ChE-309 TP-7 : Filtration

instructions for use, spring 2025

Head of TP :
Matthieu Meoli
matthieu.meoli@epfl.ch

Course Leader :
Wendy L. Queen
wendy.queen@epfl.ch

1. Declaration of the objective

The new Chavalon gas-fired power plant is experimenting with a new method to sequester the CO_2 produced by their plant. They would like to add CaO to the water to create $Ca(OH)_2$. CO_2 is bubbled in this solution to create calcium carbonate $CaCO_3$. Since calcium carbonate is insoluble, it precipitates in the form of a fine dispersion. According to their calculations, they expect to have 1000 m^3/day of calcium carbonate suspension in the water, with a concentration of 2 g/L. Chavalon is then required to separate the calcium carbonate from the water before returning the water to the Rhône. The company has hired you to design a filtration system capable of accomplishing this task, and to offer your suggestions on the filtration process.

2. Theoretical basis.

2.1 Introduction

Filtration is a basic mechanical or physical operation widely used in the chemical industry, by which the solid particles present in a suspension are separated from the fluids (liquids or gases) by using a porous medium, which retains the solid but allows the fluid to pass through. The suspension to be filtered is called *slurry*. The solid medium used to retain the solid is called *a filter medium*. In general, the function of the filter medium is to act as a support for the filtration deposit, while the initial layers constitute the actual filter. The solid accumulated on the filter is called *filtration deposit* and the (more or less) clear liquid passing through the filter is called *filtrate*, *effluent* or *permeate*. The pores of the filter medium are finer than the size of the particles to be separated. The filter medium (e.g. filter paper, muslin cloth) is placed on a support. When the suspension arrives on the filter medium, the fluid flows through by virtue of a pressure difference exerted through the filter. The fluid column is subject to the action of gravity or pressure from a pumping system. The solid is trapped on the surface of the filter medium and accumulates during filtration to form a porous filtration deposit which in turn acts as an additional filter on the suspended particles. As the deposit (or “cake”) thickness increases, the flow resistance also increases until it is so high that the filtration stops.

The purpose of filtration can be to clarify the liquid or to recover the solid. In the case of clarification, the liquid is the valuable product and the solid, in minor quantities, is often disposed of without further processing. However, if it is the solid that one wishes to recover, it must very often be rinsed, wrung out and dried. *Rinsing* removes liquid contaminants from the pores between the particles in the filtration deposit. *Extraction* makes it possible to recover soluble matter from solid particles. The term *drying* refers to thermal drying, while the removal of liquid from the filtration deposit is called *spinning*. For example, it can be wrung out by gas pressure or mechanical compression.

The most important factors that affect filtration are:

- The loss of pressure between the feed and the downstream side of the filter medium
- The area of the filter surface
- The viscosity of the filtrate
- The resistance of the filtration deposit
- The resistance of the filter medium and the initial layers of the deposited cake

The filtration operation can be carried out in one of the following ways:

- Constant pressure filtration: the flow rate decreases over time.
- Constant flow filtration: the pressure increases over time.

Filtration is carried out by creating vacuum, or by applying pressure or centrifugal force. All this creates a pressure difference across the membrane, or filter medium, which is the driving force behind the reaction.

Vacuum filtration requires a vacuum pump. The pump removes the gas from the container of the filtrate, where the filtrate is separated from the gas. The filtrate is drained either by a barometric difference of at least 8 to 10 meters or by a pump capable of operating in "snore" (i.e. with a deficit of inlet fluid so that it tends to suck air). The big advantage of vacuum filters is that the deposit is directly accessible. This facilitates the automatic processing of the deposit. However, vacuum filters cannot work with hot liquids, or solvents with high saturating vapor pressures. The pressure difference across a vacuum filter is very limited, and the residual moisture of the deposit is higher than in the case of pressure filtration.

Pressure filtration typically requires only one pump to deliver the suspension and the filter is placed inside a pressurized container, and is therefore less easily accessible. Pressure filters are preferred when the product needs to be kept in a closed system for safety reasons, or if the residual moisture content is high. The treatment of the deposit is obviously more complicated in a pressure filter.

Centrifugal filtration is carried out in a centrifuge. Centrifugal force filtration requires more technical equipment, but allows in general to obtain solids with lower residual moisture.

Regardless of the driving force, the physical process of filtration can be described using several models:

- *Cake filtration* : the most frequently used model, which assumes that the solid settles on the filter medium (membrane or filter) as a homogeneous layer with constant permeability. Thus, if the flow rate dV/dt is constant, the pressure drop will increase linearly, in proportion to the amount of solid deposited. This model is particularly suitable for all hard, particle solids.

The initial stages of deposit formation are of great importance for the following reasons:

- For a given filtration pressure, the flow rate is higher at the beginning of the process, since the resistance is minimal.
- High initial filtration rates can cause the pores of the support to become clogged, causing a very high resistance to the passage of the fluid.
- The orientation of the particles in the first layers of the deposit can significantly influence the structure of the filtration deposit.

