Optimising Candle Filters for Incompressible Cakes

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Two problems involving maximising the production rates in candle filters are discussed. The first relates to the determination of the best spacing of the cylindrical filter elements for a specific slurry, given the slurry concentration and the permeability and porosity of the cake. The second problem involves finding the best operating procedure for an existing filter and a particular slurry. Given the tank diameter, pump characteristics, dead time when the filter is out of operation at the end of a batch, and the requirements for washing, the operator can only manipulate the pump rate and the cake formation time. Methodology for determining the best operating conditions are developed.

Cake thickness is the major element in determining the best spacing for tubular elements. In general, maximum production rates are obtained with thin cakes when the rate of cake formation is low. Thick cakes and wide spacing of tubes are indicated for slurries which produce rapid build-up. Low permeabilities and low concentrations result in low rates of cake formation with the reverse being true for high permeabilities and concentrations.

Due to the complexity of the problem, this paper is restricted to incompressible cakes, but the methodology can be adapted to compactible cakes. Although the conclusions based on incompressible behaviour provide a reasonable guide for compressible cakes, it should be emphasised that changes in the operating parameters can have a substantial effect on the results.

THE AVERAGE rates of production of filtrate and wet solids resulting from the operation of a filter depend upon a large number of factors. In general, the quantity of produced liquid, wash liquid, dry solids, and liquid remaining in the wet cake are of interest. Maximising either filtrate or solid rates, minimising wash liquid or liquid remaining in the cake, and cost minimisation are among topics of interest. Although seldom mentioned in the literature, compromise design of filters aimed at providing nearly optimal results for materials having a wide range of permeabilities and compressibilities is of industrial significance and can be addressed by techniques discussed in this paper.

The focus of this paper will be on maximising the volume of filtrate per unit of time. The cycle rate Q_c per unit height of tank is defined by:

$$Q_c = \frac{NV}{t_F + t_w + t_D} \qquad (1)$$

where N = number of tubes;
V = volume of filtrate per unit height of tube;
subscripts F, w, D refer respectively to cake formation, washing, and dead times.

If the tube and cake radii are given respectively by r_1 and r_2, the cake volume V_c per unit height for a single tube is:

$$V_c = \pi r_1^2 (R_2^2 - 1) \qquad (2)$$

where $R_2 = r_2/r_1$.

The filtrate volume per unit height is related to the cake volume by:

$$V = \frac{F}{1-F} V_c \qquad (3)$$

where $F = \phi_s/\varepsilon_s$ with ϕ_s and ε_s representing respectively the volume fraction of solids in the slurry and cake.

The specific problem addressed in this analysis involves a tank with a diameter of 107cm and tubes of radius r_1 = 3.175cm arranged in a triangular manner. For this design, the number of tubes is related to the pitch p_t (centre to centre distance between tubes) by:

$$N = (6.976 + 9.4p_t)/p_t^2 \qquad (4)$$

Although this formula does not give the exact value of N, it provides an excellent approximation. The maximum value occurs

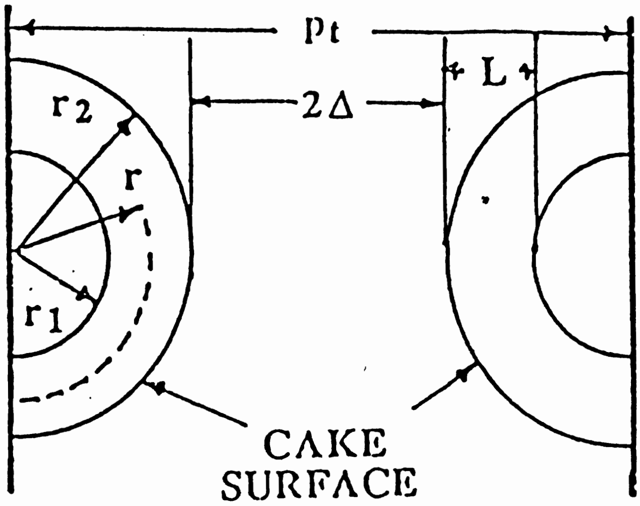

Fig 1. Geometric relationships

when the tubes touch and $p_t = 2r_1$; with p_t = 2·3.175 = 6.35cm. Eq (4) yields 174 for N.

Geometric relationships as illustration in Fig 1 lead to the following relations:

$$p_t = 2(r_1 + L) + 2\Delta = 2(r_2 + \Delta) = 2r_1 (R_2 + R_\Delta) \qquad (5)$$

where $R_\Delta = \Delta/r_1$.

