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THE LOW PRESSURE CRITICAL DISCHARGE OF STEAM-WATER
MIXTURES FROM PIPE ELBOWS AND TEES

MARCH, 1965

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THE LOW PRESSURE CRITICAL DISCHARGE OF STEAM-WATER
MIXTURES FROM PIPE ELBOWS AND TEES

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INTRODUCTION

This report presents information on an experimental investigation of the critical discharge of two-phase steam-water mixtures from piping systems when the system is opened to the atmosphere immediately adjacent to a pipe fitting.

When a high temperature and pressure liquid is allowed to escape to the atmosphere from a piping system, a choking condition will occur at the exit end of the discharge piping which uniquely limits the rate of fluid loss from the system. This choked flow condition is termed, "critical flow" or "critical discharge." The two-phase critical discharge phenomenon is of particular interest in nuclear reactor technology because it imposes the condition which determines the maximum quantity of coolant which can be lost from a reactor cooling system in the event of a piping break or a pressure vessel rupture. Knowledge of this phenomenon is required for effective and economical design of emergency reactor cooling systems and confinement systems.

Much progress has been recently made in the development of mathematical models of the critical flow phenomenon. Several of these mathematical models have been shown to produce reasonably accurate predictions of critical flow rates over limited ranges of the variables when applied to undisturbed lengths of pipe discharging to the atmosphere. Little

is known, however, of the influence of flow disturbances on the critical flow phenomenon. Such disturbances could result from a pipe fitting such as a tee, elbow, or valve immediately upstream of the location of choking. There have been indications that flow disturbances could possibly have considerable effect on critical flow rates,^(1, 2) but no specific information is available to predict the magnitude of the effect.

This investigation was undertaken to study the critical discharge of low temperature and pressure steam-water mixtures from two types of fittings -- elbows and tees and to develop preliminary correlations to allow the prediction of critical flow rates from these fittings.

SUMMARY

A program of investigation was performed to study the critical discharge of two-phase steam-water mixtures from a piping system when the system is opened to the atmosphere adjacent to a tee or elbow. Two phenomena uniquely determine the maximum rate at which a two-phase mixture can be discharged from such a system -- 1) the critical flow phenomenon and 2) the two-phase pressure-drop phenomenon. Experiments were performed at moderate temperatures and pressures on 1/2-inch commercial piping and welding fittings to study the effect of the presence of the fitting on these phenomena. In these experiments, the range of steam-water total enthalpies considered was between 500 and 1000 Btu/lb. Flow rates ranged from 200 to 800 lb/(sec)(sq ft), and measured critical pressures were between 23 and 87 psia. The results indicated that the elbow at the discharge of the flow passage influenced the critical flow rate

insignificantly. The tee in this location reduced the critical discharge rates from 10 percent at enthalpies of 900 and 1000 Btu/lb up to 24% at 500 Btu/lb. This indicates that the tee immediately upstream of the location of the flow choking acts to increase the degree of homogenization of the two-phase mixture. The data gathered in this investigation were correlated by two methods. In the first method, the critical flow phenomenon and the two-phase pressure drop across the fitting were considered as one effect, and the critical discharge rate was related to the flow enthalpy and a "pseudocritical" pressure upstream of the fitting.

In the second method of correlation, the critical flow model of Fauske⁽³⁾ was combined with the pressure loss information obtained in this investigation. These combined data were referred to the momentum exchange pressure drop model of Levy⁽⁴⁾ and the empirical relation of Thom⁽⁵⁾ to obtain a general pressure loss correlation for pipe elbows and tees during choked flow. A comparison between the resulting pressure loss correlation with one proposed by Fitzsimmons⁽⁶⁾ for normal (nonchoked) flow in similar fittings demonstrated a surprising consistency.

DISCUSSION OF THE PROBLEM

The maximum (critical) discharge rate of a flashing steam-water mixture from a long pipe to the atmosphere is a function principally of the total (stagnation) enthalpy of the flow and the pressure at the discharge end of the pipe. There is also evidence that the nature of two-phase flow patterns near the end of the pipe influences the critical

discharge rate.^(1, 2) Theories based upon hypothetical flow patterns have been formulated to describe the critical flow process in long pipes,⁽³⁾ and comparisons of these theories with experimental data have resulted in verification in some instances. There is, however, no information regarding the influence of a pipe fitting at the end of the flow passage on the flow patterns and, therefore, on the critical discharge rate.

