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DESIGN CONSIDERATIONS FOR A PULSE COLUMN SYSTEM

I. Introduction

The pulse column, a countercurrent flow, vertical type extractor originally described by W. J. D. Van Dijck, (1) has been investigated by the Chemical Research Section and the Chemical Development Section with respect to its adaptability to solvent extraction systems represented by the Redox and TBP processes. The results have been very favorable. The H.T.U. values have been lower than obtainable with packed columns and the capacities and flooding rates are almost as high as those obtainable with large packing. In the development of complete engineering specifications relating the performance of the solvent extraction unit to spacing of the perforated plates, size of the perforations, percentage "open" area, pulse frequency, pulse amplitude, it appears that only experimental studies will reveal the desired information. However, the design information concerned with the quantitative force or pressure effects of pulsation on the pulse transmitting system and the pulse column proper are subject to mathematical analysis as illustrated in the following development:

II. Objectives

The objectives of this investigation were to evaluate the hydraulic forces in the pulse column, and determine their effects on pulse column design.

III. Summary and Conclusions

The important pressures in the system are the hydrostatic heads and

(1) U. S. Patent 2,011,186, August 13, 1935

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the acceleration pressure in the pipe line connecting the pulse generator to the column. This pressure may be computed for any point of the cycle; it reaches a high negative value at the pulse generator when the pulse flow changes from positive to negative. The minimum value of the acceleration pressure is given by

$$P_{\min.} = \frac{-8\pi k l \rho w^2}{D^2 g}$$

where k = half cycle pulse volume
l = length of pipe
 ρ = density of solution in pipe
w = cycles per unit time
D = diameter of pipe
g = acceleration of gravity

Since k, l, ρ , w, and D are commonly presented in the inconsistent units of cubic inches, feet, specific gravity, cycles per minute, and inches, and since g is constant, it is desirable to revise the constant term, thus

$$P_{\min.} = -7.83 \times 10^{-6} \text{ lbs ft}^{-1} \text{ in}^{-3} \text{ min}^2 \frac{k l \rho w^2}{D^2}$$

where the dimensions are now cubic inches, feet, specific gravity, cycles per minute, and inches respectively, and $P_{\min.}$ is in pounds per square inch.

If the algebraic sum of the absolute pressures (atmospheric, hydrostatic, and acceleration) is less than the vapor pressure of the pulsed fluid, cavitation will occur and the system will be inoperable.

From this equation it may be shown that a pulse distributes itself between two connecting vessels such as a column and a jackleg, so that the volume entering each vessel is proportional to the cross-sectional area and inversely proportional to the lengths.

IV. Discussion

The pulse column system components are:

1. Pulse generator. A single or multiple piston-cylinder system with adjustable length stroke driven by a constant speed driver.
2. A transmitting system. This consists of a constant diameter pipe line joining the pulse generator to the base of the column.

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3. A pulse column. This consists of a vertical cylinder containing fixed horizontal close fitting perforated plates. The diameter is constant within the portion of the column containing the perforated plates. A larger diameter settling chamber surmounts the mixing or extraction section.

The forces and resistances in the pulse column system have been arbitrarily divided as indicated below. They will be examined in the order listed.

1. Acceleration
2. Hydrostatic
3. Fluid friction

1. Acceleration

The method for determining the forces resulting from the acceleration of a fluid in a conduit of constant cross sectional area apply to all parts of the pulse system, i.e., column section, transmission line and fittings. In the following development only the force due to acceleration of the fluid in the transmission line will be examined inasmuch as that is the major one. The case for the forces in the column due to acceleration is identical in development.

The force required to accelerate an object is equal to its mass times its acceleration ($F = ma$), or its weight times its acceleration divided by the acceleration of gravity ($F = W \frac{a}{g}$). The weight of the fluid in the pipe is

$$W = l \rho A$$

where l = length

ρ = density

A = cross-sectional area

The acceleration is the first derivative of the linear velocity, which we will compute by way of volume velocity from the total material that has passed a given point.

Let

$$V = \frac{k}{2} \sin 2\pi wt + Lt$$

where

V = total material past a given point at time t

k = half cycle pulse volume

w = cycles per unit time

t = total elapsed time

L = light phase flow rate

At time $t = 0$ the position of the pulse generator piston is midstroke.