Using these equations leads to the following equation giving the cake thickness (cm) in terms of N and R_Δ:

$$L = r_2 - r_1 = \frac{2.913}{N} [1 + \sqrt{1 + 0.02652N}] - 3.175(0.5R_\Delta + 1) \qquad (6)$$

We next turn to finding the time required to produce a cake of thickness L.

Cake Formation Time

In this summary, we shall restrict ourselves to the simple case of constant pressure filtration for which the filtration time t_F is given by:

$$t_F = M [R_2^2 \ln R_2 - (0.5 - KR_m/r_1)(R_2^2 - 1)] \quad M = \frac{F}{1-F} \frac{\mu r_1^2}{2Kp} \qquad (7)$$

where μ = viscosity;
K = permeability;
p = pressure drop across the cake and medium.

Assuming that no washing is involved, t_F can be substituted in Eq (1) to give the cycle rate. The parameters N, R_Δ, t_D, r_1, R_m, and M affect the cycle rate. Two examples are shown in Figs 2 and 3.

In Fig 2, the cycle rate is shown as a function of L and N at dead times ranging from 5-53.3min. A short dead time of 5 minutes is typical of the COPPEE filter developed in Brazil[1]. At a dead time of 5 minutes, a cake of about 1.0cm thickness will produce a rate which is approximately five times the maximum possible rate when t_D = 53.3min and L is between 2 and 2.5cm.

In Fig 3, the effect of changing permeability is demonstrated. Permeabilities range from 1.0E(−12)m² (very easy to filter) to 1.0E(−15)m² (difficult to filter). Assuming uniform spherical particles and the validity of the Carman-Kozeny equation, a permeability of 1.0E(−12) corresponds to 12 micron particles. The micron size of the particles is shown along with the permeability on the curves in Fig 3. As the size of the particles change, the medium resistance would change with a coarse medium being used for the large particles. We assumed that $R_m K$ = 0.001 leading to values of R_m ranging from 1.0E(−9) to 1.0E(−12)(1/m). The ratio of the maximum rates for the two extremes is about 6. The number of tubes drops from about 65 to 10. The cycle rate per unit area of the 12 micron particles is calculated as being about 40 times the rate per unit area of the 0.36 micron

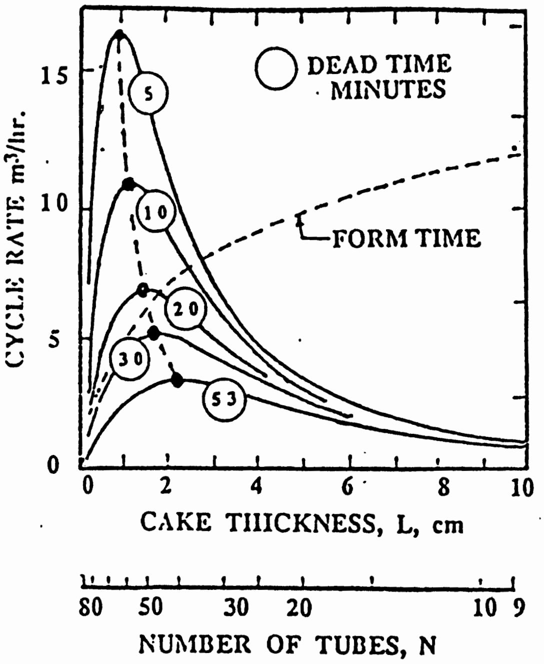

Fig 2. Cycle rate vs L and N with varying values of t_D.
$p = 500kPa\ (4.9atm)$; $\phi_s = 0.02$; $\mu = 0.001 Pa{\cdot}s\ (1.0cp)$; $\epsilon_s = 0.40$; $K = 1.0E(-14) m^2$; $R_m = 1.0E(11) m^{-1}$

