LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
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DEVELOPMENT OF A FILTER AID PROPORTIONING, MIXING, AND FEEDING SYSTEM FOR A POLISHING FILTER

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Työn tarkoituksena oli tutkia yleisimpien suodatusapuaineiden ominaisuuksia sekä niiden vaikutuksia kehitettäessä annostelu, sekoitus- ja syöttölaitteistoa kirkastussuodinten tuoteperheelle. Näiden kirjallisuustietojen, sekä käytännönkokemusten perusteella suunniteltiin laitteisto, johon määriteltiin laitetyypit sekä laskettiin investointi- ja käyttökustannukset. Laitteisto suunniteltiin soveltumaan niin esipäällystykseen kuin suodatusprosessin aikana lietesyötön sekaan pumpattavan apuaineen käyttöön. Laitteisto on helposti laajennettavissa käytettäväksi myös usean suotimen prosesseissa. Työssä suoritettiin myös esipäällysteen syötön koesarja, jossa tutkittiin syöttönopeuden sekä eri kankaiden vaikutusta syntyvään suodatuskakkuun.

Suodatusapuaineita käytetään haastavissa olosuhteissa tehostamaan suodatustehokkuutta ja suodatinkankaiden puhdistamista ja näin ollen pidentämään kankaiden käyttöikää. Esipäällystystä käytetään prosesseissa joissa suodatettavalla aineella on taipumus tukkia suodatinkankaan huokoset. Tavoitteena on muodostaa kankaan pintaan homogeeninen kerros, jolla on ennalta määritelty paksuus, noin 2 – 5 mm. Tämä kerros pitää suodatettavan aineen erillään suodatinkankaasta, jolloin sen puhdistaminen on helpompaa. Kerros myös parantaa suodatustehokkuutta toimiessaan suodattavana kakkuna sekä estäen suodatinkankaan tukkeutumisen.

Suodatettavan aineen sekaan syötettävän apuaineen tarkoituksena on estää tahmean ja läpäisemättömän kakun syntyminen, joka lyhentää suodatussykliä. Sekaan syötettävä huokoinen suodatusapuaine pitää kasaantuvan kakun permeabiliteetin korkeana, jolloin suodatussykliä voidaan jatkaa pidempään.

Abstract

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Development of a Filter Aid Proportioning, Mixing, and Feeding System for a Polishing Filter

Master´s thesis

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108 pages, 47 figures, 25 tables, 6 appendices

Examiners: Ilkka Turunen, Antti Häkkinen

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The purpose of this work was to study the characteristics of the most commonly used filter aid materials and their influences on the design of proportioning, mixing, and feeding system for polishing filter family. Based on the literature survey and hands-on experience a system was designed with defined equipment and capital and operating costs. The system was designed to serve precoating and bodyfeeding applications and is easily extended to be used in multiple filter processes. Also a test procedure was carried out where influences of flux and filter cloths to accumulated cake were studied.

Filter aid is needed in challenging conditions to improve filtration efficiency and cleaning, and thus extend the operating life of the filter media. Filter aid preparation and feeding system was designed for the use of two different filter aids; precoat and bodyfeed. Precoating is used before the filtration step initiates. If the solids in the filterable solution have a tendency to clog the filter bag easily, precoat is used on the filter bag to obtain better filtration efficiency and quality. Diatomite or perlite is usually used as a precoating substance. The intention is to create a uniform cake to the overall surface of the filter cloth, with predetermined thickness, 2 – 5 mm. This ensures that the clogging of the filter cloth is reduced and the filtration efficiency is increased.

Bodyfeed is used if the solids in the filterable solution have a tendency to form a sticky impermeable filter cake. The cake properties are enhanced by maintaining the permeability of the accumulating cake by using the filter aid substance as bodyfeed during the filtration process.

List of symbols and abbreviations

A	Cross-sectional area of the bed	m^2
a_b	Bodyfeed dosage	kg
A_o	Initial filter area	m^2
a_p	Precoat dosage (mass per unit area)	kg/m^2
d_l	Depth of precoat deposit	m
d_2	Depth of bodyfeed cake	m
h	Height of a single leaf	m
k	Permeability of the porous network	m^2
L	Bed depth	m
N	Number of leaves	-
ΔP	Pressure difference	-
q	Volume flow rate	m^3/h
V	Filtrate volume	m^3
w	Width of a single leaf	m
μ	Liquid viscosity	Ns/m^2
ρ_b	Bulk density of the precoat	kg/m^3

CFP	Capillary flow porometry
DE	Diatomaceous earth
DS	Dry solids
ESA	Envelope surface are
MFP	Mean flow pore size

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Appendices

1. Introduction

In this thesis a filter aid proportioning, mixing, and feeding system for vertical leaf filter family is designed. At first the most widely used filter aid materials, grade selection guidelines, and their influence on the system and its equipment are examined. The designing consists of pre-engineering where the background and demands for the process are studied, and detailed engineering where piping and instrumentation diagram is prepared and equipment are dimensioned, enquired, and selected. Finally when the filter aid system is designed, capital cost and operating cost calculation are accomplished and their results are used for reanalyzing of the designed system.

