Experimental Determination of Specific Filtration Resistance Under Constant Pressure

Atishendu Gupta
Shashank Bharti

Introduction

In many stages of papermaking, water is removed from the pulp slurries and many of these operations are essentially the application of filtration. Some of the examples are washing of pulp stock after cooking and bleaching, various stages of thickening, sheet formation on papermaking wire and recovery of fibers from white water.

Basically filtration is the mechanism of fluid flow through a porous medium. Filtration may be conducted according to any desired schedule; but most of the theoretical developments have been restricted to either constant pressure differential across the filter mat, or a constant rate of filtration. The former is of particular interest in the papermaking process on a cylinder mould because during almost whole of the sheet forming process the pressure difference which causes water drainage through the forming wire, remains constant and is equal to the difference of stock level in the vat and the white water level inside the cylinder. In this paper, filtration under constant pressure only is considerad.

Atishendu Gupta and Shashank Bharti, Research Scholars, Technical University of Lodz, Institute of Papermaking and Papermachines, Poland.

Though for a long time stock freeness is considered to be a criteria for drainage properties of fibres, but freeness has no direct relation with the rate of drainage through a fiberous mat. The drainage behaviour can be more exactly predicted if the specific filtration resistance of the fibers could be determined under the same condition (or at least under a simulated condition) as in the actual process. Specific filtration resistance is an important property of pulp slurry and is a reliable index of drainage behaviour which can be utilized in the design and operation of commercial equipments

Principle of filtration

During filtration, fibers in the pulp slurry are retained on the filter medium and form a fiberous mat through which the filtrate must flow. On its way, filtrate meets the resistance of the mat which has already been deposited and the resistance associated with the filter medium.

Fig. 1 shows diagramatically a section through the porous mat and

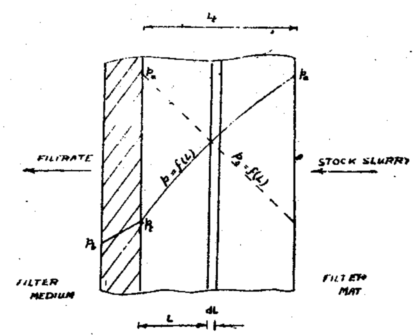

Fig. 1: Distribution of fluid pressure (p) and stress pressure (p_s) in the filter mat at any time 't'.

the filter medium at a definite time t seconds from the start of the filtration process. At this time thickness of the mat, measured from the filter medium at right angle to it is 'L' cm*. The filtration area measured perpendicular to the direction of fluid flow is 'F' cm^2. Considering a layer of mat of thickness 'dL' cm. at a distance 'L' cm. from the filter medium, let the fluid pressure at this layer be p dyne/cm^2. Assuming that the filtrate flow velocity through this mat is sufficiently low to ensure laminar flow, Kozeny-Karman equation for rate of filtration may be written as[1]:

$$q=\frac{1.dQ}{Fdt}=\frac{1}{K}\cdot\frac{\varepsilon^3}{\mu(1-\varepsilon)^2S^2}\cdot\frac{dP}{dL} \quad (1)$$

*The suffix 't' to any symbol denotes the final value of the symbol after a definite time t.

where:

dQ/dt — rate of filtration, cm^3/sec

q — flow rate of filtrate per unit area or superficial flow velocity of filtrate, cm/sec

ε — porosity of the mat, dimensionless

S — external specific surface of a single fiber. cm^{-1}

dp/dL — pressure gradient across the layer of thickness dL, $dyne/cm^3$

K — a constant, dimensionless

μ — viscosity of the slurry, dyne. sec/cm^2

The thickness of the elemantary mat under consideration may be expressed in terms of the fibers as:

$dm=\rho(1-\varepsilon).F.dL$

where:

ρ — density of fibers, g/cm^3

dm — mass of fibers in thickness dL, g

The terms K, S and ε in eqn. 1 depend on the stress presure P_s which is zero at the upstream face of the filter mat where the fluid pressure is P_a and is maximum and equal to P_a at the filter medium[2]. At the layer under consideration, the stress pressure is $P_s=P_a-P$. Therefore eqn. 1 may be writteu as :

$$-\frac{d(P_a-P)}{KS^2(1-\varepsilon)/\varepsilon^3\rho}=\frac{\mu q}{F}.dm \quad (1_a)$$

