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CORRELATION OF PRESSURE DROP DATA

ISOTHERMAL FLOW THROUGH STANDARD PROCESS TUBE ASSEMBLY

Prepared by: Carol A. Sege
Approved by: H. S. Labin H89: 1-5-50
Co-Ed. Sege. 1-5-50

Design Staff, Reactor Division, Design & Construction Division

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CORRELATION OF PRESSURE DROP DATA

ISOTHERMAL FLOW THROUGH STANDARD PROCESS TUBE ASSEMBLY

SUMMARY

The experimental data presented in HDC-1255 for the pressure drops through the various portions of a standard process tube assembly for isothermal flow are correlated in this report. Data include orifice sizes up to 0.310 inches.

The equations have been adapted for the calculation of pressure drops or flow rates for clean tubes in pile operation. A systematic procedure is outlined for determining the pressure drops through each portion of the tube assembly. A method is presented for calculating the flow rate through a process tube from header pressure and panellit gauge readings.

Sample calculations applied to "H" pile operation are appended. (See Appendix III)

RESULTS

The general equation for the pressure drop through any portion of the process tube assembly in terms of flow rate is:

$$-\Delta P = c (\text{gpm})^n, \text{ where } c \text{ and } n \text{ are constants}$$

$-\Delta P$ = pressure drop, psi
 gpm = flow rate, gallons per minute (constant temp. runs)

The test data for any section of the assembly was correlated by plotting pressure drop versus flow rate on log paper, drawing a straight line through the experimental points, and determining the constants "c" and "n" from the graph. The equations based upon the data plotted in Figures III - VIII were determined in this manner. The experimental points are shown on each graph.

Figures I and II are reproduced from HDC-1255 so that the reader may know the dimensions of the standard process tube assembly, the dummy loading pattern, and the location of the pressure taps.

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(P) CIRCLES DESIGNATE PRESSURE TAP LOCATIONS AND NUMBERS

SCHEMATIC SKETCH OF TEST EQUIPMENT

FIGURE NO. I

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PROCESS TUBE SLUG LOADING ARRANGEMENT

ALL SLUGS WERE 1.440" IN DIAMETER
THE SLUG LOADING ARRANGEMENT,
STARTING FROM THE DISCHARGE END
WAS AS FOLLOWS:

- 1 - 6.125" LONG STAINLESS STEEL
- 1 - 7.000" LONG STAINLESS STEEL (SEE SKETCH)
- 1 - 6.159" LONG CANNED LEAD
- 8 - 8.000" LONG PERFORATED ALUMINUM
(SEE SKETCH)
- 2 - 6.159" LONG CANNED LEAD
- 4 - 6.125" LONG SOLID ALUMINUM
- 64 - 4.390" LONG CANNED LEAD

48-5/16" HOLES
PERFORATED ALUMINUM SLUG

STAINLESS STEEL SLUG

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FIGURE NO. II

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FLOW RATE gpm

DC-1560

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DISCUSSION

The pressure drop through each portion of the process tube assembly is discussed. References are made to figures in the RESULTS section. The equations tabulated at the end of this section may be used to calculate pressure drops for non-isothermal flow provided that no boiling occurs. Factors for adapting these equations to the calculation of pressure drops through tubes of different dimensions have been included.

I Active Section

The pressure drop across the active section at constant temperature is plotted against flow rate in Figure III. The corresponding equation from Section F of HDC-1176 is also plotted for comparison. For the same flow rate and water temperature, the pressure drop predicted by the equation from HDC-1176 is about 9% lower than the experimental values.

II Standard Dummy Section

The pressure drop through the standard dummy section is shown as a function of flow rate in Fig. IV. The pressure drop through the dummy section is composed of the drop through the portion containing solid slugs and the drop through the portion containing perforated slugs, both of which are shown in Fig. IV. The loading pattern is given in Fig. II. The pressure drop per unit length through the perforated slugs is only 14% of that through the solid slugs.

III Pressure Drop from Inlet Header to Panellit Gage

In HDC-1176 the pressure drop from the inlet header to the panellit gage, with an orifice in the line, was represented by the equation.

$$(1) \Delta P_{1-3} = \frac{W^2}{A_o^2 K^2} \left[1 - \left(\frac{A_o}{.237} \right)^2 \right]$$

A_o = orifice area, in.²

W = lb/hr. of H₂O

ΔP_{1-3} = pressure drop from inlet header to panellit gage

$K_1 = 17.9 \times 10^3$

This pressure drop may be more accurately visualized as the sum of a pressure drop through the inlet pigtail and a drop across the orifice. The data from these experiments has shown that the drop through the pigtail varies as $(W)^{1.8}$ while the drop across the orifice varies as $(W)^2$, thereby making equation (1) limited in application.

