Exercise 2A: Filtration in filter press

Course 28121: Chemical Unit Operations Laboratory

Team B

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A_{new}	Total cloth filtration area of upscale filtration unit	m^2
L	Cake thicknes m	
A_c	Cake area	m^2
K_c	Constant	n/a
M_0	Mass of the saturated wet cake before dryingkg	
M_{fn}	Mass of the saturated wet cake after drying	kg
t	time s	
Δp	Total pressure drop across the cake and cloth	Pa
α	Specific cake resistance	m/kg
c	Concentration of dry solids in suspension	kg/m^3
n	Moles	mol
MW	Molecular weight	g/mol
ε	Porosity	n/a
ρs	Density of the solid kg/	m^3
ρl	Density of the liquid	kg/m^3
W	Wash ratio	n/a
R_m	Resistance of filter cloth/plate	m^{-1}
q_0	Volumetric liquid flow	m^3/s
M_{ws}	Mass of wet solids in the cake	kg
M_s	Mass of dry solids in the cakekg	
M_l	Mass of aqueous solution of filter press	kg
$M_{effluent}$	Mass of effluent	kg
M_c	Mass of cellulose in solution	kg
S_∞	Irreducible cake saturation	%
μ	Viscosity of the filtrate = 0.00102 kg/(m*s) [3]	kg/(m*s)
A	Total cloth filtration area	m^2
V_0	Initial volume of suspension in the vessel	m^3
V_{wash}	Volume of water needed to decrease the conductivity of the effluent to city water conductivity	L
V_{fp}	Volume of filter press empty space	L

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Abstract

In this experiment the filtration of an insoluble fine grained product from an aqueous suspension is monitored using a traditional horizontal plate and frame filter press. The operation takes place in three parts: Preparation of the suspension, filtration and filter cake washing. After saturation the residual hold-up of liquid in the cake is minimized by blowing with compressed air (air deliquoring) through the filter. Cake volume, resistance in the filter cake/filter cloth and other filter properties are determined using a mathematical filter model and experimental results. The washing of the filter cake can be followed using conductivity measurements on the effluent. Suspension results are obtained from mixing 2 soluble salts which immediately produce an insoluble precipitate. We added 1.40 kg MgSO4, 7H2O 1.45 kg Na3PO4, 12 H2O 0.25 kg Cellulose fibre in total 150 litre suspension which is used for the whole filtration process. Progress of the filtration and washing vs. time as curves is discussed in depth. The concentration of insoluble dry solids of $Mg_3\left(PO_4\right)_2$ in the suspension is determined using two methods, first : Based on the initial volume of solution in the suspension, and the initial amount of $Mg_3\left(PO_4\right)_2$ in the suspension and Second : Based on the filter cake weight and effluent volume. Properties like specific filter cake resistance (α) , resistance of filter cloth/plate (Rm.) , filter press liquid hold-up i.e. the dead space and void volume in the press and cake are calculated. The properties of cake like the cake voidage, cake solid density and the irreducible cake saturation are calculated and reasons explored. Wash ratio and the possibility of ideal plug flow process in a filter press is discussed. Also a discussion for Mass Balance of Na_2SO_4 is done from the production point of view. The flow pattern and cake build up through the press during the 3 modes: Filtration, air deliquoring and washing, and their functioning is explained. And at last a hypothetical commercial set up is discussed

Introduction

Filtration is used in any industry to separate undissolved solids from the bulk liquid. Either the fluid or the solid may be the valuable product. The plant includes a down-scaled industrial filter press with 6 cakes, a vessel with up to 250 liter suspension, circulation pump, instruments etc. The filter cake can be washed and air dried. Results can be used to up-scale the plant to industrial level.

It is a widely used unit operation to separate undissolved solid particles from the bulk liquid of a suspension. Either the particles or the filtrate is the valuable product. The horizontal filter press is a simple and well known piece of equipment. It can be supplied in any sizes – from pilot units with small dimensions and few frames to large scale industrial units with many frames. It can be designed to withstand high pressures, which may be necessary to handle thick filter cakes or provide high filtration rates. Thus the flexibility in capacity is high, but the disadvantage is the batch mode and the heavy manual workload in dismantling, cleaning and assembling in between the filtrations. Filter presses with automatic filter cake discharge exists. The filter plates may be of a flexible diaphragm type which are moved automatically one by one for assembling and cake drop. A robotic cleaning device can clean the filter diaphragm which can be filled with compressed air to expand and facilitate the cake removal. Other alternatives for automatic and semi-continuous filtration equipment exists, for instance band filters or rotary drum filters with automatic precoating, washing and removal of the filter cake. For vacuum filters the maximum filtration Δp is less than 1 bar, which is below what can be achieved on a filter press. Separation on the molecular level is not particular matter filtration in this sense, but for instance is performed by using membrane processes like ultrafiltration.