Filtration deposits can be of two types:

- **Compressible deposits**: with this type of deposit, an increase in the pressure difference or flow rate leads to the formation of a denser deposit, with a higher resistance.
- **Non-compressible deposits**: the flux resistance of a given volume of deposit is not significantly affected by the pressure difference through the filter, nor by the rate of deposition of the material.

- *Blocking filtration*: Pressure drop is caused by solid particles clogging pores. Soft or gelatinous particles retained by a sieve exhibit such behavior. If the dV/dt flow rate is constant, the pressure drop increases exponentially with the amount of fluid filtered, the number of free pores asymptotically approaching zero. The pores may belong to a filter medium, or they may be pores inside a filtration deposit consisting of thick particles, which are clogged by fine migrating particles.
- *Deep bed filtration* : solid particles are retained by a deep filter layer. This happens, for example, with sand filters for the clarification of drinking water, which retain even colloidal particles. The typical effect of deep bed filtration is the adhesion of solids to the grains of the filter, comparable to charcoal adsorption. Only relatively large particles are retained by filtering effect. When the filter has been saturated with the solid, the solid concentration in the filltrate flowing through the filter gradually approaches that of the feed suspension.
- *Tangential filtration* : in this model, the suspension flows at high speed, tangentially to the surface of the filter, preventing the formation of a deposit. Only a small flow of liquid passes through the filter medium. A certain layer of solid accumulates at the boundary with the filter surface and reduces the flow rate. After an initial period, a dynamic equilibrium is established between convective transport of the solid on the surface of the filter and displacement of the solid by turbulence and diffusion.

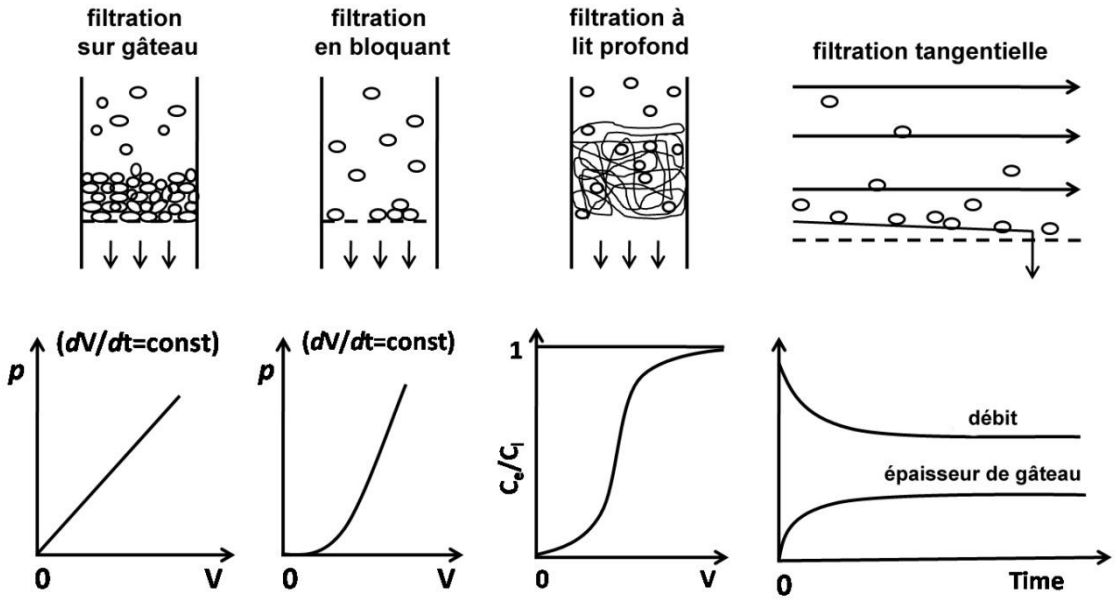

Figure 1. Filtration models

- *Surface filtration* is the opposite of deep bed filtration. The solid is retained on the surface of a filter medium. In general, the models of cake filtration or blocking filtration can be applied to it.

- *Screening* refers to a classification process that traps particles below a certain size and allows the smallest to pass through. The term "screening" is often used to refer to surface filtration with a sieve as filter medium. Its mode of operation is similar to "screening" as long as the filter medium is clean, but this clearly becomes a cake filtration as soon as a layer of solid has formed.

