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APPROXIMATE METHOD OF CORRELATING PANELLITT
PRESSURE WITH FRONT-HEADER PRESSURE AT THE
CRITICAL FLOW POINT IN REACTOR ORIFICE
ASSEMBLIES.

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APPROXIMATE METHOD OF CORRELATING PANELLIT PRESSURE
WITH FRONT HEADER PRESSURE AT THE CRITICAL FLOW
POINT IN REACTOR ORIFICE ASSEMBLIES

Purpose

The purpose of this report is to present the derivation of equations useful as a guide for prediction of the critical flow point in orifice assemblies.

Introduction

The presence of cavitation and critical flow during testing of CG-558 orifices lead to the investigation of methods to eliminate critical flow over suitable operating ranges. During the investigation, equations were developed for correlating critical flow with Panellit pressures and front header pressures. These are the easily measured pertinent pressures associated with reactor process tubes.

For the purpose of this report, critical flow in an orifice assembly is defined as the maximum flow rate possible with a particular constant upstream (front header) pressure regardless of further decrease in downstream (front nozzle barrel) pressure. Critical flow is accompanied by cavitation. Cavitation can cause serious vibration and abrasion problems in pigtails and other fittings.

Summary and Conclusions

Equations are herein developed which allow prediction of the Panellit gage reading at which critical flow should begin for a particular front header pressure, based on empirical determination of the Panellit reading at the critical point for some other front header pressure. For primary orifices at the critical limit,

$$Pan = FH - R_p(FH - 3 + 15)$$

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and for secondary orifices at the critical limit,

$$P_{an} = FH - N_s(FH - Z + 15)$$

where

P_{an} = Panellit gage reading in the control room at the critical limit, psig.

FH = Front header gage reading in the control room, psig.

Z = Head of water equivalent to the elevation of the process tube above the control room gages expressed in psi.

R_p & N_s = Constants determined experimentally at some front header pressure.

Typical values of R_p and N_s have been found to be between 0.51 to 0.75. It has been found that the values of R_p and N_s vary markedly with orifice entry shape (i.e. round, sharp, taper), markedly with orifice holder geometry, and slightly with orifice diameter. Variations of R_p and N_s with front header pressure were found to be quite small.

It is suggested that these equations be used in checking orifice assemblies to identify those operating sufficiently close to cavitation to warrant special treatment. The cavitation constants R_p and N_s were determined from tests of one or a few orifices. Individual orifices vary. It is therefore suggested that some allowance for orifice variation be made when applying these equations to on-reactor assemblies.

Details and Discussion

Cavitation and critical flow of liquid through a restriction, such as an orifice, is associated with a low static pressure at the vena contracta of the flowing stream. The low pressure causes vaporization as well as degasification of the liquid at this point. Cavitation is caused by the vapor suddenly condensing at some point downstream of the vena contracta where the static pressure is greater due to velocity effects.

The familiar flow equation may be written for various sections across an orifice as

$$F = C_1 (P_1 - P_{vc})^{\frac{1}{d_1}} = C_2 (P_2 - P_{vc})^{\frac{1}{d_2}} = C_3 (P_1 - P_2)^{\frac{1}{d_3}} \quad (1)$$

where

F = flow rate per unit area of orifice cross section

P_1 = the upstream pressure, psia

P_{vc} = the pressure at the vena contracta, psia

P_2 = the downstream pressure, psia

C & d are constants dependent mainly upon the shape of the orifice and orifice holder.

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From the above equation, it is apparent that if P_1 is held constant then the flow can be increased by decreasing P_2 . However, at some value of P_2 , P_{vc} would be equal to the vapor pressure of the liquid, P_{vp} , and some liquid would be vaporized. This is called the critical point and equation (1) becomes

$$F_c = C_1 (P_1 - P_{cvc})^{1/4} = C_1 (P_1 - P_{vp})^{1/4} = C_3 (P_1 - P_2)^{1/4} \quad (2)$$

where

$P_{cvc} = P_{vp}$ = Vapor pressure of the liquid, psia

F_c = The critical flow rate per unit area of orifice cross section.