Design and construction

The experimental setup is illustrated in the P&I-diagram in Figure 1. T1 is a stirred vessel (~ 300 liters) used for making the suspension. The pump P1 pumps the suspension to the filter press F1, from which the effluent is collected in the vessel T2. The total weight of T2 is continuously measured by a scale WT1 (accuracy 0.05 kg). Circulation of the suspension through valve V4 and the vessel agitator can keep the suspension homogenous. Cold city water for preparation of the suspension and for cake washing, as well as compressed air for deliquoring the filter cake, are supplied from the buildings main utility supply lines. The filter comprises of 6 sets of frames and filter support plates. Other necessary equipment for the exercise are a conductivity meter, a scale for weighing the solid dry product, buckets, stop watches, beakers and an oven.

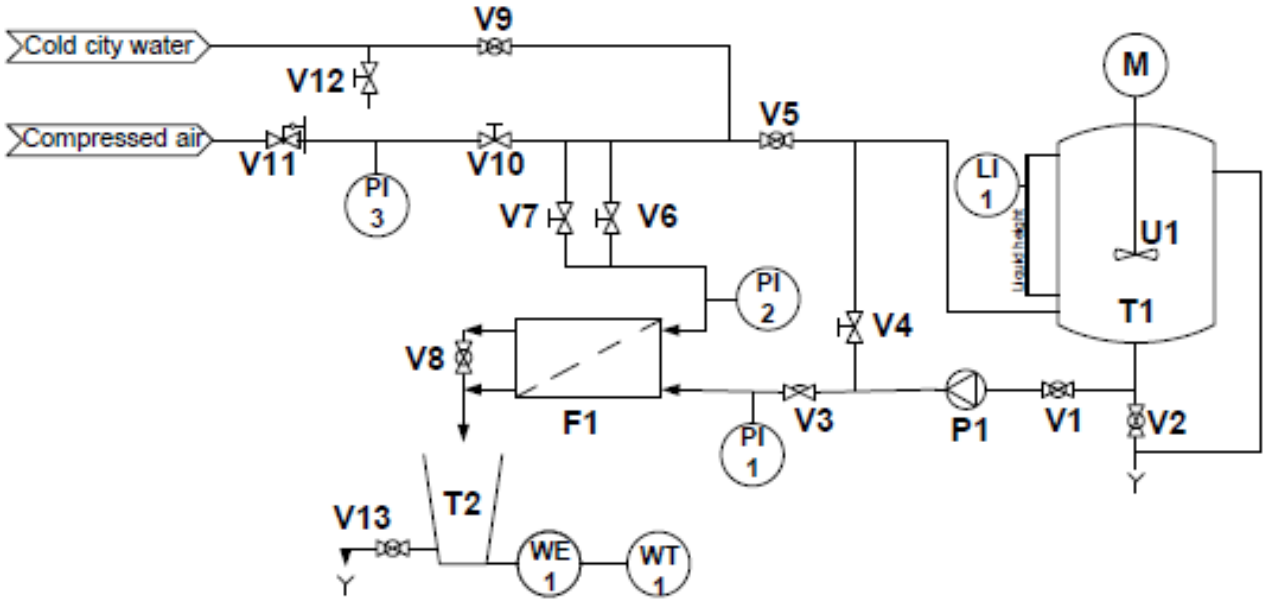
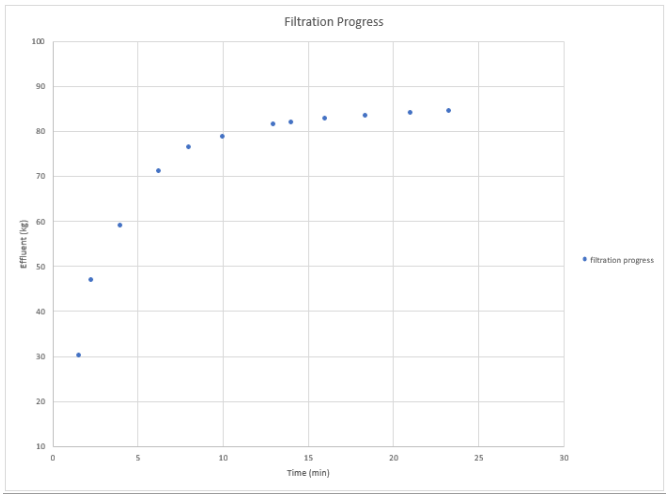
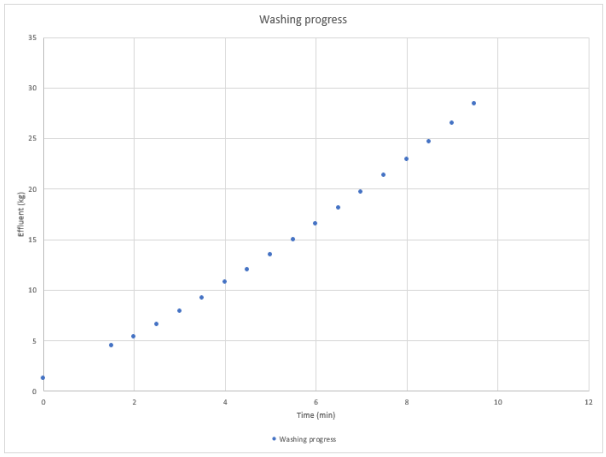


Figure- 1 Design and construction of system

Results and analysis

Progress of the filtration and washing vs. time as curves





$\log_{10}(a)$

Figure 2- Plot of progress of filtration VS time

Figure 3- Plot of progress of washing VS time

In the beginning of filtration, the solid starts settling between the filter plates, which create resistance for suspension to pass through these plates, due to which in the start the graph shows mass of effluent increases with higher rate but slows down as the process proceed and reaches nearly a steady state in the end. As graph shows it is constant as the time reaches to 16 min of the filtration process.