The effect of the pipe fitting might be to cause a partial homogenization of a separated flow as a result of turbulence induced by the fitting. If the flow was initially homogenized, on the other hand, centrifugal forces set up by the change of flow direction might cause a separation of the phases. It was anticipated, therefore, that present theories based upon specific flow patterns would not be adequate for analysis of a pipe with a fitting at the discharge end.

The effect of an exit fitting on the maximum discharge rate cannot be considered alone without also considering the effect of the fitting on the pressure drop. Both the critical flow and the two-phase pressure-drop phenomena jointly determine maximum discharge rate, and knowledge of critical flow effects of the fittings would be of little use unless its effect on the pressure-drop phenomenon is known also. Correlations are available to analyze two-phase pressure drop through various fittings;⁽⁶⁾ however, the applicability of these correlations to the fitting configuration under study was considered doubtful. These correlations considered the fittings to be complete with inlet and exit

pipng. In such fittings, total friction pressure drop is a result of both the frictional effects occurring in the fitting and friction effects in the downstream piping resulting from the additional turbulence caused by the fitting. For the case under investigation, the downstream piping was absent and, therefore, these friction effects due to downstream turbulence were also absent.

This preliminary investigation was undertaken to study the effects of two types of terminal fittings -- the tee and the elbow -- on both the critical flow and the two-phase pressure-drop phenomena at low temperatures and pressures. The methods and techniques developed will be applied to a future study of these phenomena at pressures approaching 2000 psia.

APPARATUS

A representation of the two test sections employed during this investigation is shown in Figure 1.

The elbow test section consisted of a 12-inch length of commercial 1/2-inch schedule 40 stainless steel piping on which was welded a standard 90-degree long radius elbow (Flowline). This test section was oriented in the apparatus so that the two-phase mixture was discharged directly from the unused side of the elbow into a large receiver. The direction of the discharged flow was vertically downward. The test section was provided with 0.010-inch diameter wall pressure taps at 1/2-inch intervals along its length as shown in Figure 1. Additional

Figure 1. Test Section Arrangement

pressure taps were installed at 90 degrees near the discharge end of the tee to establish the pressure gradient at that point.

The tee test section was similar to the elbow test section. The tee was installed so that it acted as an elbow discharging the two-phase flow to the receiver through the branch side. On the unused leg of the tee was welded an eight-inch length of pipe which was capped. This test section was provided with pressure taps at 1/2-inch intervals along the straight section and at the locations shown in Figure 1. The unperturbed cylindrical portion of the branch side of the tee was very short and, therefore, it was possible to provide wall taps at only one location -- 0.0312-inch from the discharge.

Following all welding, the test sections were carefully ground and honed to remove any constrictions resulting from welding. Measurements of the elbow test section showed the bore to be 0.625 ± 0.002 -inch diameter. The straight side of the tee test section was found to be 0.622-inch diameter, and the discharge side was 0.625-inch.

These test sections were installed in turn in the two-phase flow apparatus originally constructed for the investigation reported in Reference (2). This apparatus is shown schematically in Figure 2. The two-phase mixtures of desired quality were formed by the physical mixing of 225 psia saturated steam (suitably throttled) and water heated to 385°F. The mixing was performed in a special chamber which was provided with baffles to induce mixing of the phases. The steam-water mixture

Figure 2. Schematic Drawing of Apparatus

produced in the chamber was conveyed to the entrance of the test section through a four-foot length of two-inch pipe. This passage reduced any turbulence formed in the mixing process.

The steam supplied to the mixing chamber was taken from a 3-inch, 225 psig steam main, and its enthalpy was determined by means of an "Ellison U-Path Calorimeter." The temperature within the barrel of the calorimeter was measured by a certified mercury-in-glass thermometer. After the enthalpy determination, the steam passed through a sharp-edge orifice flowmeter and then through a throttling valve which was used to regulate the steam flow to the mixing chamber.