2.2 Types of Filtration Equipment: Filter Classification

Factors to consider when choosing an appropriate filter and optimal operating conditions include:

- The properties of the fluid: viscosity, density, corrosive properties

- The nature of the solid: particle size and shape, size distribution and filling characteristics

- The concentration of solid in the "slurry"

- The amount of material to be processed and its cost

- The type of product to be extracted: solid, liquid, or both

- The need to rinse the filtered solid

- The flow of suspension to be treated

Filters can be classified according to different criteria:

Criterion	**Filter type**
Solid retention	Surface, deep bed
Filtration technique	Cake, tangential, "screening"
Driving force	Under pressure, vacuum, mechanical pressure, magnetic/electric field, capillarity
Operation	Discontinuous, continuous, quasi-continuous, automatic, self-controlled, programmed, pre-coated
Filter element	1) bag, belt, candle/cartridge, disc, sheet/plate, Nutsche, pressing plate, tube 2) horizontal, vertical, single-element, multi-element, stationary, swivel 3) open, closed
Discharge of the solid	Scraper, vibration, centrifugation, discharge, rollover, manual
Application	Fast equilibrium systems, moderate and slow equilibrium systems, liquid clarification, glues, sludges and pulps, non-fluid systems

2.3 Filter medium and filter agents

Filter medium for industrial filtration must meet a number of conditions. First and foremost, it must remove the solid to be purified from the "slurry" and give a clear filtrate. In addition, the pores should not become clogged so that the filtration rate does not become too low. The filter medium must allow the deposit to be removed easily and cleanly. Obviously, it must have sufficient strength not to tear and must be chemically stable with respect to the solution used.

In some cases, the solid to be filtered is very thin and forms a dense, impermeable deposit, which quickly blocks any filter medium fine enough to retain them. In practice, the filtration of these materials requires that the porosity of the deposit increases to allow the passage of the fluid at a reasonable flow rate. This is achieved by using a filter agent.

Filter agents are inert powders, added to the liquid to be filtered, which increase the porosity and permeability of the deposit. They are very useful, provided that the presence of the filter

agent in the solid is tolerated. The filter agent can be separated from the filtration deposit later by dissolving the solid or burning the filter agent.

Filter agents are used in two ways:

- As a pre-coating layer, to protect the filter medium and improve the clarity of the liquid
- In suspension to increase the flow rate

Preliminary laboratory tests help identify the right agent type. The selection is done in three steps:

1) Selection of the right material, based on its chemical resistance and purity (perlite, diatomaceous earth, cellulose, carbon)
2) Selection of the grade (particle size) of the filter agent. The particle size should be as coarse as possible to give low filter resistance, but fine enough to prevent filtered particles from percolating through the pores of the deposit. For quality selection, a layer of pre-coating is prepared by filtering a diluted solution of filter agent. The solution is then filtered through this layer.
3) The selection of the quantity of filter agent. As a first approximation, a quantity of filter agent is used which gives a deposit of volume equal to the filtered material to be separated. It is then mixed with the suspension, and the filterability of the mixture is determined. If the flow rate is too low, the next trial is performed with a larger amount of filter agent.

2.4 Basic theory of filtration

The theoretical principle of filtration is based on the quantification of the basic relationship describing the velocity of a fluid:

$$v = \frac{F}{R} \qquad \text{(eq. 1)}$$

where:

F: driving force (gravity, pump thrust or centrifugal force)

R: the sum of the resistance exhibited by the filter medium and the solid deposit formed on top. The flow is hindered by the fact that the fluid must pass through an irregular medium, consisting of small ducts formed in the interstices of the deposit, and the filter medium.

2.5 Cake filtration: calculation of pressure drop

2.5.1 Definition of filter resistance and deposit permeability: Darcy's equation

The flow resistance of a cake filter can be described by Darcy's law (eq. 2) (see Figure 2). Consider a liquid flowing through a filtration deposit (or a trickle of water percolating through mud, as originally considered by Darcy). The pressure drop ***ΔP*** ***($P_{final} - P_{initial}$)*** of this flow is proportional to:

1) The flow rate per unit area *dV/(Adt)* [m/s]
2) The thickness of the cake *H* [m]
3) The *viscosity* μ of the liquid [N· s/m^2] or [Pa s]
4) A constant α_H describing the relative resistance of the cake as a function of its thickness [m^{-2}]:

$$-\Delta P_1 = \frac{\mathrm{d}V}{A \cdot \mathrm{d}t} \cdot H \cdot \mu \cdot \alpha_\mathrm{H} \quad [\mathrm{Pa}] \qquad \text{(eq. 2)}$$

The inverse of the resistance of the cake, also called permeability *k*, is given by:

$$k = \frac{1}{\alpha_\mathrm{H}} \qquad [\mathrm{m}^2] \qquad \text{(eq.3)}$$

Sometimes it makes more sense to define the thickness of the cake in terms of solid mass per unit area (in kg/m^2). This leads to a slightly different equation of resistance, with the following factors:

1) The flow rate per unit area *dV/(Adt)* [m/s]
2) The thickness of the cake m_s/A [kg/m^2]
3) The *viscosity* μ of the liquid [N· s/m^2] or [Pa s]
4) A *constant* α_M describing the relative resistance of the cake as a function of its mass [m/kg].