In order to clean the filter cake from sodium sulphate it is washed using water. The efficiency of the washing process is monitored by measuring the conductivity of the effluent. Rate of washing (effluent flow) is determined by reading the scale WT1 with time. The washing is stopped when the conductivity of the effluent is almost identical to pure city water shows the washing of filters is completed.
As the graph shows mass of effluent increases with time, which indicates the washing of plates is proceeds with time reducing the resistance for suspension to flow through the plates.

Concentrations of Magnesium Phosphate

The concentration of insoluble dry solids of $Mg_3\left(PO_4\right)_2$ in the suspension is determined as follows :

- Based on the initial volume of solution in the suspension, and the initial amount of $Mg_3\left(PO_4\right)_2$ in the suspension
- Based on the filter cake weight and effluent volume.

Concentration is calculated based on the stoichiometric ratios presented in the following chemical reaction

3 MgSO4.7H2O + 2 Na3PO4.12H2O -> Mg3(PO4)2.xH2O (s) + 3 Na2SO4 + z H2O

Based on the initial volume of solution in the suspension, and the initial amount of M $g_3\left(PO_4\right)_2$ in the suspension

Quantity of chemicals used are equinormal :
1.40 kg MgSO4.7H2O
1.45 kg Na3PO4.12 H2O
0.25 kg Cellulose fiber (filter aid, type Becocel 150)
In total 150 liter suspension

$$\text{Moles of MgSO4.7H2O} = \frac{1.40 \cdot 1000\ g}{246.4746\ \left(\frac{g}{mol}\right)} = 5.68\ mol$$

$$\text{Moles of Na3PO4.12 H2O} = \frac{1.45 \cdot 1000\ g}{380.1240 \cdot \left(\frac{g}{mol}\right)} = 3.81\ mol$$

$$Moles\ of\ Mg3(PO4)2\ formed = \frac{(Moles\ of\ MgSO4.7\ H2O)}{3} = \frac{5.68}{3} = 1.893\ mol$$

$$Moles\ of\ Na2SO4\ formed = Moles\ of\ MgSO4.7\ H2O = 5.68\ mol$$

thus preparation concentration of $Mg_3\left(PO_4\right)_2\left(c_1\right) = \frac{1.893}{150} \cdot Molecular\ mass\ of\ Mg_3\left(PO_4\right)_2$

$$\left(c_1\right) = \frac{1.893}{150} \cdot 262.8577$$

$$c_1 = 3.317\ \frac{g}{l}$$

thus preparation concentration of $Na_2SO_4 \cdot \left(c_0\right) = \frac{5.68}{150} \cdot Molecular\ mass\ of\ Na_2SO_4$

$$\left(c_0\right) = \frac{5.68}{150} \cdot 142.0421$$

$$c_0 = 5.378\ \frac{g}{l}$$

Thus the concentration of $Mg_3\left(PO_4\right)_2$ i.e c_1 found using this method is 3.317 $\frac{g}{l}$

Based on the filter cake weight and effluent volume.

The volume of effluent is calculated by measuring the weight of the remaining effluent in the tank, after the rest of the experiment is conducted.It is assumed that volume of $Mg_3\left(PO_4\right)_2$ is in the effluent. It took 13 and a half buckets of to empty the tank the weigths of each were measured and added to yield a total mass of 243.3 kg remaining in the tank. Given the initial volume in the T1 was 150 L and during the process an additon of almost 190 L of water was added hence the net flow of the effluent is calculated as

$$Vol.\ of\ effluent = Initial\ Volume\ in\ tank + Volume\ of\ water\ added - Volume\ calculated\ using\ buckets$$
$$Vol.\ of\ effluent = 150 + 190 - 243.3 = 96.7\ L$$

Thus Vol of effluent = 96.7 L

Conductivity of city water : c0 = 0.78 mS/cm

Mass of dried samples = Mass of sample and tray - Mass of tray

For Sample 1
Mass of dried sample = 0.76 - 0.67 = 0.09 kg
For Sample 2
Mass of dried sample = 0.77 - 0.67 = 0.1 kg
For Sample 3
Mass of dried sample = 0.77 - 0.67 = 0.1 kg

Total mass collected in filter press $M_{total} = \frac{(0.09 + 0.1 + 0.1)}{3} \cdot 6 = 0.58\ kg$

$$\text{Mass of cellulose inside filter press} = \frac{\text{Vol of effluent}}{\text{Total Volume}} \cdot \text{Mass of Cellulose}$$

$$\text{Mass of cellulose inside filter press} = \frac{96.7}{150} \cdot 0.25 = 0.16116\ kg$$

concentration of $Mg_3(PO_4)_2$ i.e $c_1 = \frac{(M_{total} - \text{Mass of cellulose inside filter press})}{\text{Vol effluent}}$

$$c_1 = \frac{(0.58 - 0.16116) \cdot 1000\ g}{96.7\ l}$$

$$c_1 = 4.331\ \frac{g}{l}$$

Thus the concentration of $Mg_3(PO_4)_2$ i.e c_1 found using this method is 4.331 $\frac{g}{l}$

Now the difference between the values of c_1 calculated using both these methods can be explained by the fact that the number of water of crystalization in the product is not taken in consideraton in the first method but for the second method it is taken in consideration also in experiment there is loss of water from filter press whivh has not been included also the amount of water added might have been a bit off.