A. Pressure Drop through Pigtails

The pressure drop through the pigtail is shown as a function flow rate in Fig. V. It should be noted that, for the apparatus used in these tests, the total pressure drop through the inlet pigtail was greater than the drop through the outlet pigtail. Variations in pigtail pressure drops are to be expected since the bends in the pigtails are not likely to be uniform.

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B. Orifice Pressure Drop

The portion of the pressure drop between the inlet header and the panellit gage due to the drop across the orifice is given by equation (2).

$$(2) \Delta P_o = \Delta P_{1-3} - \Delta P_p = \frac{W^2}{A_o^2 K^2} \left[1 - \left(\frac{A_o}{.237} \right)^2 \right]$$

ΔP_{1-3} = pressure drop from inlet header to panellit gage, psi

ΔP_o = portion of ΔP_{1-3} due to pressure drop across orifice, psi

ΔP_p = portion of ΔP_{1-3} due to pressure drop through pigtail = .102 (gpm) 1.8.
(See Fig. IV)

$$K = 19.5 \times 10^3$$

K is an average of 17 values which are tabulated in Appendix I for various orifice sizes and flow rates.

IV Pressure Drop between Panellit Gage and Inlet Nozzle

The pressure in the inlet nozzles can be higher than the pressure recorded at the panellit unit. Since the panellit gage is located near the vena contracta of the orifice, there is a pressure recovery between the panellit gage and the inlet nozzle. The pressure regain is usually greater than the entrance loss between these two points. These experiments have provided sufficient data to calculate these effects independently of each other.

A. Entrance Loss

The entrance loss from the panellit gage to the inlet nozzle is plotted as a function of flow rate in Fig. VI. The entrance loss data was obtained from the test in which there was no orifice in the line.

B. Pressure Regain

The pressure regain from the panellit gage to the inlet nozzle is shown as a function of flow rate for various orifice sizes in Fig. VII. The pressure regain for a given flow rate and orifice size was determined from the experimental data by adding the entrance loss from Fig. VI to ΔP_{1-4} . The equations of the lines shown in Fig. VII are given in Table I.

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TABLE I

Pressure Regain from Panellit Gage to
Inlet Nozzle for Various Orifice Sizes (from Fig. VII)

<u>Orifice Size, inches</u>	<u>Pressure Regain, psi</u>
0.310	$\Delta P_R = 3.4 \times 10^{-3} (\text{gpm})^{2.5}$
0.270	$\Delta P_R = 6.2 \times 10^{-3} (\text{gpm})^{2.5}$
0.240	$\Delta P_R = 9.4 \times 10^{-3} (\text{gpm})^{2.5}$
0.200	$\Delta P_R = 14 \times 10^{-3} (\text{gpm})^{2.5}$
0.175	$\Delta P_R = 20 \times 10^{-3} (\text{gpm})^{2.5}$
0.140	$\Delta P_R = 27 \times 10^{-3} (\text{gpm})^{2.5}$

V Overall Pressure Drop

The total pressure drop between the inlet and exit headers through a standard process tube assembly is plotted as a function of flow rate for various orifice sizes in Fig. VIII. Figures III, IV, and V show that the pressure drops through the active section, dummy section, and pigtaills, which comprise the largest portions of the total pressure drop, vary as $(\text{gpm})^{1.8}$. Therefore, the equations given in Fig. VIII, in which total pressure drop varies in the same manner, will give a rapid and reliable estimate of the pressure drop through the standard tube assembly.

VI Summary of Equations

Upon the basis of the experimental data correlated in this report, the procedure listed below is recommended for determining the pressure drop through the process tube assembly or any portion thereof under non-boiling conditions. Corrections for temperature, length, and area have been taken from HDC-1176.

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Pressure Drop Location
Inlet Header to Panellit Gage

Recommended Equation or Graph

$$\Delta P_{1-3} = \Delta P_o + \Delta P_p$$

$$-\Delta P_o = \frac{W^2 \left[1 - \left(\frac{A_o}{A_0} \right)^2 \right]}{A_o^2 K^2}$$

$$-\Delta P_p = 22.2 \left(\frac{W}{10^4} \right)^{1.8}$$

or see Fig. V, Curve II

$$K = 19.5 \times 10^3$$

Panellit Gage to Inlet Nozzle

$$\Delta P_{3-4} = \Delta P_E + \Delta P_R$$

$$-P_E = 5.07 \left(\frac{W}{10^4} \right)^{1.5}$$

or see Fig. VI

$$\Delta P_R = \text{See Table I or Fig. VII}$$

Unloaded Section and Annulus
Contraction

$$-\Delta P_{4-5} = 149 \left(\frac{W}{10^4} \right)^{2.7}$$

(V at inlet H₂O temp.)