The water supplied to the mixing chamber was furnished by a centrifugal pump rated at 100 gpm and 500 psig. This pump was equipped on the suction side with a 3000-gallon head tank with a float-type level controller. The purpose of this head tank was to isolate the test equipment from pressure fluctuations occurring in the supply system. The water discharging from the pump was metered by means of turbine-type flow meters and then heated in a shell-and-tube heat exchanger which was supplied with 225 psig steam on the shell side. Following the heating of the water, its temperature was measured by means of thermocouples before being throttled and injected into the mixing chamber.

The pressures sensed by the wall pressure taps were conveyed to an electrically indexed 48-position rotary valve by means of 1/16-inch stainless steel tubing. The rotary valve allowed the sequential indication of each of the pressures along the test section by means of one 0-300 psi precision pressure gage.

The test section discharged into a chamber formed by a one-foot length of 8-inch schedule 40 pipe which was flanged and blanked at both ends as shown in Figure 2. The effluent from the apparatus was discharged to an atmospheric drain through a length of 4-inch pipe and a valve.

EXPERIMENTAL METHOD

In Reference (7), it was shown that the critical flow model of Fauske,⁽³⁾ one of the more widely accepted mathematical models, predicts that the critical pressure is approximately proportional to mass velocity for constant total enthalpy. Since it was desirable to compare the results of this investigation to this theory, an experimental method was employed which would establish the isenthalpic line on a P_{CR} - G_{CR} graph. Experimental runs were performed at total enthalpies of 1000, 900, 800, 700, 600, and 500 Btu/lb for each test section. Generally, four or five flow rates equally spaced between the minimum and maximum capabilities of the equipment were considered. The maximum flow rate possible at each enthalpy was determined by the maximum admission characteristics of the steam supply system, and the minimum flow rate was determined by low-flow accuracy limitations of the steam flow meter.

The quantity of steam and heated water required to produce a mixture of the desired total enthalpy and flow rate was calculated using standard thermodynamic procedures and assuming adiabatic flow and negligible slip between phases. Since an interaction existed between steam enthalpy and flow rate and between the water flow rate and temperature, the calculation

had to be performed several times before an accurate setting of the total enthalpy was possible. Generally, it was possible to balance the flows sufficiently to hold the total enthalpy of the mixture to within a calculated 5 Btu/lb of the desired value during the period of testing.

During all tests, the valve between the downstream receiver and the drain was fully open so that the downstream pressure never rose more than a fraction of a psi over atmospheric pressure.

Following the setting and stabilization of the flow rates, all thermocouple temperature indications, flow rates, and pressures were measured and recorded.

RESULTS AND DISCUSSION

Serious difficulties were encountered during this experimentation in the determination of critical pressures employing the usually accepted extrapolation procedures. In studies of critical discharge from straight pipe sections, extremely rapid decompressions have been observed in the final fractions of an inch of the pipe.^(1, 2, 8) Therefore, many small, closely spaced wall pressure taps are usually employed in critical flow investigations to establish the pressure gradient near the exit. The gradient is then extrapolated to the discharge plane to establish the pressure at that point. This pressure is called the "critical pressure." Extreme precautions must be taken in the measurement and extrapolation procedures because small inconsistencies and errors are magnified by the extrapolation.

In the present investigation, the flow was required to turn sharply immediately before its discharge to the atmosphere. Centrifugal forces and vortices set up by this turn undoubtedly caused an unsymmetric arrangement of the two-phase mixture in the pipe. Therefore, pressure gradients near the discharge of the elbow test section were irregular and unequal at the various azimuthal stations around the discharge. These irregularities were subsequently amplified by the extrapolation procedure, and the results could not be adequately interpreted. Therefore, this procedure was abandoned and, instead, an average pressure measured at the wall taps 0.0312-inch from the discharge was used as the critical pressure. If this method was used with a straight pipe test section, the value of critical pressure obtained would be bracketed by the values obtained by the experimental method of References (1) and (2) and the experimental method of Reference (8). Since deviations of the critical pressure measured in this manner from the defined critical pressure are small in the range of temperatures and pressures under consideration, valid comparisons between experimental data and theoretical predictions are possible.

Figures 3, 4, and 5 show the comparison between the experimental critical flow data and the predictions of the mathematical model proposed in Reference (3). Excellent correspondence was obtained between the 1/2-inch elbow data and the predictions of theory. Typical deviations ranged only to several percent. This behavior indicates that the elbow exerts little influence on the critical flow mechanisms.