Now if we include water of crystallization then in the first method mass of $Mg_3(PO_4)_2.xH_2O$ will increase by $18 \cdot x$ grams

thus preparation concentration of $Mg_3(PO_4)_2(c_1) = \frac{1.893}{150} \cdot Molecular\ mass\ of\ Mg_3(PO_4)_2$

$$(c_1) = \frac{1.893}{150} \cdot (262.8577 + 18 \cdot x)$$

Now if we take c_1 to be 4.331 $\frac{g}{l}$ then,

$$4.331 = \frac{1.893}{150} \cdot (262.8577 + 18 \cdot x)$$

x solves to ~ 5

hence the crystal water of the magnesium phosphate is found to be 5

Specific filter cake resistance (α) and resistance of filter cloth/plate (Rm.)

Calculation of specific filter cake resistance (α) and resistance of filter cloth/plate (Rm).
we have -

$$\frac{t}{V} = \frac{V}{2} K_c + \frac{1}{q_0}$$

$$K_c = \frac{\mu c \alpha}{\Delta p A^2}$$

$$\frac{\mu_m}{A \Delta p} = \frac{1}{q_0}$$

Plot of t/V against V results in a straight line with slope Kc/2. Based on that, Rm and α is calculated from (2) and (4).

V *the total amount of filtrate which has passed the cloth at the time t [m^3].*

μ *viscosity of the filtrate (here equal to pure water) [kg/(ms)]*

A *the total filtration area of the cloth [m^2]*

Δp *total pressure drop across filter cake and cloth [N/m^2]=[pa]*

α *specific resistance in the filter cake [m/kg]*

c *concentration of dry solids in suspension [kg/m^3]*

R_m *resistance of filter cloth/plate [m^{-1}]*

From the graph we can get the slope and intercept to get the required values from the above equation.