The term $KS^2(1-\varepsilon)/\varepsilon^3\rho$ is the specific filtration resistance[2,3] (cm/g) and is represented by 'r'. Integrating eqn. (1_a) under the boundry conditions

$m=0$ when $P_a-P=0$ and

$m=m_t$ when $P_a-P_t=\triangle P_{1t}$, where $\triangle P_{1t}$ is the pressure drop across the mat at time t. We get the basic equation for pressure drop through the fiberous mat as follows:

$$q=\frac{1}{F}\cdot\frac{dQ}{dt}=\frac{\Delta P_{1t}}{\mu r_1 m_t/F)} \quad \ldots (3)$$

Eqn. 3 reveals that the specific filtration resistance is the pressure drop required to give unit filtrate flow velocity when the viscosity of filtrate is unity and the mat contains unit mass of fibers per unit mat area. Han[4] interpreted it as the derivative of total filtration resistance with respect to the basis weight of the mat formed because in the analysis of drainage, the concept of a constant filter medium is a conventional starting point[5]. If this additional resistance is denoted by R (cm^{-1}), then by an analogy with eqn. 3 we get

$$q=\frac{1.\ dQ}{F\ dt}=\frac{\triangle P_{2t}}{\mu R} \quad \ldots \ldots (4)$$

where:

$\triangle P_{2t}$ — pressure drop across the filter medium after time t, i. e., $\triangle P_{2t}=P_t-P_b$, P_b being the fluid pressure at downstream side of the filter medium (see fig. 1,) $dyne/cm^2$.

Since the overall pressure drop is sum of the pressure drops $\triangle P_{1t}$ and $\triangle P_{2t}$, we can write

$$q=\frac{\triangle P}{\mu\left(\frac{r\ m_t}{F}+R\right)} \quad \ldots \ldots (5)$$

where:

$\triangle P$ — overall pressure drop, $dyne/cm^2$.

If the quantity of fibers not retained on the filter medium and eventually has been carried along with the filtrate is neglected, then the mass of fibers deposited will be propertional to filtrate volume[6] and eqn. 5 becomes

$$dt/dQ=AQ+B \quad \ldots \ldots (6)$$

where:

$$A=\frac{C\mu r}{F^2\triangle P}$$

$$B=\frac{\mu R}{F\triangle P}$$

C — stock consistency, g/cm^3

and the final solution of eqn. 6 becomes

$$t=\frac{\mu}{\triangle P}\left[\frac{Cr}{2}\left(\frac{Q}{F}\right)^2+R\left(\frac{Q}{F}\right)\right] \quad (6_a)$$

Analytical explanation of eqn. 6 to calculate sp. fil. resistance

If a number of observations on filtrate volume collected as a function of time are made, then for any two successive observations, the ratio $\triangle t/\triangle Q$ (which closely represents dt/dQ in eqn. 6) can be calculated, where $\triangle t$ is the time between the observations and $\triangle Q$ is the increment of filtrate volume collected over the time period $\triangle t$. Since dt/dQ is a linear function of Q, a value of $\triangle t/\triangle Q$ is the slope of the 't' vs. 'Q' curve at a point $Q=(Q_1+Q_2)/2$, i. e., half-way between the observed values of Q that defines $\triangle Q$. Then arithmatic mean of each two successive observations of Q can be plotted against $\triangle t/\triangle Q$ for the same pair of readings. The best straight line through these points has a slope equal $A=C\mu r/F^2\triangle p$. Knowing 'A', value of 'r' can be calculated since other terms are known.

Experimental equipment and procedure

A simple apparatus (fig. 2) was fabricated for t vs. Q observations. The filtration tube was made of 68 mm ID cast iron with 7 overflow lines at a vertical distance of 100 mm from each other. Flanges at the bottom of the filtration tube permitted the insertion of a screen septum and a slide gate. The slide gate could be instantaneously opened or closed. Stock level inside the tube above the screen septum could be maintained at a desired height by opening one of the overflow line and closing the rest.