Active Section

$$-\Delta P_{5-6} = 320 \left(\frac{60}{t} \right)^{0.2} \left(\frac{W}{10^4} \right)^{1.8} L_V$$

(V and t at average H₂O temp.)

See Fig. III for L = 23.4 ft.

and H₂O temp. = 60°C.

Dummy Section

$$\Delta P_{6-7} = \Delta P \text{ solid slugs} + \Delta P \text{ perf. slugs}$$

$$-\Delta P \text{ solid slugs} = 320 \left(\frac{60}{t} \right)^{0.2} \left(\frac{W}{10^4} \right)^{1.8} L_{SV}$$

$$-\Delta P \text{ perf. slugs} = 45 \left(\frac{60}{t} \right)^{0.2} \left(\frac{W}{10^4} \right)^{1.8} L_{pV}$$

(V and t at outlet H₂O temp.)See Fig. III for ΔP_{6-7} with
standard dummy loading and H₂O
temp. of 60°C.

Outlet Pigtail

$$-\Delta P_{7-9} = 22.2 \left(\frac{W}{10^4} \right)^{1.8}$$

or see Fig. VI, Curve II

Inlet Header to Outlet Header

$$\Delta P_{1-9} = \Delta P_{1-3} + \Delta P_{3-4} + \Delta P_{4-5} + \Delta P_{5-6} +$$

$$\Delta P_{6-7} + \Delta P_{7-9}$$

or see Fig. I

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- * The temperature dependence of the equations recommended for determining ΔP_{4-5} , ΔP_{5-6} , and ΔP_{6-7} has been assumed to be the same as that reported in HDC-1176. Most of the tests of HDC-1255 were performed at only one water temperature, namely 6° C. For different annulus dimensions, the pressure drop in the solid sections can be modified by multiplying by the factor $\left(\frac{0.351}{A}\right)^{1.8} \left(\frac{0.153}{D_e}\right)^{1.2}$, where A is the new cross-sectional area for flow in sq. in., and D_e is the equivalent diameter of the annulus in inches.

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APPENDIX ITable of Nomenclature

- A - cross sectional area for flow, inches²
 A_o - orifice area, inches²
 c - a constant
 D_e - equivalent diameter, inches,
 gpm - flow rate - gallons per minute
 K - orifice constant, 19.5×10^3
 K_1 - orifice constant from HDC-1176, 17.9×10^3
 L - length of active section, ft.
 L_s - length of solid slugs in dummy section, ft.
 L_p - length of perforated aluminum slugs in dummy section, ft.
 n - a constant
 ΔP - pressure drop, psi
 ΔP_E - entrance loss between panellit gage and inlet nozzle, psi
 ΔP_o - pressure drop across orifice, psi
 ΔP_p - pressure drop through pigtail, psi
 ΔP_R - pressure regain after orifice between panellit gage and inlet nozzle - psi.
 ΔP perforated slugs - pressure drop through portion of dummy section containing perforated slugs, psi.
 ΔP solid slugs - pressure drop through portion of dummy section containing solid slugs, psi.
 t - temperature ° F.
 V - specific volume, $\frac{ft^3}{lb}$, at temperature, t
 W - flow rate, lb/hr.
 1, 2, 3, ... 9 subscripts refer to pressure tap locations in Figure I.

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APPENDIX IITabulation of K, Orifice Constant for Various Flow Rates and Orifice Sizes

Orifice Diameter	Flow Rate	ΔP_o	K
inches	lb/hr	psi	
0.310	1.183×10^4	58.7	19.5×10^3
	1.168×10^4	54.4	19.9×10^3
	1.07×10^4	43.1	20.2×10^3
	$.97 \times 10^4$	35.2	20.6×10^3
	$.87 \times 10^4$	29.8	19.9×10^3
0.270	1.09×10^4	98.8	18.7×10^3
	1.08×10^4	92.0	19.2×10^3
	$.99 \times 10^4$	73.0	19.6×10^3
	$.88 \times 10^4$	60.2	19.3×10^3
	$.78 \times 10^4$	46.4	19.4×10^3
0.240	1.00×10^4	133	18.8×10^3
	$.99 \times 10^4$	127	19.2×10^3
	$.90 \times 10^4$	112	19.7×10^3
	$.79 \times 10^4$	81.2	19.2×10^3
	$.70 \times 10^4$	61.1	19.5×10^3
0.200	$.85 \times 10^4$	186	19.6×10^3
0.175	$.70 \times 10^4$	230	19.0×10^3