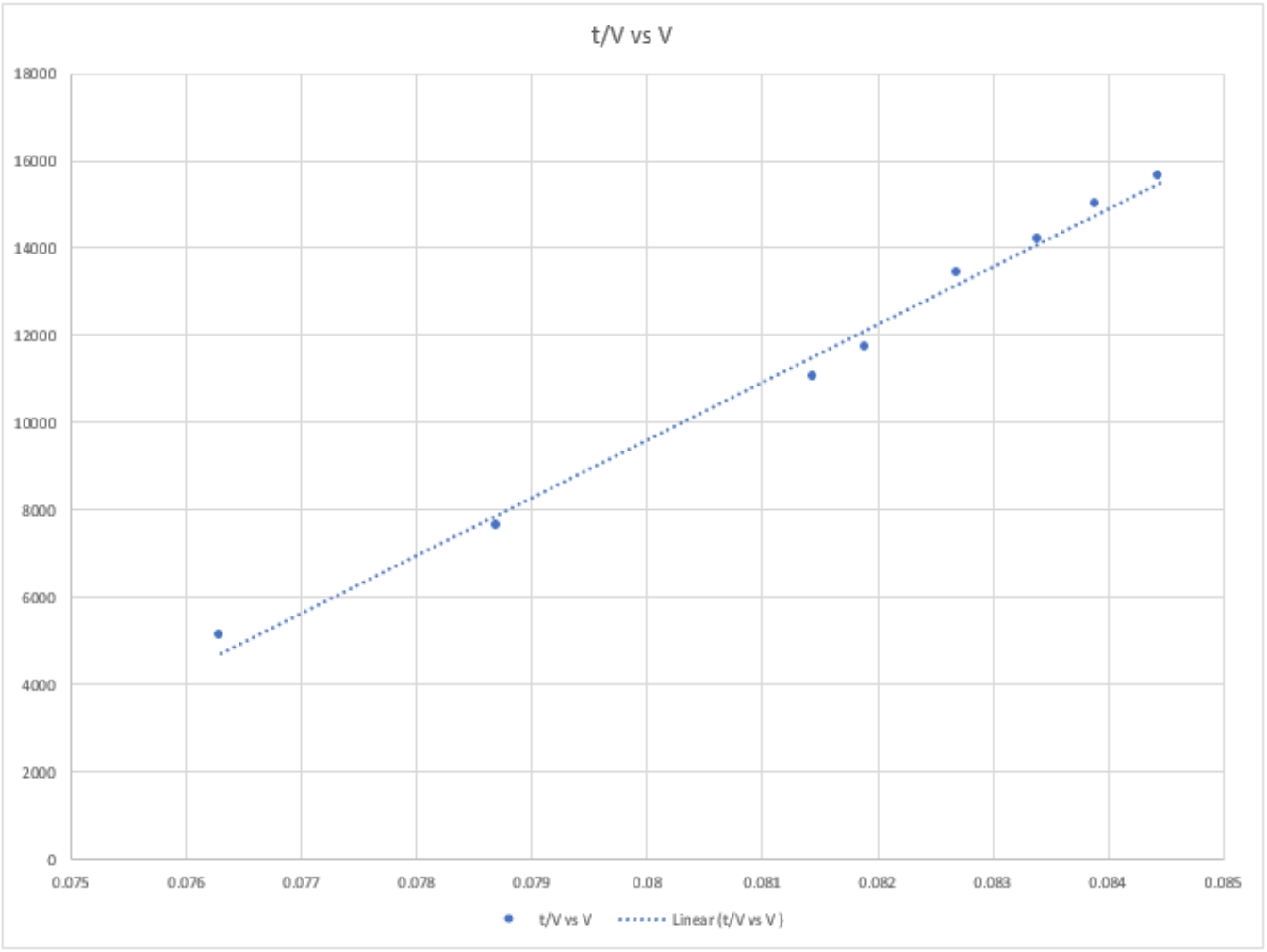


Figure 4 - plot of t/V VS V

By using linear regression we can find the best trendline to get the slope of line and intercept of required data. For above graph we have *0.99*, which is a good value of coefficient of coorelation.
Estimated values
Slope =1323308.9
Intercept = 103250

From the given data of filter plates -
$A = 0.0447\ m^2$
$c = 4.45\ kg/m^3$
$\Delta p = 0.3\ 10^5\ Pa$
$\mu = 1.02\ 10^{-3}\ kg/ms\ at\ 20^oC$
from graph -
$K_c/2 = 1323308.9$
$K_c = 2646617.8$
$1/q_0 = 103250$
from equation 2 filter cake resistance (α) can be calculated as-
$\alpha = 3.5\ \ 10^{10}\ m/kg$
$Rm = 1.357\ \ \ 10^{11}\ \ m^{-1}$

Dead space and void volume

To determine the filter press liquid hold-up i.e. dead space and void volume in the press and cake the deliquoring process is analysed and the results are used. The filter cake can be considered as a matrix of solid particles surrounded by voids. In a wet cake, which has not been deliquored by air blowing, the entire voidage (porosity) is filled by water. The cake is said to be fully saturated (saturation S = 100 %). When blown by air, all the water is removed, and the weight loss Ml from the cake blowing therefore corresponds to the voidage. The residual water, which cannot be removed by air deliquoring, is bound and identified as the minimum moisture content or the irreducible cake saturation (S∞, in %) and equals to the water occluded by the solids, whether it may be as crystal water, water bound to the solid surfaces or "water in closed pores". S∞ can be determined as the weight loss by heating the air deliquored cake in an oven

The mass of the washed filter cake is 1.2 kg and the masses of the deliquored filter cakes are 0.97 kg and 1.1 kg.

Mass of loose water in one filter cake = Mass of washed sample - Average Mass of Deliquored sample

$$Mass\ of\ loose\ water\ in\ one\ filter\ cake = 1.2 - \frac{(0.97 + 1.1)}{2} = 0.165\ kg$$

$$Mass\ of\ loose\ water\ in\ 6\ filter\ cake = 0.165 \cdot 6 = 0.990\ kg$$

$$Void\ Volume = \frac{Mass\ of\ loose\ water}{density\ of\ water} = \frac{0.990\ kg}{1 \cdot \left(\frac{kg}{l}\right)} = 0.990\ l$$

$$Dead\ Volume = 2.8 - 0.99 = 1.81\ l$$

Cake voidage, Cake solid density and Cake saturation.

cake volume is equal to $L \cdot Ac$,
where,

L	*cake thickness*
Ac	*cake area*
M	*mass of the saturated wet cake*
M_{Ws}	*mass of the (wet) solids in the cake*
Ms	*mass of the dry solids*
ε	*cake porosity (voidage)*
ρs	*solid density*
ρl	*liquid density*

ρs *is given by*

$\rho s = Ms/LA$

mass of dry cake = 0.76, 0.77, 0.77
$L = 0.015m$
$A = 0.2^2 - \pi 0.025^2 = 0.037\ m^2$

for cake voidage

$M_l = L \cdot Ac \cdot \varepsilon \cdot \rho l$

$$\varepsilon = \frac{M_l}{l \cdot A \cdot \rho l}$$

$$\rho l = 1000 \ \frac{kg}{m^3}$$

	Cake Voidage	*Cake solid Density* $\cdot\left(\frac{kg}{m3}\right)$	*Cake Saturation* $\cdot (L)$
sample 1	*0.41*	*180.18*	*0.43*
sample 2	*0.38*	*180.18*	*0.5*
sample 3	*0.23*	*162.12*	*0.5*
Average	*0.34*	*174.16*	*0.48*

Table 1- Data of cake voidage, cake solid density, cake saturation

The physical appearance of the saturated filter cake as well as of the deliquored cakes - saturated filter cake is wet as compared to deliquored cake and has good amount of water in it's voidage, deliquored cakes has more chances to break due to less water in it, but as per calculation we know amount of water loss by deliquoring is very less.