Well dispersed stock suspension was fed to the supply box. To avoid settling of fibers, an electrically driven agitator was used in the supply box. Stock was allowed to flow from the supply box to the filtration tube. When the desired head was built up in the filtration tube and overflow started, the slide gate was instantaneously opened to full. Filtrate was collected in a callibrated vessel and the volume of filtrate collected as a function of time, was noted. The mat formed on the screen septum was dried and weighed.

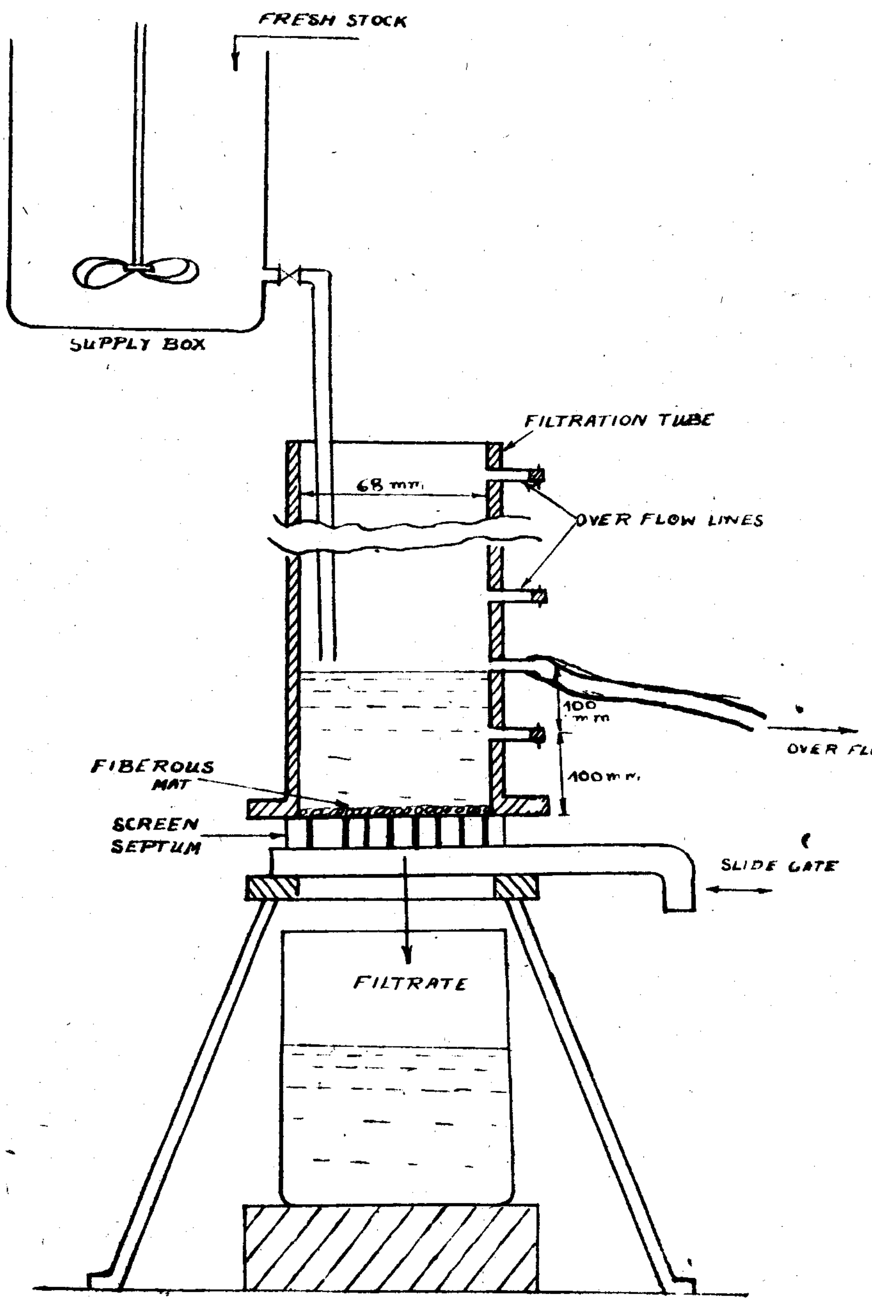

Fig. 2: Details of constant pressure filtration apparatus (not to scale).