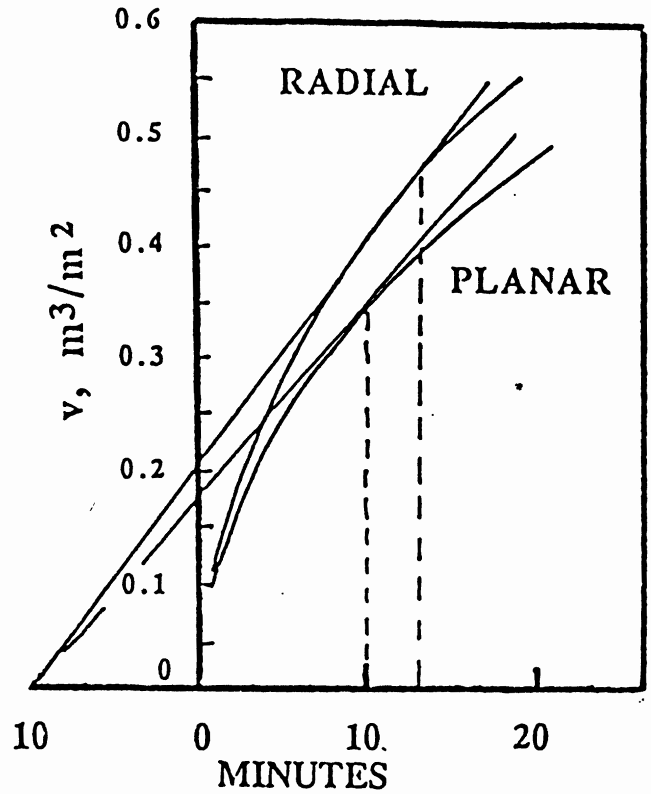

Fig 4. Graphical determination of optimum cycle rate. Parameters same as in Fig 2 with $K = 1.0E(-14) m^2$; $R_m = 0$

particles. The thin cake (about 6mm) suggested for the very resistant cake (0.36 microns) permits augmentation of the number of tubes and surface area in comparison with the 12 micron particles. That increase in area partially offsets the lowered permeabilities.

Comparison of Radial and Planar Filtration

In planar filtration, as occurs in presses and leaf filters, it is commonly understood that for a non-washing filtration with negligible medium resistance, the maximum cycle rate occurs for both constant pressure and constant rate when the time of filtration equals the dead time. That relationship depends upon the existence of a parabolic relation between the filtrate volume V and t.

Letting $R_m = 0$ in Eq (7) leads to:

$$t = M\,[R_2^2 \ln R_2 - 0.5\,(R_2^2 - 1)] \tag{8}$$

Replacing R_2 by the volume of filtrate per unit surface area of tube, we arrive at:

$$t = 0.5M\,[(Gv + 1)\ln(Gv + 1) - Gv \tag{9}$$

where $v = V/2\pi r_1$ and $G = 2(1 - F)/r_1 F$.

For constant pressure filtration on a planar surface:

$$t = \frac{\mu F}{2(1 - F)Kp} v^2 = \frac{M}{r_1} v^2 \tag{10}$$

In Fig 4, plots of Eqs (9) and (10) are depicted. Lines drawn at a tangent to the two curves from a point representing a dead time of 10min leads to the optimum times of 10min for the planar filtration and 13min for the candle filter starting with the same area.

It can be shown generally that the optimum time for a candle filter is always larger than the dead time. Consequently, it is not possible to use the condition of $t_F = t_D$ as developed for planar filtration. If the volume vs time relationship is not parabolic, different criteria will apply. Among situations not having parabolic behaviour are:

- ☐ Pressure supplied by centrifugal pump;
- ☐ Horizontal surfaces with substantial sedimentation;
- ☐ Vertical surfaces with varying thickness due to sedimentation;
- ☐ Non-Newtonian liquids in slurry;
- ☐ High medium resistance with thin cakes.

The large number of possible cases and the associated wide differences in behaviour make it difficult to arrive at general guidelines for optimising filter performance.

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A more comprehensive version of this paper covering other aspects of optimisation is available from the authors.

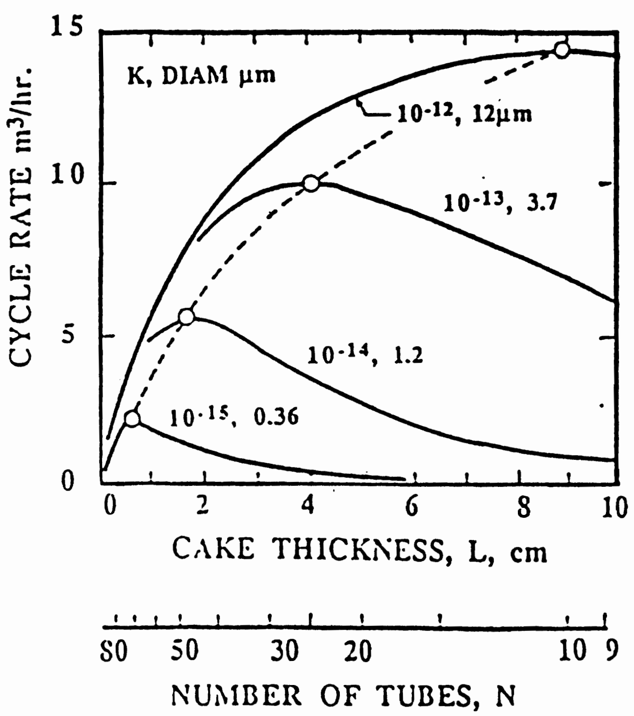

Fig 3. Cycle rate vs L and N with varying values of K. Conditions same as in Fig 2 except $KR_m = 0.001$