Wash ratio and ideal plug flow process

Wash ratio W describes the number of cake liquid volumes Ml to be exchanged with washing liquor in order to reach a certain solute concentration. i.e,

$$wash\ ratio = \frac{the\ volume\ of\ water\ used\ to\ wash\ the\ filter}{voidage\ volume}$$

The volume of water used to wash the fiter = Volume of water until the conductivity of the water effluent is the same conductivity as pure water.

Conductivity of city water : c0 = 0.783 mS/cm
Density of water (effluent) : 1kg/l

Volume of water used to wash filter	*Conductivity*
0	1.663
0.45	1.336
1.72	1.174
2.37	0.956
3.77	0.897
4.92	0.853
6.05	0.827
7.62	0.820
8.45	0.809
10.12	0.799
11.02	0.790
12.47	0.782

Table 2- Data of volume of water used to wash filter and conductivty

Conductivity is plotted against volume of washing water and is modelled by a decreasing exponential decaying trend.

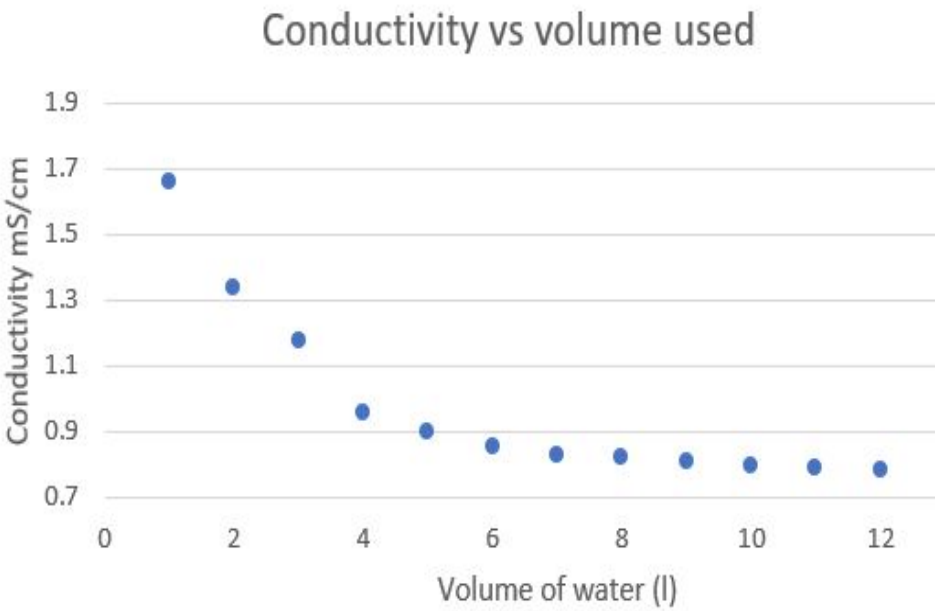


Figure 5- plot of conductivity VS volume used

The total volume of water needed to decrease the conductivity of effluent to the conductivity of cold city water is V wash = 12.47 L

$$wash\ ratio = \frac{the\ volume\ of\ water\ used\ to\ wash\ the\ filter}{voidage\ volume}$$

$$wash\ ratio = \frac{12.47}{0.99} = 12.59$$

For plug flow wash ratio of 1 is considered to be ideal. The wash ratio calculated in the experiment is much greater than 1 hence washing is not considered as an ideal plug flow process.

Mass balance for Na_2SO_4

Mass balance for Na_2SO_4 for the entire process is done below

In order to demonstrate relevant filtration characteristics an artificial suspension is made. The suspension results from mixing 2 soluble salts which immediately produce an insoluble precipitate:

$$3\ MgSO_4, 7H_2O + 2\ Na_3PO_4,12H_2O \rightarrow Mg_3(PO4)_2, xH_2O\ (s) + 3\ Na_2SO_4 + z\ H_2O$$

By using stoichiometry amount of Na_2SO_4 can be calculated-

Molar mass of $Na_3PO_4,12H_2O$

$= 380.124\ g$

No of moles of $Na_3PO_4,12H_2O$

$= given\ mass/\ molar\ mass$

$= 1.45\ kg\ /380.124\ g$

$= 3.814545\ moles\ of\ Na_3PO_4,12H_2O$

By using above equation, we have-

2 moles of $Na_3PO_4,12H_2O$ will give 3 moles of Na_2SO_4

So 3.814545 moles of $Na_3PO_4,12H_2O$ will give $= 5.721817\ moles\ of\ Na_2SO_4$

$Molar\ mass\ of\ Na_2SO_4 = 142.04\ g/mol$

$Which\ corresponds\ to = 812.7269\ g\ of\ Na_2SO_4$

So we have $812.7269\ g$ of Na_2SO_4, if we assume that all of the components in the reaction has reacted completely.

mass of Na_2SO_4 in effluent is given by = $conc\ of\ in\ effluent * volume\ of\ effluent$

$c_0 = 5.378\ \frac{g}{l}$

$Vol = 96.7\ L$

$Mass = 520.05\ g$

Mass of Na_2SO_4 in cakes is given by $= conc\ of\ Na_2SO_4\ in\ effluent * volume\ of\ water\ in\ cake * 6$