We get the following equation, instead of equation 2:

$$-\Delta P_1 = \frac{\mathrm{d}V}{A \cdot \mathrm{d}t} \cdot \frac{m_s}{A} \cdot \mu \cdot \alpha_\mathrm{M} \qquad \text{(eq. 4)}$$

For practical reasons, the viscosity μ is often not measured separately. It is then included in the term $\alpha_H \mu$ (in mPa · s/m^2) or $\alpha_M \mu$ (in mPa · s · m/kg), respectively.

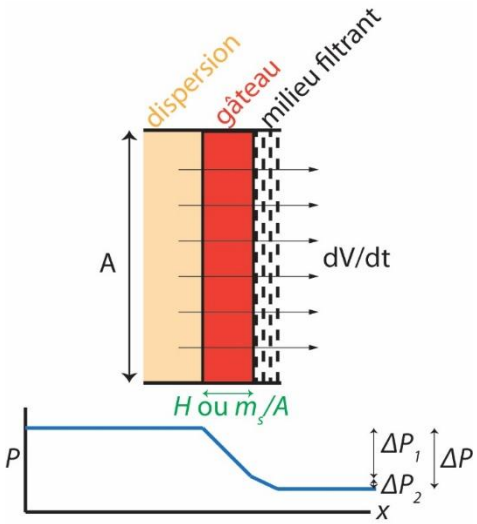

Figure 2. Definition of filter resistance: $\alpha_H \mu$ = resistance relative to the thickness of the cake; $\alpha_M \mu$ = resistance relative to solid mass

2.5.2 The cake filter equation

The total pressure drop through a filter is composed of the pressure drop ΔP_1 through the cake, given by Equation 2 (or 4), and the pressure drop ΔP_2 through the filter medium, which can be written as:

$$-\Delta P_2 = R_m \cdot \mu \cdot \frac{dV}{A \cdot dt} \qquad \text{(eq. 5)}$$

where *Rm* [m^{-1}] is the resistance of the filter medium.

The total pressure drop is therefore equal to:

$$-\Delta P = -\Delta P_1 - P_2 = \alpha_H \cdot \mu \cdot H \cdot \frac{dV}{A \cdot dt} + R_m \cdot \mu \cdot \frac{dV}{A \cdot dt} \qquad \text{(eq. 6)}$$

or

$$-\Delta P = -\Delta P_1 - P_2 = \alpha_M \cdot \mu \cdot \frac{m_s \cdot dV}{A^2 \cdot dt} + R_m \cdot \mu \cdot \frac{dV}{A \cdot dt} \qquad \text{(eq. 7)}$$

If the suspension is a homogeneous mixture, the thickness of the *cake H* (or m_s/A) will be proportional to the amount of filtrate.

The concentration is described by the K factor:

$$K_H = \frac{H \cdot A}{V} \qquad \text{(eq. 8)}$$

or

$$K_M = \frac{m_s}{V} \qquad \text{(eq. 9)}$$

This gives:

$$-\Delta P = \frac{\alpha_{\mathrm{H}} \mu K_{\mathrm{H}}}{A^2} \cdot V \cdot \frac{\mathrm{d}V}{\mathrm{d}t} + \frac{R_{\mathrm{m}} \mu}{A} \frac{\mathrm{d}V}{\mathrm{d}t} \qquad \text{(eq. 10)}$$

or

$$-\Delta P = \frac{\alpha_{\mathrm{M}} \mu K_{\mathrm{M}}}{A^2} \cdot V \cdot \frac{\mathrm{d}V}{\mathrm{d}t} + \frac{R_{\mathrm{m}} \mu}{A} \frac{\mathrm{d}V}{\mathrm{d}t} \qquad \text{(eq. 11)}$$

Differential equations 10 and 11 can be integrated either for a constant flow rate or for a constant pressure. Constant flow integration (*dV/dt* = const.) gives the solution:

$$-\Delta P = \frac{\mu}{A} \cdot \frac{\mathrm{d}V}{\mathrm{d}t} \cdot \left(\frac{\alpha_{\mathrm{H}} K_{\mathrm{H}}}{A} \cdot V + R_{\mathrm{m}} \right) \qquad \text{(eq. 12)}$$

or

$$-\Delta P = \frac{\mu}{A} \cdot \frac{\mathrm{d}V}{\mathrm{d}t} \cdot \left(\frac{\alpha_{\mathrm{M}} K_{\mathrm{M}}}{A} \cdot V + R_{\mathrm{m}} \right) \qquad \text{(eq. 13)}$$