Figure 3. Comparisons of the Pressure Indication at the Last Test Section Wall Tap (0.020-inch from Discharge) with Predictions of the Fauske Separated Flow Model at 500 and 800 Btu/lb

Figure 4. Comparisons of the Pressure Indication at the Last Test Section Wall Tap (0.020-inch from Discharge) with Predictions of the Fauske Separated Flow Model at 600 and 900 Btu/lb

Figure 5. Comparisons of the Pressure Indication at the Last Test Section Wall Tap (0.020-inch from Discharge) with Predictions of the Fauske Separated Flow Model at 700 and 1000 Btu/lb

Larger deviations, however, were observed between the experimental data for the 1/2-inch tee and the predictions of the mathematical model. These deviations ranged from about 10% at enthalpies of 900 and 1000 Btu/lb increasing up to 24% at 500 Btu/lb. This behavior suggested that the tee immediately upstream of the location of choking acted to increase the degree of homogenization of the two-phase mixture.

Reasons for the necessity of simultaneously considering both the critical flow and the two-phase pressure-drop phenomena in tees and elbows were discussed earlier in this report. Two different methods were used to present the pressure drop information gathered in this investigation.

Method I. The critical flow phenomenon and the two-phase pressure drop around the fitting were considered as one combined effect, and the critical discharge rate was correlated with the flow enthalpy and a pressure upstream of the fitting. This upstream pressure was termed the pseudocritical pressure.

Method II. The critical flow phenomenon was assumed to be accurately describable by means of the mathematical critical flow model of Reference (3), and a correlation was performed of the data for the pressure drop through the fitting.

Figures 6 and 7 show the data correlated by Method I described above. In this correlation, the pseudocritical pressure was arbitrarily defined as the pressure occurring eight pipe diameters upstream of the centerline of the fitting discharge.

Figure 6. Maximum Discharge from 1/2-inch Pipe Tees with Pressures Referred to Upstream of Tee Entrance. Flow to Atmosphere is Through Branch Side.

Figure 7. Maximum Discharge from 1/2-inch Pipe Elbow
with Pressure Referred to Elbow Entrance

In the test sections employed in this investigation, this position was always greater than 10 pipe diameters from the entrance to the test section. Therefore, it was assumed that the pressure at this point was unperturbed by entrance effects. Actually, the pressure to which this correlation was referred could have been taken at any point from eight pipe diameters upstream of the fitting to the joint between the fitting and the 1/2-inch entrance piping, and the effect on the resulting correlation would have been negligible. This is because the pressure variation in this region of the piping was a very small percentage of the total combined pressure drop effect of the fitting and the flow-choking phenomenon.

It was found that the pseudocritical pressure for the tee was always greater than that observed for the elbow at corresponding enthalpies and flow rates. The deviations between these pressures ranged from 32% at an enthalpy of 500 Btu/lb up to 46% at 900 Btu/lb. Although it appeared that the deviation between the pseudocritical pressures for the tee and elbow remained approximately constant at any one enthalpy, it was impossible to verify this behavior because of range limitations of the flow apparatus used in this experimentation.

Although this method of correlation provides graphs which are convenient for the numerical calculation of critical flow rates for the piping configuration under consideration, it doesn't provide the information necessary for the application of the results to other ranges of variables not covered in the experimentation. Therefore, extrapolation of the curves in Figures 6 and 7 is not recommended.

In the second method of data correlation, the critical pressure was postulated to be related to the maximum discharge rate and the flow enthalpy by the critical flow model of Reference (3). The pressure drop from a point eight diameters upstream of the fittings to the critical pressure at the exit of the fitting was then correlated by a method proposed by Fitzsimmons⁽⁶⁾ in his study of two-phase pressure losses in piping components. He found that the friction two-phase to liquid-phase pressure drop ratio $\Delta P_{TPF}/\Delta P_0$ for various fittings could each be uniquely related to $\Delta P_{TPF}/\Delta P_0$ for a straight pipe.