$= 5.378 \cdot 0.165 \cdot 6\ g$

$= 5.324\ g$

Mass of Na_2SO_4 remaining is given by $= conc\ of\ Na_2SO_4\ in\ effluent * volume\ of\ water\ in\ tank$

$= 46 * 5.378$

$= 247.388\ g$

$= 274.278\ g$

we have-

Mass balance equation of Na_2SO_4 -

$$M_L = M_{ini} - M_{effluent} - M_{cakes} - M_{remain}$$

$$M_L = 812.7269 - 520.05 - 5.324 - 247.388\ \ g$$

$$M_L = 39.9649\ g$$

we have *812.7269 g* of N a_2SO_4 initially, during the experiment some amount is lost in effluent and little amount in cakes, however the amount of sodium sulphate lost in cakes is very less. Finally the remaining amount is left in tank T1. The amount of sodium sulphate lost is *39.96 g* while doing the experiment, we can asumme that the mass is lost in cracks and in leaked suspension.

Flow pattern and cake build up

3. Flow pattern through the filter

Front view:

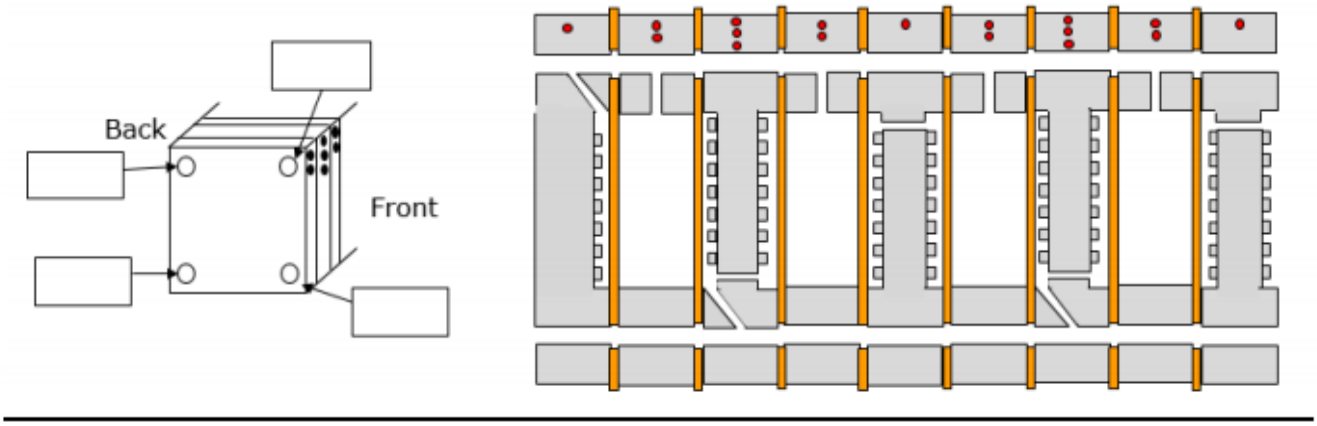


Figure 6- Front view of filter system

In the filtration process we have, each plate is dressed with filter cloth on both sides and, once pressed together, they form a series of chambers that depend on the number of plates. The entire pack of plates is supported by side or overhead presser plates. And all the plates are compressed properly to prevent the leakage of suspension from the filter.
During the filtration the suspension enters the plates from the upper left corner of plates in front view, as there exist filter membrane the solid is unable to pass the filter membrane and as the suspension proceed in the plates the solid deposits in the gaps below the 2 dots plates, once the first gap filled the solid starts to deposit in the next gap, and finally we get the pure effluent as water going in container T2.

Back view:

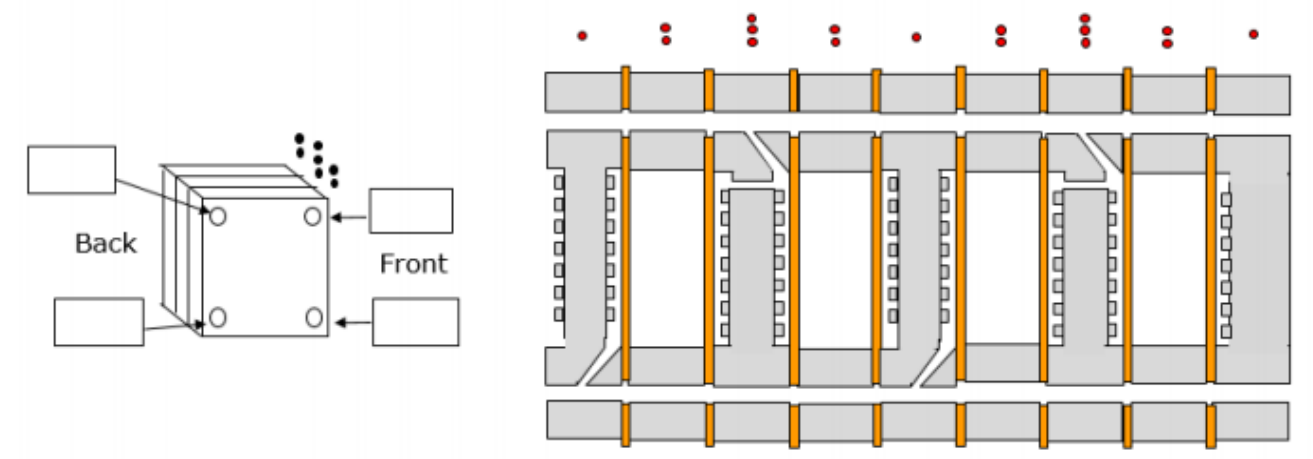


Figure 7- Back view of filter system

Washing process can be explained by back view, when cold city water enters the cavities through the above openings at high pressure remove the impurities or unwanted ions. Finally in the diliquifying process dry air is passed to remove excess water, still some water is left in pores which is residual water, which cannot be removed by air deliquoring, is bound and identified as the minimum moisture content or the irreducible cake saturation and equals to the water occluded by the solids, whether it may be as crystal water, water bound to the solid surfaces or “water in closed pores”. To remove most of the amount of water we use a washing pressure twice the filtration pressure.

Commercial Installation

The total necessary filtration area and the total ideal filtration time for a commercial installation having 5 m3 suspension of the same composition, same concentration, same frame thickness, same filtration pressure and ideal filtration conditions

Total necessary filtration area is calculated below

Area A = $\frac{5}{0.15} \cdot 12 \cdot \left(0.2 \cdot 0.2 - \pi \cdot 0.025^2\right)$

$A = 15.214\ m^2$

Total ideal filtration time

$$\frac{t}{V} = \frac{K_c \cdot V}{2} + \frac{1}{q_0}$$

$$K_c = \frac{\mu c \alpha}{A^2 \cdot \Delta p}$$

$$q_0 = \frac{A \cdot \Delta p}{\mu R m}$$

thus , $t = \frac{\frac{\mu c \alpha}{A^2 \cdot \Delta p} \cdot V^2}{2} + \frac{\mu R m \cdot V}{A \cdot \Delta p}$

where ,

$c = 4.45\ kg/m^3$

$\Delta p = 0.3 \cdot 10^5\ Pa$

$\mu = 1.02\ 10^{-3}\ kg/ms\ at\ 20^oC$

$\alpha = 3.5 \cdot 10^{10}\ m/kg$

$Rm = 1.357 \cdot 10^{11}\ m^{-1}$

thus Time $t = \frac{\left(1.02 \cdot 10^{-3} \cdot 4.45 \cdot 3.5 \cdot 10^{10}\right)}{15.214^2 \cdot 0.3 \cdot 10^5 \cdot 2} \cdot 5^2 + \frac{1.02 \cdot 10^{-3} \cdot 1.357 \cdot 10^{11} \cdot 5}{15.214 \cdot 0.3 \cdot 10^5}$

$t = 1802.277154$ sec

$t = 30.03$ min

Discussion and conclusions

In this experiment we have the suspension results from mixing 2 soluble salts which immediately produce an insoluble precipitate. We added 1.40 kg MgSO4, 7H2O 1.45 kg Na3PO4, 12 H2O 0.25 kg Cellulose fibre in total 150 litre suspension which is used for the whole filtration process. In the beginning of filtration, the solid starts settling between the filter plates, which create resistance for suspension to pass through these plates, due to which in the start the graph shows mass of effluent increases with higher rate but slows down as the process proceed and reaches nearly a steady state in the end. As graph shows it is constant as the time reaches to 16 min of the filtration process. In order to clean the filter cake from sodium sulphate it is washed using water. concentration of $Mg_3\left(PO_4\right)_2$ i.e c_1 found to be 3.317 $\frac{g}{l}$ based on the initial volume of solution in the suspension, and the initial amount of $Mg_3\left(PO_4\right)_2$ in the suspension and 4.331 $\frac{g}{l}$ based on the filter cake weight and effluent volume.
Specific filter cake resistance (α) and resistance of filter cloth/plate (Rm) are determined for cake structure determination and to compare wet and de-liquored cake, saturated filter cake is wet as compared to de-liquored cake and has good amount of water in its voidage, de-liquored cakes has more chances to break due to less water in it, but as per calculation we know amount of water loss by de-liquoring is very less. The total volume of water needed to decrease the conductivity of effluent to the conductivity of cold city water is V wash is found as 12.47 L. For plug flow wash ratio of 1 is considered to be ideal. The wash ratio calculated in the experiment is much greater than 1 hence washing is not considered as an ideal plug flow process.

During the experiment some amount of sodium sulphate is lost in effluent and little amount in cakes, however the amount of sodium sulphate lost in cakes is very less. Finally, the remaining amount is left in tank T1. The amount of sodium sulphate lost is 39.96 g while doing the experiment, we can assume that the mass is lost in cracks and in leaked suspension. Then flow pattern and cake build up through the press during the 3 modes: Filtration, air deliquoring and washing is analysed by plates diagram. For a Commercial establishment the time is found to be 30.03 min and the area is found to be 15.214 m^2

References.

1. Clement et al., Kemiske enhedsoperationer, Polyteknisk Forlag 2004.
2. McCabe et al., Unit Operations of Chemical Engineering, McGraw-hill, any edition
3. A very good and illustrative source for filtration equipment: http://www.solidliquid-separation.com/