Any further decrease in the downstream pressure would not cause P_{vc} to change but would only tend to cause more liquid to vaporize. Equation (2) would not hold for further decrease in downstream pressure since the flow rate would remain constant regardless of P_2 .

Rearranging equation (2) for the critical point

$$(P_1 - P_2)^{1/4} = \frac{C_1}{C_3} (P_1 - P_{vp})^{1/4}$$

or assuming $d_3 = d_1$ (*)

$$P_1 - P_2 = C_4 (P_1 - P_{vp}) \quad (3)$$

Since P_{vp} is very small (< 0.5 psia for cold water) compared to P_1 and P_2 , it may be neglected and the equation written as

$$C_4 = \frac{P_1 - P_2}{P_1} \quad (4)$$

This equation indicates that the ratio of the total pressure drop to the upstream pressure should be constant, in spite of variations in orifice diameter and upstream pressure, for the same orifice entry shape and orifice holder geometry.

Apply equation (4) to the primary orifice of an orifice assembly it becomes

$$C_4 = R_p = \frac{FH_a - P_{an} a}{FH_a} \quad (5)$$

Equation (5) can be expressed in terms of gage pressures as

$$R_p = \frac{FH_g - P_{ang}}{FH_g + 15 - Z} \quad (6)$$

or

$$P_{ang} = (1 - R_p) FH_g - R_p(15 - Z) \quad (7)$$

$$= FH_g - R_p(FH_g - Z + 15) \quad (7a)$$

(*) Such constants are always near 2.0.

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where FH and Pan refer to the front header and Panellit pressure, respectively, and Z is the liquid head difference between the process tube and the control room gages expressed as psi. Subscripts a and g denote absolute and control room pressures, respectively. It is to be remembered that equations (2) through (7a) apply only at the critical point.

If the secondary orifice is the controlling orifice as far as critical flow is concerned, equation (4) can be written as

$$C_h = \frac{FH_a - FN_a}{FH_a} \quad (8)$$

Where FN is the front nozzle barrel pressure. A flow equation similar to equation (1) may be written for a double orifice assembly as

$$F_c = K_p (FH - P_{an})^{\frac{1}{m_p}} = K_s (P_{an} - FN)^{\frac{1}{m_s}} \quad (9)$$

or

$$P_{an} - FN = \left(\frac{K_p}{K_s} \right)^{m_s} (FH - P_{an})^{\frac{m_s}{m_p}} \quad (10)$$

But

$$\begin{aligned} FH - FN &= (FH - P_{an}) + (P_{an} - FN) \\ &= (FH - P_{an}) + \left(\frac{K_p}{K_s} \right)^{m_s} (FH - P_{an})^{\frac{m_s}{m_p}} \end{aligned} \quad (11)$$

Substitute (11) into (8) to obtain

$$R_s = \frac{(FH_a - P_{an a}) + \left(\frac{K_p}{K_s} \right)^{m_s} (FH_a - P_{an a})^{\frac{m_s}{m_p}}}{FH_a} \quad (12)$$

Subscripts p and s refer to primary and secondary orifices respectively. Assuming $n_p \approx n_s$ and expressing the pressures as control room gage pressures, equation (12) becomes

$$R_s = \frac{(FH_g - P_{ang}) \left[1 + \left(\frac{K_p}{K_s} \right)^{m_s} \right]}{FH_g + 15 - Z} \quad (13)$$

or

$$\begin{aligned} P_{ang} &= (1 - N_s) FH_g - N_s (15 - Z) \\ &= FH_g - N_s (FH_g - Z + 15) \end{aligned} \quad \begin{aligned} (14) \\ (14a) \end{aligned}$$

where

$$N_s = \frac{R_s}{1 + \left(\frac{K_p}{K_s} \right)^{m_s}}$$

From (14a)

$$N_s = \frac{FH_g - P_{ang}}{FH_g - 15 - Z} \quad (15)$$

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Equations (6) and (15) indicate that the pressure drop between upstream and downstream measurement points are nearly a fixed fraction of the pressure drop between the upstream pressure and the vena contracta pressure (the vena contracta pressure being essentially zero at the critical point). It is also apparent from these equations that large values of R_p and N_g are more desirable than small values.