For ΔP_{total}= const., the integration gives:

$$\mathrm{d}t = \frac{\alpha \mu K}{A^{2 \cdot (-\Delta P)}} \cdot V \cdot \mathrm{d}V + \frac{R_{\mathrm{m}} \mu}{A \cdot (-\Delta P)} \cdot \mathrm{d}V \qquad \text{(eq. 14)}$$

$$t = \frac{\alpha_{\mathrm{H}} \mu K_{\mathrm{H}}}{2A^{2 \cdot (-\Delta P)}} \cdot V^2 + \frac{R_{\mathrm{m}} \mu}{A \cdot (-\Delta P)} \cdot V \qquad \text{(eq. 15)}$$

or

$$t = \frac{\alpha_{\mathrm{M}} \mu K_{\mathrm{M}}}{2A^{2 \cdot (-\Delta P)}} \cdot V^2 + \frac{R_{\mathrm{m}} \mu}{A \cdot (-\Delta P)} \cdot V \qquad \text{(eq. 16)}$$

2.5.3 Specific resistance of the cake

The specific resistance of the cake, α, (α_{H} or α_{M}) is a function of the void fraction (porosity of the cake) ε and the specific surface of the particles in m^2, S_0. It is also a function of pressure, since pressure influences ε. By performing constant pressure experiments for different pressure drops, the variation of α with ΔP can be found. If α is independent of ΔP, the cake is incompressible. An empirical equation often used is:

$$\alpha = \alpha' \cdot (-\Delta P)^{\mathrm{s}} \qquad \text{(eq. 17)}$$

where α' and s are empirical constants. The compressibility constant s is zero for incompressible cakes. The constant s is usually between 0.1 and 0.8.

2.6 Filtration procedure

For the filtration of a given material, at constant concentration of suspended solid, the specific resistance and dry cake mass per unit volume of filtrate are constant; thus, the resistance of the cake varies proportionally with the volume of filtrate. Thus, equations 10 and 11 can be rearranged as:

$$\frac{\mathrm{d}t}{\mathrm{d}V} = \frac{\alpha\mu K}{A^2 \cdot (-\Delta P)} \cdot V + \frac{R_\mathrm{m}\mu}{A \cdot (-\Delta P)} \qquad \text{(eq. 18)}$$

This is the general equation for filtration, and it is valid for all types of *incompressible cake* filtration (for α_H, K_H or α_M, K_M). It has three variables: time, volume and pressure drop. All other terms are constant for the filtration of a specific material at constant concentration of the "slurry". Specific resistance is a property of suspended particles, but not of the concentration of the feed flow; while the dry cake mass per volume of filtrate is both a property of the suspended particles and the concentration in the slurry. Equation 18 can be solved by fixing one of the three constant variables.

By controlling the pressure difference so that it remains constant throughout the process, **constant pressure filtration** is achieved. It is clear that at constant pressure the filtration speed will decrease as the thickness of the cake as well as its resistance to filtration increases. For this type of filtration, it is often very useful to trace the instantaneous flow resistance as a function of the filtered quantity. The resistance is characterized by the pressure drop (–ΔP) related to the instantaneous flow rate dV/dt.

$$\frac{\mathrm{d}t}{\mathrm{d}V} = K_\mathrm{p} \cdot V + B \qquad \text{(eq. 19)}$$

$$\leftrightarrow t = \frac{K_\mathrm{p}}{2} \cdot V^2 + B \cdot V \qquad \text{(eq. 20)}$$

Where

$$K_\mathrm{p} = \frac{\mu \cdot \alpha_M \cdot K_M}{(-\Delta P) \cdot A^2} \qquad [\mathrm{s/m^6}] \qquad \text{(eq. 21)}$$

$$B = \frac{\mu \cdot R_\mathrm{m}}{(-\Delta P) \cdot A} \qquad [\mathrm{s/m^3}] \qquad \text{(eq. 22)}$$

To find K_p and B, it is then possible either to use equation 20 directly (and use a second order fit) or, as shown in Figure 3, linearize it (t/V = time of filtration over volume filtered) to obtain a graph of slope $K_p/2$ and intercept B.

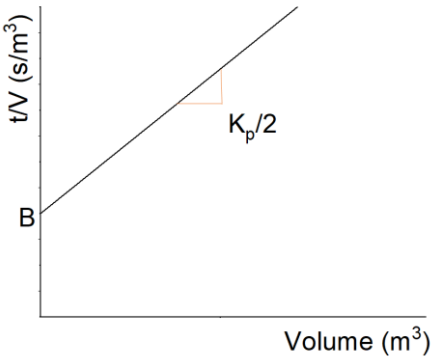

Figure 3. Determination of constants in the case of constant pressure filtration.

Once these constants are obtained, the values of α_M (or α_H) and R_{m} can be determined. To determine the effect of a pressure change, it is necessary to perform different tests at different pressures and calculate the compressibility constant *s*. For this, we represent log α as a function of $\log(-\Delta P)$, which gives a line of slope *s* and intercept at α'.

