On the Critical Flow of Vapor Liquid Mixtures by Cruver and Moulton

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We have recently observed that the critical flow chart for two-phase expansion of water provided in the above cited (*1*) paper gives predictions which are very close to those made by the present writers in their paper (*2*) published earlier this year. A comparison of predicted values is given below, for an outlet quality $X = 10\%$.

Outlet Pressure (lb./sq.in.abs.)	500	200	100	50	25	10
Critical Mass Flow (lb./sq.ft. sec.)						
Cruver and Moulton Predictions	6,200	3,200	1,900	1,100	550	270
Linning, Pexton, Alderson Predictions	6,500	3,400	1,900	1,100	600	270

These results show a remarkable similarity and, at first sight, seemed to lend mutual support for two theories which have little else in common.

The Cruver and Moulton theory is based on the postulate that at the critical outlet condition the phase velocity ratio is the cube root of the phase specific volume ratios (corresponding to minimum kinetic energy for a given mass flow or maximum mass flow for a given kinetic energy). The other theory is derived using the three basic conservation laws to arrive at six equations of flow. These can be integrated numerically in a step-by-step process which follows the expansion until critical outlet conditions are reached. Beyond this point the equations are incompatible. The critical outlet condition can also be recognized by the approach of the ratio $-VdP/d(KE)$ to unity, where V is the specific volume, P the pressure, and (KE) the kinetic energy of steam-water mixture, that is $-VdP$ is the maximum rate of conversion of internal to kinetic energy which is theoretically possible. Empirical information in the shape of wall and interphase friction factors is required to obtain a numerical solution to the two-phase flow equations. It might be considered on the evidence of the above comparison that the two theories lend some support to each other, but further examination reveals that this is not so. The Cruver-Moulton theory leads to a critical outlet velocity ratio of 9.8 whereas the other theory predicts a corresponding value of 15.3. Furthermore, it is found that in this particular case the fluid kinetic energy is practically unchanged over the velocity ratio range 8 to about 20 as shown in the graph. It follows, rather surprisingly, that an arithmetically correct prediction of critical mass flow for specified outlet pressure and quality is not a sensitive test of the validity of any theory.

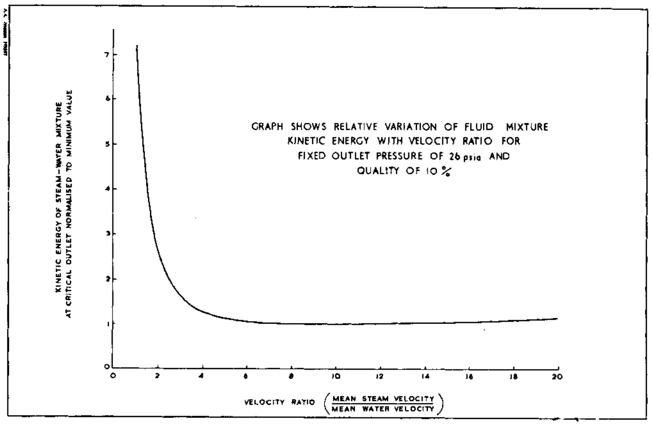

Fig. 1. Variation of fluid mixture kinetic energy.

Perhaps it should be added that we are discussing here the situation which would prevail if thermodynamic equilibrium conditions were to obtain throughout an expansion and that while this is of considerable theoretical interest, in practice deviations from thermodynamic equilibrium near the critical outlet significantly affect actual flow behavior.

LITERATURE CITED

1. Cruver, J. E., and R. W. Moulton, *AIChE J.*, **13**, 52 (1967).
2. Linning, D. L., A. F. Pexton, and M. A. H. G. Alderson, *J. Mech. Eng. Sci.*, **10**, No. 1, 64 (Feb., 1968).

Diffusion in Membrane-Limited Blood Oxygenators

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Membrane blood oxygenators mimic natural lungs in separating blood and gas phases by a permeable membrane. Resistance to gas transfer is contributed by both membrane and blood film, but the ultimate limit on the