To find the ratio $\Delta P_{TPF}/\Delta P_0$ for the test conditions in the present investigation, it was necessary to determine the single-phase pressure loss from a point eight diameters upstream of the fittings to the exit of the fitting. This information could not be obtained from published values of fitting pressure-drop factors, since these factors are generally given for fittings installed in continuous piping systems and include friction losses occurring in the piping downstream of the fitting resulting from turbulence caused by the fitting. Therefore, an experiment was performed using cold water (20°C) to determine this pressure loss information. The results of this experiment are shown in Figure 8. The experimental head loss factor (K) obtained for the tee and elbow were 1.32 and 0.195, respectively. Corresponding published factors for these fittings with downstream piping are 1.6 and 0.3. Using this experimental data, the single-phase pressure drop was

Figure 8. Single-Phase (water) Pressure Drop for Tee and Elbow Test Sections at 20°C. Head Loss of 1 Velocity Head is Assumed at Discharge to Receiver.

calculated for each test condition for the water temperature corresponding to the saturation value at the algebraic average pressure in the tee, and the ratios $\Delta P_{TPF}/\Delta P_0$ were formed.

These values of $\Delta P_{TPF}/\Delta P_0$ determined for the tee and elbow were compared to these ratios calculated for a straight pipe at corresponding enthalpies and average pressures. Two methods were used to calculate these straight pipe friction pressure drop ratios, the Levy momentum exchange model and the Thom empirical correlation (extrapolated slightly to the range of pressures of interest). Several checks were made of the validity of the extrapolation of the Thom correlation to lower pressures by using the pressure-drop data for the upstream piping. In general, correspondence between extrapolated values and experimental values was within 16%.

Figures 9 and 10 give the relationship between the experimental two-phase flow frictional pressure-drop ratio and the calculated ratio for straight pipe sections. These figures also present the data obtained by Fitzsimmons for tees and elbows complete with exit piping. The referral of the correlation to the Levy momentum model as in Figure 9 gave slightly different answers than obtained with the Thom empirical correlation in Figure 10. This could be explained by noting that the qualities investigated ranged from 27 to 80%. This is out of the principal range of maximum accuracy of the momentum exchange model.

Figure 9. Two-Phase Pressure Drop Correlation for 1/2-inch Pipe Tees and Elbows During Critical Discharge. Farthest Downstream Pressure is Assumed to be the Critical Pressure Predicted by the Fauske Model. Reference Pressure Drop Ratio Obtained from the Levy Momentum Exchange Model.

Figure 10. Two-Phase Pressure Drop Correlation for 1/2-inch Pipe Tees and Elbows During Critical Discharge. Farthest Downstream Pressure is Assumed to be the Critical Pressure Predicted by the Fauske Model. Reference Pressure Drop Obtained from an Extrapolation of the Empirical Data of Thom.

Consistent with the findings of Fitzsimmons, the tee acting as a bend was found to have a two-phase - single-phase frictional pressure-drop ratio greater than observed for the elbow. Although the present data and Fitzsimmons' data are separated by about one cycle in both directions in Figure 10, the alignment of the data is good. This is surprising because of the already discussed differences in the basic configuration considered in each of these investigations. However, no valid extrapolation (or interpolation) of these curves into this uninvestigated region can be made without the availability of additional information.

REFERENCES

1. D. W. Faletti. "Two-Phase Critical Flow of Steam-Water Mixtures," Dissertation, University of Washington, Seattle, Washington, 1959.
2. F. R. Zaloudek. The Low Pressure Critical Discharge of Steam-Water Mixtures from Pipes, HW-68934 REV, March, 1961.
3. H. K. Fauske. Contribution to the Theory of Two-Phase One-Component Critical Flow, ANL-6633, October, 1962.
4. S. Levy. "Steam Slip -- Theoretical Prediction from Momentum Model," J. Heat Transfer, Trans. ASME Series C, Vol. 82, 1960.
5. J. R. S. Thom. "Prediction of Pressure Drop During Forced Circulation of Boiling Water," Int. J. Heat and Mass Transfer, Vol. 7, 1964.
6. D. E. Fitzsimmons. Two-Phase Pressure-Drop in Piping Components, HW-80970 Rev. 1, March, 1964.
7. A. N. Nahavandi and M. P. Rashevsky. A Digital Computer Program for Critical Flow Discharge of Two-Phase Steam-Water Mixtures, CVNA-128, February, 1962.
8. H. S. Isbin, J. E. Moy, and A. J. R. DaCruz. "Two-Phase Steam-Water Critical Flow," A.I.Ch.E. Journal 3, No. 3. 1957.

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