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The term "Lt" represents the amount of light phase that has passed a given point from the steady state flow. The term " $\frac{1}{2} \sin 2\pi wt$ " represents the pulse. When $wt = n$, where "n" is an integer, the pulse term is zero. As wt increase to $n + 1/4$, corresponding to a quarter term of the pulse pump, the term $\frac{1}{2} \sin 2\pi wt$ also increases to $\frac{1}{2}$, the maximum value of the pulse amplitude. At $n + 1/2$ we are back to zero, and $n + 3/4$ we get the minimum value. At $n + 1$ a new cycle starts.

$$\frac{dV}{dt} = k\pi w \cos 2\pi wt + L$$

is the rate of change of volume with time, or the flow rate. If we divide this by the cross-sectional area "A" we have the linear velocity.

$$\frac{dV}{Adt} = \frac{k\pi w \cos 2\pi wt + L}{A}$$

The rate of change of the linear velocity with time is the acceleration, or

$$a = \frac{-2 k\pi^2 w^2 \sin 2\pi wt}{A}$$

The force necessary for such accelerations is thus:

$$F = W \frac{a}{g} = (1/A) \frac{(-2k\pi^2 w^2 \sin 2\pi wt)}{A g}$$

But pressure is force per unit area so:

$$P = \frac{(1/A) (-2k\pi^2 w^2 \sin 2\pi wt)}{A g} = \frac{-2 1/A k\pi^2 w^2 \sin 2\pi wt}{A g}$$

or, since $A = \frac{\pi D^2}{4}$ where D is the diameter

$$P = \frac{-8\pi 1/A k w^2 \sin 2\pi wt}{D^2 g}$$

This equation is valid in any system of units. Since it is accepted practice to express pressure in terms of pounds per square inch the constant is revised. Consolidation of the conversion factors necessitated by the use of the units shown below for the other terms in the equation results in a

constant with the value of $7.83 \times 10^{-6} \frac{\text{lbs min}}{\text{ft in}^3}$

$$P = \frac{-(8)(3.1416)(62.4 \text{ lbs ft}^{-3}) 1k w^2 \sin 2\pi wt}{(32.2 \text{ ft sec}^{-2})(60 \text{ sec min}^{-1})^2 (1728 \text{ in}^3 \text{ ft}^{-3}) D^2}$$

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$$P = \frac{7.83 \times 10^{-6} \text{ lbs min}^2}{\text{ft in}^3} kl \rho_w^2 \sin 2\pi wt$$

The equation above is valid in any units, but more particularly, gives P in pounds per square in. when

k = half cycle pulse volume - cubic inches

l = length of line - feet

ρ = specific gravity - dimensionless

w = cycles per minute

D = diameter of pipe - inches

For design consideration, the only cases we are interested in are the cases where P reaches its minimum (most negative) pressure. At this point $\sin 2\pi wt = 1$, hence

$$P_{\min} = -7.83 \times 10^{-6} \frac{\text{lbs min}^2}{\text{ft in}^3} \frac{kl \rho_w^2}{D^2}$$

Connection in series

For units in series with different cross-sectional areas, such as a transmission line with different diameters and a column, the individual pressures due to acceleration are additive.

Connection in parallel

For units in parallel, such as the pulse column and its jackleg, the distribution of forces may be found as follows:

The pressure in the column at the point of attachment of the jackleg will be the same as in the bottom of the jackleg and may be determined as indicated.

$$P = \frac{-8\pi kl \rho_w^2 \sin 2\pi wt}{D^2} = \frac{-8\pi k'l' \rho_w^2 \sin 2\pi wt}{D'^2}$$

$$\text{or } \frac{kl}{D^2} = \frac{k'l'}{D'^2}$$

$$\text{or } \frac{k}{l} = \frac{l'}{k} \times \frac{D'^2}{D^2}$$

Hence, the pulse distributes itself among two communicating vessels directly proportional to the squares of the diameters and inversely as the lengths.

2. Hydrostatic head

By selecting the point of entrance of the pulse transmission line into

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the column as the datum plane and calculating the individual static pressures in the transmission line and column the hydrostatic head becomes the sum of the two pressures if the generator is below the datum plane or the difference of the column pressure minus the transmission line pressure if the generator is above the datum plane.

3. Frictional forces

The frictional forces in a pulse column system are low, and generally may be neglected in designing a pulse column system. They are included for purposes of illustration in the detailed example in the appendix.

Illustrative examples

For purposes of illustration a case approaching the conditions expected in the TBP process will be considered.