With this apparatus the effect of the following variables on specific filtration resistance can be studied:

- Stock consistency (theoretically it has no effect[2])
- stock temperature (since temperature is related to viscosity)
- nature of filter medium
- filtration pressure
- extent of stock furnish
- additive-

However, only effect of pressure on specific filtratian resistance is presented here. Other variables arbitrarily chosen as follows: unbleached sulfite pulp at 0.3% consistency, freeness 45° SR, temperature 13°C, no additives and number 21 brass wire as screen septum.

Discussion on results

The volumes sf filtrate collected as a function of time for different fiitration pressures are shown in Fig. 3. specific filtration resistance is calculated from the slope (gradient) of $\Delta t/\Delta Q$ vs. Q plots as shown in Fig. 4.

Fig. 5 shows the calculated values

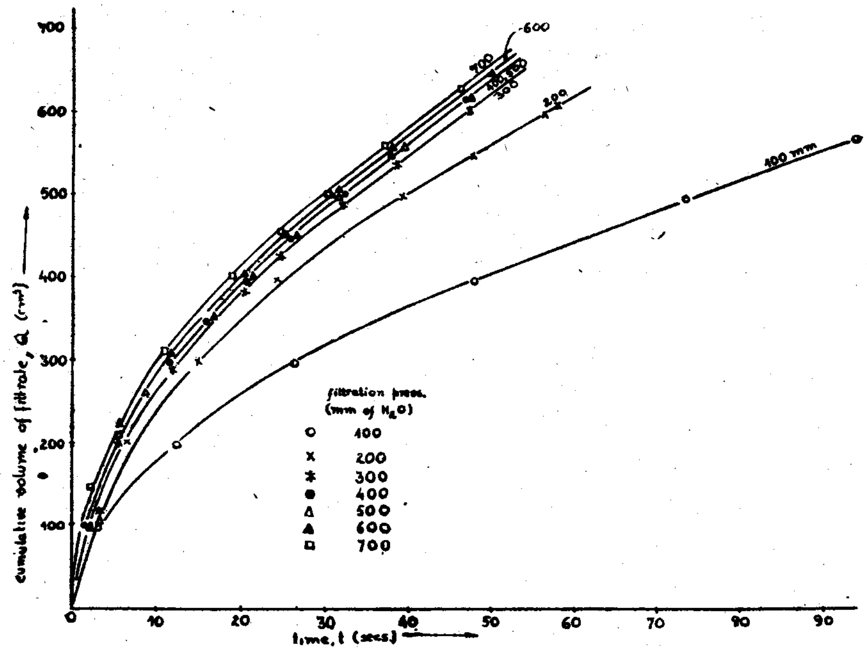

Fig. 3: Effect of filtration pressure on drainage.