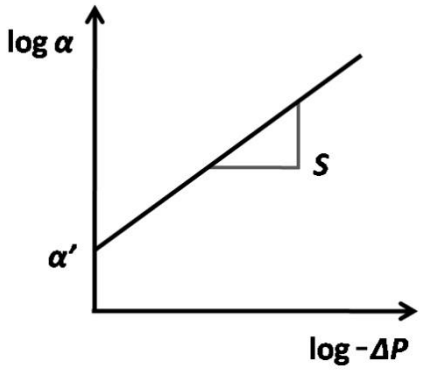

Figure 4. Determination of the compressibility constant s in constant pressure filtration.

The experimental determination, in a pilot plant, of the parameters K_p and *B* and that of R_m, α, s and $\alpha'$are necessary for the design or selection of a filter for a specific system, to choose the filtration medium that allows the maximum solid retention, and for the determination of the operating conditions (temperature, pressure,...).

On the other hand, if the flow rate dV/dt is constant, then the pressure drop through the filter cake will increase in direct proportion to the volume of filtrate passed (*V)*. In this case, the pressure will increase as the filtration process takes place, due to an increase in the thickness of the cake (and the resistance to filtration). For the study of filtration under these conditions, we can solve equation 18 in $(-\Delta P)$:

$$(-\Delta P) = \frac{\mu \cdot \alpha_M \cdot K_M}{A^2} \cdot \frac{\mathrm{d}V}{\mathrm{d}t} \cdot V + \frac{\mu \cdot R_{\mathrm{m}}}{A} \cdot \frac{\mathrm{d}V}{\mathrm{d}t} \qquad \text{(eq. 23)}$$

where:

$$\frac{dV}{dt} = q \qquad \text{(eq. 24)}$$

Since this is a constant speed process, equation 9 can be written as follows:

$$-\Delta P = K_v \cdot V + C \qquad \text{(eq. 25)}$$

where:

$$K_v = \frac{\mu \cdot \alpha_M \cdot K_M \cdot q}{A^2} \qquad [N/m^5] \qquad \text{(eq. 26)}$$

$$C = \frac{\mu \cdot R_m}{A} \qquad [N/m^2] \qquad \text{(eq. 27)}$$

Assuming that the cake is incompressible, K_v and C are characteristic constants of the "slurry", the cake, the flow etc... Thus, a plot of the pressure drop, $-\Delta P$, as a function of the total volume of filtrate collected, V, gives a line for a constant flow rate dV/dt. The slope of the line is K_v, and the intercept is C. The pressure increases with the thickness of the cake.

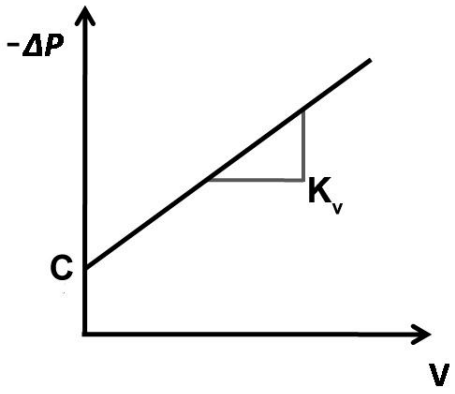

Figure 5. Determination of constants in constant flow filtration.

3. Practical Laboratory Exercises

3.1 Objectives

Your objective is the experimental determination, in a pilot plant, of the K_p and B parameters and that of R_m, α, s and α' of CLARCEL suspension in water, with a concentration of 10 g/L.

3.2 Description of the installation

To study CLARCEL filtration, you are equipped with a pilot plant with a stacked filter module (with 5 filter plates). Figure 6 demonstrates the principle of filtration. The system has a 100 L filtrate tank and a 120 L feed container equipped with an agitator. The filter system consists

of two stainless steel spacers (one is fixed and the other is mobile) and five filtration plates (two **end filtration plates** and three **intermediate filtration plates**). The number of these intermediate plates can be modified to allow the variation of the filtration surface. Each end filtration plate provides 1 filter surface whereas an intermediate filtration plate provides 2 filter surface. Each filter surface has an area of 0.0625 m^2. The total filtering surface is the product of (number of filter surface) and (surface area of one cloth filter). During filtration, the supply of the suspension arrives at the center of each plate, the filtrate passes through the filter cloth and is collected towards the channeled evacuation of each of the plates, while filter cakes are gradually formed in between the filtration plates. Before you start, it is important to familiarize yourself with the different valves and flow circuits!

