office has had considerable experience in fabricating 100 kc./s. quartz vibrators and incorporating them in suitable oscillator circuits to maintain clocks or frequency standards. It is the general experience that these oscillators have a slow frequency change even after several months of uninterrupted operation. This change is extremely small, being of the order of one part in 10^9 a day for a good clock to one part in 10^{11} for the best clock. Recent tests have shown that the frequency-change or 'ageing' can be reduced by using the crystal vibrator at a temperature which is lower than the normal 50° C.

Fig. 1 shows the results of some tests on a 100 kc./s. *GT*-cut quartz crystal operating at two different temperatures, one within a few millidegrees of a nominal 50° C. and the other of a nominal − 10° C.