Given:

Column diameter	20 in.
Pulse amplitude in column	1/2 in.
Line length (existing line through concrete)	15 ft.
Line diameter (existing line through concrete)	2 in.
Specific gravity of fluid in line	0.803
Vapor pressure of fluid in line	0.3 p.s.i.
Pressure in vapor space above column	14.7 p.s.i.
Hydrostatic head between top of column and pulse pump	0.0

To find:

What is the maximum frequency at which this system can be operated?

Allowable acceleration pressure at pulse pump
 $-14.7 + 0.3 = -14.4$ p.s.i.

Pulse volume

$$k = \frac{(20)^2}{(2)} \frac{\pi}{2} = 157 \text{ in}^3$$

$$-14.4 = \frac{7.83 \times 10^{-6} \times 157 \times 15 \times 0.803 \times w^2}{2^2}$$

$$\frac{(14.4)(4)}{7.83 \times 10^{-6} \times 157 \times 15 \times 0.803} = w^2$$

$$w^2 = 3900$$

$$w = 63.5 \text{ cycles/min.}$$

Example II

Given

Column

Height	12 ft.
Diameter	20 in.
Pulse amplitude in column	0.5 in.
Specific Gravity (average)	1.26
Pulse frequency cycles/min.	50.

Pipe lines (Section A and B)

Section A

Length	16 ft.
Diameter	4 inches
Specific Gravity	0.803

Section B

Two existing lines through concrete
in parallel, each

Length	15 ft.
Diameter	2 inches
Specific Gravity	0.803

Hydrostatic head at pulse pump	0.0
Vapor pressure at pulse pump	0.3 p.s.i.
Pressure at top of column	14.7 p.s.i.

To find - Will it operate?

A. Find k

$$k = \left(\frac{20}{2}\right)^2 \frac{\pi}{2} = 157 \text{ in}^3$$

B. Find acceleration pressure in each section.

1. Column

$$P_{\min.} = \frac{-7.83 \times 10^{-6} \times 157 \times 12 \times 1.260 \times 50^2}{20^2} = -0.11 \text{ p.s.i.}$$

2. Section A of pipe

$$P_{\min.} = \frac{-7.83 \times 10^{-6} \times 157 \times 16 \times .803 \times 50^2}{4^2} = -2.5$$

3. Section B of pipe

$$P_{\min.} = \frac{-7.83 \times 10^{-6} \times 157 \times 15 \times 0.803 \times 50^2}{2 \times 2^2} = -4.6 \text{ p.s.i.}$$

C. Find minimum pressure at pulse pump

$$P = 14.7 - 0.11 - 2.5 - 4.6 + 0 = 7.5$$

P is greater than 0.3, the vapor pressure of the pulsed fluid, and the system will operate.

Appendix

A Redox system as defined below was comprehensively examined under two conditions. The results illustrate the negligible effect of factors other than hydrostatic head and pressure due to acceleration.

System Dimension and Operating Conditions

	<u>Case I</u>	<u>Case II</u>
Column Diameter, Inches	8.0	8.0
Column Height, Feet	15.0	15.0
Number of Plates	60	60
Free Area of Plates, percentage	23	23
Length of Transmission Line, Feet	25	100
Diameter of Transmission Line, Inches	1.5	1.5
Pulse Frequency, Cycles/Min.	60	60
Pulse Amplitude, Cu. In./Stroke	25	45
Pulse Amplitude, In./Stroke	0.50	0.90
Elevation of Generator above Base of Column, Feet	0	25
Specific Gravity, In Column	1.3	1.3
Specific Gravity, Light Phase In	0.80	0.80
Light Phase Flow Rate, Gals./Hr./Sq.Ft.	1320	1320
Heavy Phase Flow Rate, Gals./Hr./Sq.Ft.	660	660

Pressure and Resistance

Values of wt

	0	1/4	1/2	3/4
<u>Case I</u>				
Hydrostatic	8.45	8.45	8.45	8.45
Fluid Flow Friction	0.12	1.11	.12	-0.43
Acceleration	+6.29	0	-6.29	0
Atmospheric	14.7	14.7	14.7	14.7
Absolute pressure at pulse generator	29.56	24.26	16.98	22.72

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0 1/4 1/2 3/4

Hydrostatic	-0.22	-0.22	-0.22	-0.22
Fluid Flow Friction	00.42	5.68	0.42	-4.11
Acceleration	45.36	0	-45.36	0
Atmospheric	14.7	14.7	14.7	14.7
Absolute pressure at pulse generator	60.26	20.16	-30.46	10.37

Case II is not operable, as the pressure at the pulse generator drops below the vapor pressure of the pulsed fluid, and cavitation will occur.

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