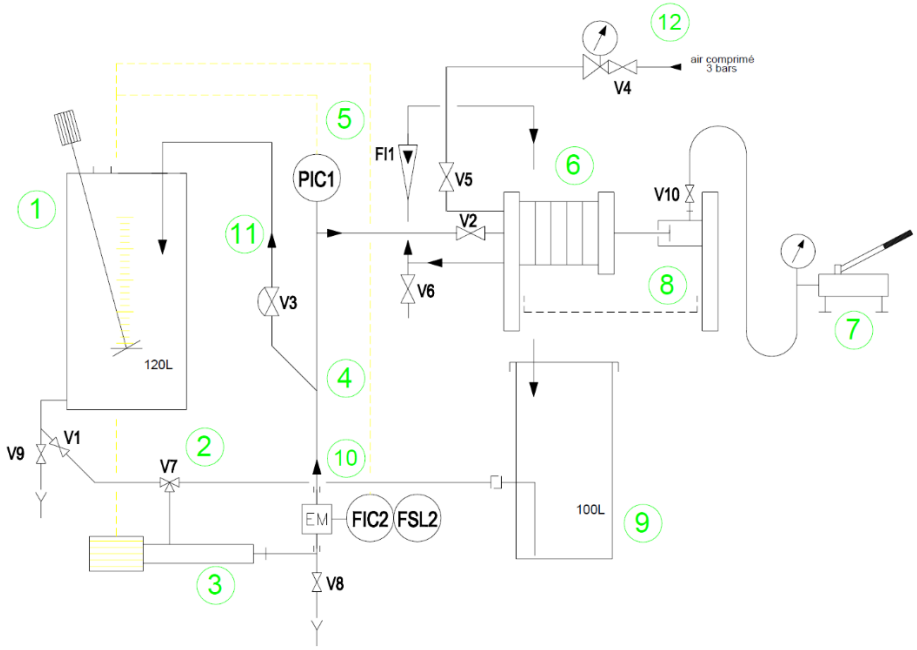

Figure 6: Illustration of the filtration system

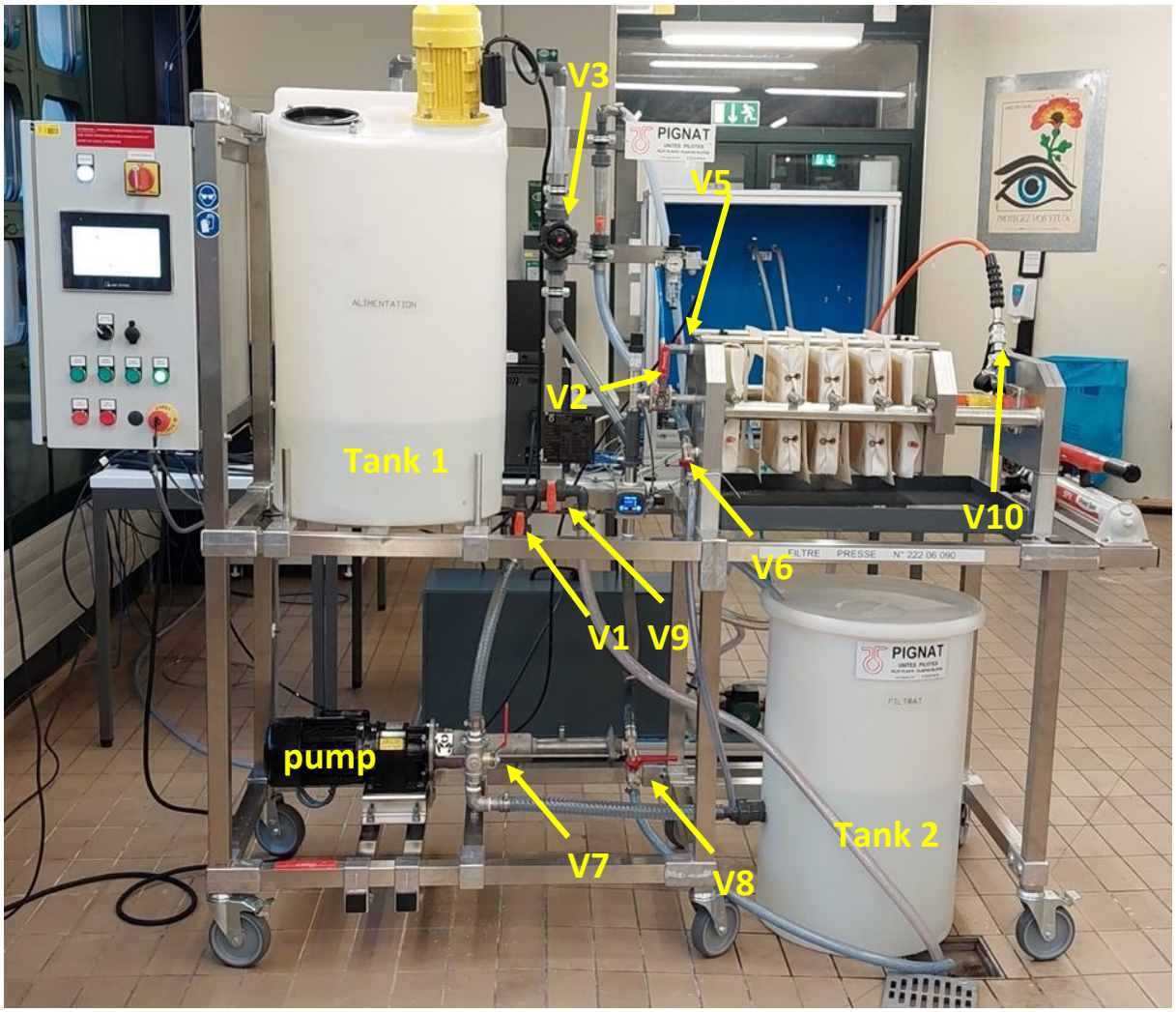

Figure 7: Picture of the installation

3.3 Experimental procedure

Careful! Observe the flow path and the arrangement of the valves. Always make sure the valves are in correct positions before turning on the pump. Please bring a USB stick with you !