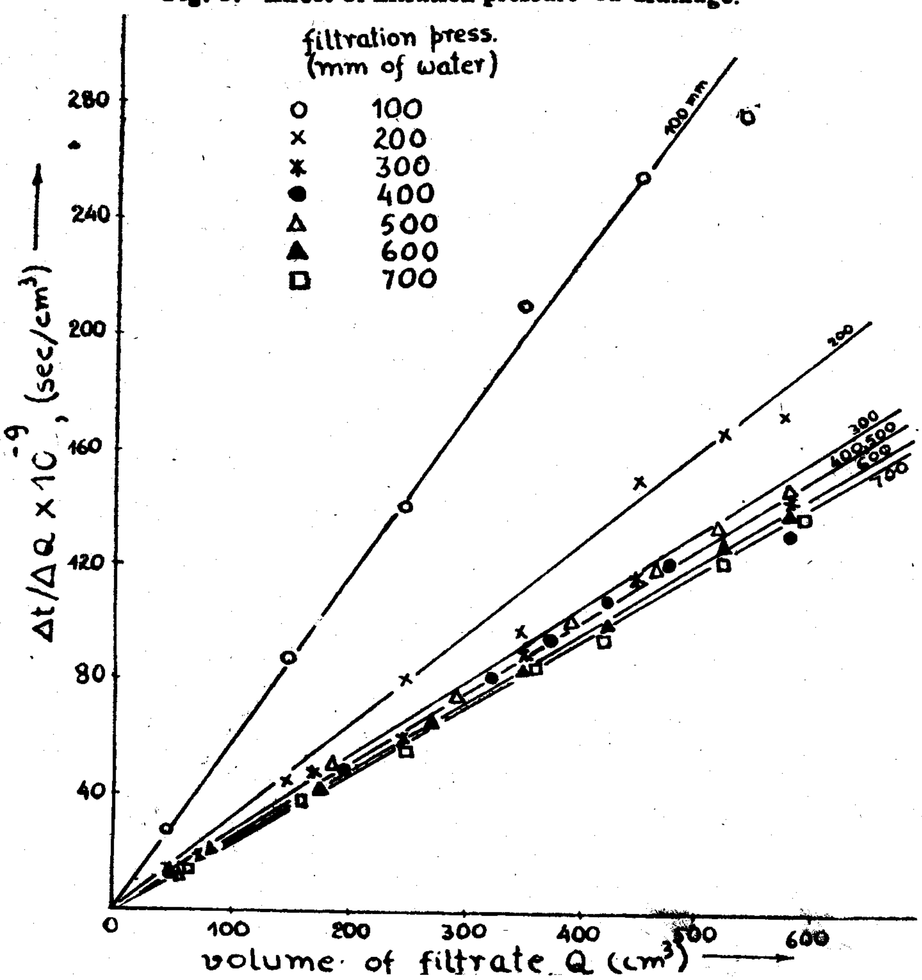

Fig. 4. Plot of $\Delta t/\Delta Q$ vs. Q. Data taken from fig. 3.

of specific filtration resistance as a function of filtration pressure $r=f(\Delta p)$.

From Fig. 5 it is clear that at low filtration preassures (upto 200 mm of water head), specific filtration resistance 'r' increases very slowly and nearly linearly with the pressure drop 'Δp.' Gradually rate of increase of specific filtration resistance with filtration pressure, $dr/d(\Delta p)$, increases with rise in filtration pressure (in the range 200 to 300 mm of water). This causes the curve to bend abruptly towards γ-axis. Again at higher pressures, the rate $dr/d(\Delta p)$ becomes almost constant i.e., the specific filtration resistance increases nearly linearly with filtration pressure. This may be explained as follows:

At low pressures, the fibers are loosely held up on the wire and the pores available for drainage are bigger in size. Therefore the resistance offered by the mat is small and it iincreases slowly as the mat becomes more compact with increasing filtration pressure. Increasing mat compactness also causes the fines to be retained which were previously able to pass through the pores. Thus $dr/d(\Delta p)$ increases more abruptly. But at higher pressures a state of saturation is reached from the view point of fine retention. Mat compactness only increases but relative retention of fines remains the same. Specific filtration resistance increases with increasing mat compactness but its rate of growth, $dr/d(\Delta p)$, remains almost constant.

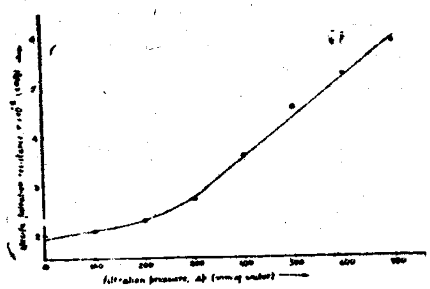

Fig. 5. Variation of specific filtration resistance with pressure.

Literature

1. Ingmanson WL., *Tappi*, 35(10), 439, (1952)

2. MaCabe, W.L. and Smith, J.C., Unit Operations, McGraw-Hill Book Co. Inc., New York, (1956)

3. Lapinski J., Maszyni i urzadznia papiernicze, cz III, Wydawnictwo Przemyslu Lekkiego Spozyczego, Warsaw, (1962)

4. Han, S. T., *Tappi*, 45 (4), 292, (1962)

5. Wrist, P. E., *Pulp and Pap. Mag. of Can.*, 55(6), 115,(1954)

6. Steenberg. B., Borgstrom J. and Kjensjord, R.I., *Svensk Papper-std.*, 31(2), 40, (1955).

Please remember