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APPENDIX III

Calculation of Pressure Drops and Flow Rates in "H" Pipe

Operating Data (from H. A. Laybourn - 12/8/49)

Tube No: #2469

Orifice Zone: 0.285"

Dummy Loading Pattern:

Header Pressure: 355 psia

Panellet Pressure: 245 psia

In Exit Nozzle {1-5ⁿ Perf. Aluminum slug
 {1-5ⁿ " " "

Exit Nozzle Pressure: 69.5 psia

10-8" Perf. Aluminum slugs

Inlet H₂O Temp: 12° C.

4-8" Solid

Outlet H₂O Temp: 49° C.

Calculations of Exit Nozzle Pressure by Method on Page 14

A. Calculations of Water Flow Rate in Tube #2469

$$\Delta P_{\text{header to panellit}} = \Delta P_0 + \Delta P_p$$

$$-\Delta P \text{ header to panellit} = \frac{w^2 \left[1 - \left(\frac{A_0}{237} \right)^2 \right]}{A_0^2 K^2} + 22.2 \left(\frac{w}{10} \right)^{1.8}$$

$$355 - 245 = 59.4 \left(\frac{W}{10^4} \right)^2 + 22.2 \left(\frac{W}{10^4} \right)^{1.8}$$

$$W = 1.166 \times 10^4 \text{ lb/hr}$$

$$1.166 \times 10^4 \text{ lb/hr} = 23.3 \text{ gpm}$$

B. Calculation of Pressure Drops

$$1) \Delta P_{\text{panallit to inlet nozzle}} = \Delta P_E + \Delta P_R$$

$\Delta P_H = 13.1$ psi (by interpolation for
.285" orifice from
Fig. VII)

$$\Delta P_E = 5.07 \left(\frac{W}{10^4} \right)^{1.5} = -6.4 \text{ psi}$$

$$\Delta P_{\text{panellit to inlet nozzle}} = 13.1 - 6.4 = +6.7 \text{ psi}$$

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Appendix III (cont'd)

$$2) \Delta P_{\text{unloaded section and annulus contraction}} = -149 \left(\frac{w}{10^4} \right)^2 V$$

$$= -3.2 \text{ psi} \quad V = .0160 \text{ at } 12^\circ \text{C.}$$

$$3) \Delta P_{\text{active section}} = -320 \left(\frac{60}{t} \right)^{0.2} \left(\frac{w}{10^4} \right)^{1.8} L V$$

$$= -147.5 \text{ psi}$$

$$L = 23.41 \text{ ft.}$$

$$t = \frac{12 + 49}{2} = 30.5^\circ \text{C.} = 87^\circ \text{F.}$$

$$V = .0161 \frac{\text{ft}^3}{\text{lb}}$$

$$4) \Delta P_{\text{dummy section}} = \Delta P_{\text{solid slugs}} + \Delta P_{\text{perforated slugs}}$$

$$-\Delta P_{\text{solid slugs}} = 320 \left(\frac{60}{t} \right)^{0.2} \left(\frac{w}{10^4} \right)^{1.8} L_s V \quad t = 120^\circ \text{F.}$$

$$\Delta P_{\text{solid slugs}} = -15.9 \text{ psi} \quad V = .0162 \frac{\text{ft}^3}{\text{lb}}$$

$$L_s = \frac{32}{12} \text{ ft.}$$

$$\Delta P_{\text{perf. slugs}} = -45 \left(\frac{60}{t} \right)^{0.2} \left(\frac{w}{10^4} \right)^{1.8} L_p V \quad L_p = \frac{80}{12} \text{ ft.}$$

$$= -5.6 \text{ psi}$$

$$\Delta P_{\text{dummy section}} = -5.6 - 15.9 = -21.5 \text{ psi}$$

$$5) \Delta P_{7-8} = -7 \text{ psi (estimated)}$$

$$6) \sum \Delta P_{\text{calculated}} = +6.7 - 3.2 - 147.5 - 21.5 - 7 = -172.5 \text{ psi}$$

$$\sum \Delta P_{\text{from operating data}} = -175.5 \text{ psi}$$

Equations from HDC-1176 led to a 200 psi pressure drop or an error of 14%. The flow rate calculated from the header-panellit readings was 24.9 gpm. This value was used to calculate pressure drops between the panellit gage and the outlet nozzle.

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