3.3.1 System preparation

1. Check that the tanks 1 & 2 are clean and that the filtrate outlet hose is inside the collection tank 2.
2. Discuss the number of filter plates needed. Place the plates starting with the end plate on the left side, then other plates with the filtration drain on the front side, and finish with the right-side end plate. Push the movable stainless-steel spacer until it clamps the filtration plates.

3. Place a replacement element between the spacer and hydraulic cylinder head. Close oil pump valve, open valve V10 and pump until a pressure of 250 bar is achieved. Close valve V10 to maintain oil pressure in the cylinder and release oil pump valve.
4. Prepare the suspension to be filtered (10 g/L). Check that valves V1, V9 are closed. Fill tank 1 with water until you reach a volume of 100 L. Weigh the necessary amount, i.e. 1 kg of CLARCEL solid. Power up the control cabinet using the main switch. Start stirring and gradually introduce the solid into the tank to ensure the homogenization of the suspension. Open V1 when the suspension is homogeneous.

3.3.2 Constant pressure filtration

1. Ensure that the filters are well built (pressure on the plates maintains) and that the equipment is ready to carry out a filtration operation.
2. Open valve V3 and place valve V7 in the position to pump from tank 1 (valve V2 stay closed).
3. Set the pressure on the touchscreen to a desired value (between 0.5 bar and 2.0 bar maximum); the system should be able to maintain a constant pressure while filtration is ongoing. Press the green button on the control cabinet to start filtration. Make sure the flow is continuous and circulates back to tank 1 by observing hose 11. At the moment, the system works in a closed-loop.
4. To start the filtration, open V2 and close V3. At the **same time**, set the volume to zero (RAZ) on the touchscreen. Note the time (on the equipment) when the filtration starts. You should see the pressure increase slowly until the set value is reached.

   You can track the curves of different parameters on the touchscreen. Note the time when the setting pressure is reached and the time when it is impossible to keep the pressure constant.
5. When the pressure is not constant anymore and increases rapidly, stop the filtration. Switch the pump on dewatering mode (marche débâtissage). Keep pressing the dewatering button until most of the water has been sucked out from the plates and you start to see air bubbles in the hose. Close V2 and open V3.
6. Open **(slowly!)** V5 to blow the remaining liquid present in the filters. Close V5 when almost all the water was removed.
7. Pump the hydraulic cylinder to reach a pressure of 200 bar. Open the V10 to equalize the pressure and open the oil pump to retract the piston.
8. Collect the filter cake. Use a non-metallic spatula (plastic ruler) to gently scrape the cloth and collect the filter cake. Weigh the resulting wet cake mass (for the report, consider calculating the theoretical mass of the dried cake).

9. Rinse the filter cloth as well as the plastic spacers under running water, reassemble the plates with the right order and orientation.
10. Change your experimental parameter (e.g. setting pressure) and repeat the above procedures.

3.3.3 After filtration

1. When the filtration is done, position the valve V7 to pump the water from tank 9, stir and start filtration. Water from tank 9 will now be pumped back to tank 1. Drain the remaining suspension in tank 1 by opening V9. Repeat the operation until the tank and hoses are clean (use tap water if needed).
2. Make sure the filter plates and plastic spacers are abundantly rinsed under running water, the stainless-steel spacers are well cleaned.
3. Clean the working area, make sure there is no visible wet solid, powder or contamination.
4. Export data with a USB from the control cabinet. Afterwards, switch it off.

Report

In addition to the filtration characterization that you performed as described above, please answer the following:

Can you design a filtration system to treat the continuous flow of $CaCO_3$ indicated in the introduction (1000 m^3/day at a concentration of 2 g/L). Your system will consist of a filter and a storage tank. The $CaCO_3$ stream first flows into a tank and is then pumped (at 2.3 bar) into the filter. When the filter is saturated with the cake, the pump must be stopped and the filter must be cleaned (the flow of $CaCO_3$ will accumulate in the storage tank at this time). Assume that the filter is saturated when the flow rate has dropped to 10% of its initial value and take a time to clean the saturated filter cake by 5 min per m^2. What is the minimum filter area required to handle $CaCO_3$ flow? How much is needed for storage? Can you imagine a better way to design the filtration system?