R_p for the primary orifice has been found to depend on orifice entry geometry but not significantly on orifice diameter in a fixed orifice holder geometry. This may be expected. Since the tendency to cavitate is associated with a very low pressure at the vena contracta, any smoothing of the orifice entry tends to alleviate cavitation by producing a larger diameter vena and a larger static pressure at the vena for a given orifice diameter. Experimentation bears this out. An orifice with a rounded or tapered entrance results in a higher cavitation or critical point constant, R_p , and a higher critical flow rate than an orifice with a sharp entrance.

N_g for a secondary orifice depends on K and n for both primary and secondary orifices and thus depends on the orifice diameters as well as the entry shape. This arises only from the fact that it is more desirable to express a cavitation constant, N_g , as a function of front header and Panellit pressures rather than front header and front nozzle pressures. Consequently, the reproducibility of values N_g for different sets of orifices of the same diameter depends strongly on the reproducibility of K and n values for both orifices.

Table I presents selected experimental data showing the variation or lack of variation of the critical point constants, R_p and N_g , with front header pressure, orifice diameter, orifice entry shape, and orifice holder geometry.

Using a particular critical flow constant from Table I, the Panellit pressure at the critical flow point may be calculated for any desired front header pressure. If the observed Panellit pressure falls below the critical value predicted for a particular orifice geometry, that orifice assembly is probably running in critical flow. Because of variations between one orifice and the next, some suitable safety margin should be applied when determining whether an individual tube is operating sufficiently close to cavitation to warrant special treatment.

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TABLE I

SELECTED EXPERIMENTAL DATA AT THE
CRITICAL FLOW POINT

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Orifice Size Entry Shape	Limiting Orifice	Holder Geometry	Flow (gpm)	Front HDR Panellit Nozzle			Calculated Critical Flow Constant	% Deviation (5)	Parameter Illustrated	
				Pressure (psig)	Pressure (psig)	Pressure (psig)				
0.302 T (1)	0.302	C	45.0	415	101		$R_p = 0.73$	Orifice Diameter	Orifice Holder Geometry	
0.277 T	0.277	C	38.5	415	105		$R_p = 0.72$			
0.266 T	0.266	C	36.6	415	105		$R_p = 0.72$			
0.316 T	0.316	K	46.0	325	128		$R_p = 0.59$			
0.290 T								Orifice Diameter		
0.377 T	0.377	K	39.8	325	115	57	$N_s = 0.63$			
0.272 T										
0.332 T	0.332	K	33.2	325	121	47	$N_s = 0.59$			
0.257 T								Orifice Diameter		
0.290 T	0.290	K	27.7	325	152	52	$N_s = 0.51$			
0.191 R. (2)			18.8	500	186	93	$N_s = 0.609^{(4)}$	± 0.2	Orifice Entry Shape (6)	
0.252 S. (3)	0.252	B-558	19.6	545	205	105				
			31.8	500	171	-	$R_p = 0.638^{(4)}$	± 1.9		
0.243 R.	0.243	B-558	33.2	545	188	-				
0.191 R.			20.0	500	151	59	$N_s = 0.679$	Avg.		Front Header Pressure
0.243 R.	0.243	B-558	20.85	545	165	65	$N_s = 0.677$	0.676		
0.191 R.			19.8	500	150	59	$N_s = 0.667$	$\pm 0.6\%$		
0.243 R.	0.243	B-558	20.45	545	177	80	$N_s = 0.680$	- 1.3%		
0.191 T			20.45	500	135	38	$N_s = 0.703^{(4)}$	± 0.9		Orifice Entry Shape (6)
0.243 T	0.243	B-558	21.5	545	150	40				
0.221 T			29.0	500	114		$R_p = 0.75^{(4)}$	$+ 0.5$		
0.323 T	0.221	B-558	30.5	545	125					

(1) Orifice entry tapered - angle and length of taper varied for C and K reactors -30° included angle to midpoint for 558 orifices.

(2) Orifice entry rounded to $\sim 1/16$ " radius.

(3) Orifice entry sharp (i.e. no special entry preparation).

(4) Average values of N_s or R_p for several different specimens of the same size combination.

(5) Range of % deviation from average for any of the specimens tested.

(6) In comparing these various entry shapes, compare like constants, either R_p or N_s

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