The outcome of the theoretical part is to produce an introduction to the use and selection of filter aid materials, which can be used as a basis for Larox test personnel in determining the right material and grade for a certain processes. The selection is quite demanding as there are many variables that have to be taken into account and therefore only guidelines can be presented to support and shorten the testing periods. This theoretical part consists of the filter aid basics in chapter 2, where an introduction to the work is given with filtration related equations. A thorough theoretical filtration point of view is excluded from this project and the focus is on practical side. In chapter 3 the filter concept, vertical leaf filter is presented to give an understanding of the basic structure and its interaction to the design of the filter aid system. The two filter aid applications, precoating and bodyfeeding, and their normal literature process variables are discussed in chapters 4 and 5. Filter aid materials and their characteristics and grade selection criteria are presented in chapter 6, which gives a wide understanding of the grade differences and process optimization in the filter aid point of view.

In addition to the theoretical part, actual design part with complementary practical precoating test procedure was carried out. The detailed engineering part was accomplished in the facilities of Pöyry Industry Oy and the filter aid test procedure in the facilities of Lappeenranta University of Technology. The outcome of the design is to provide an efficient and reliable filter aid preparation system without forgetting the economical point of view. The objective of the intensive, complementary laboratory test work was to get a hands-on experience of the variables that has an effect on the precoating fundamentals. The acquired results are compared to the guideline values found from the literature.

2. Filter aid basics

Filter aid materials are used to enhance the properties of a filter media and thus the overall filtration process. The basic principle of filter aid filtration was developed by US Army to the World War II as the soldiers needed a portable, efficient filter to remove parasites from the drinking water /1, 2/. Since then filter aid materials are used in various industries.

The possibility to enhance the filtration process is of great importance because in many production processes the filtration step is a quality and cost-determining processing step. It is beneficial and sometimes essential to use filter aid materials when filterable solution has a tendency to clog the filter bags easily or it produces a sticky impermeable filter cake. If such phenomena occur it results in decreased filtration quality, efficiency and shortens the life time of a filter media. In systems where the filtration resistance is high, unwanted solids can only be removed efficiently and economically by use of filter powder. Basically the filter aid materials and their usage can be divided into two different operations, precoating and bodyfeeding. The differences between filtrations with and without filter aid are presented in table 1.

Table I. The differences between filtration with and without filter aid /3/.

With filter aid	Without filter aid
– Fast filtration	– Too slow filtration
– Long cycles	– Too short cycles
– Maximum clarity	– Inadequate clarity
– Very easy cleaning	– Filter very difficult to clean

The most typical precoating and bodyfeeding materials that are available commercially are (expanded) perlite and diatomaceous earth according to Yang *et al.* /4/. Also the share of the use of cellulose based filter aids are increasing /5/. These are the most used filter aids and therefore described and examined more thoroughly in this study. Other conventionally used filter aid materials are rice hull ash, asbestos, and inactivated carbon. Even though there are two different applications where and how to use filter aids, the same filter aid material can be used and the only difference being the concentration that is usually higher in bodyfeeding. The concentration is higher because the bodyfeed is fed into the filterable solution stream prior to filtration. Because of this the introduced carrier liquid volume of the bodyfeed solution can be kept at a lower level and due to that the unnecessary diluting of the slurry feed is avoided. If the slurry feed is diluted vainly it results in reduced total filtration efficiency.

As it was noted in the previous paragraph the most important filter aid materials are expanded perlite, processed diatomaceous earth and cellulose. Perlite is an amorphous glassy siliceous volcanic rock that has relatively high water content. When the perlite is processed and rapidly heated it expands 4 – 20 times its original volume, creating highly porous material with numerous interstices /6/. DE is another inorganic mineral powder that is commonly used as a filter aid material. It is formed from the sedimentary accumulations and is composed primarily of the skeletal remains of microscopic aquatic plants, diatoms. By processing its physical properties are enhanced to suit for many industrial applications /7/. The third filter aid material that is more thoroughly discussed in this work is cellulose as its share is increasing /5/. Cellulose, processed for filter aid purposes, is an economical, efficient, and environmental alternative to the conventionally used materials. These materials and their characteristics are discussed in chapter 6.

Before feeding the filter aid material to a filter unit, the powder has to be mixed effectively to carrier liquid media i.e. fresh water or filtrate. Filter aid materials are usually delivered to the site in so-called big bags (~1 m^3). The conventional way is to mix the filter aid powder with fresh water in the first cycle of the filtration process, and when the filtering unit is in operation; filtrate can be used instead of fresh water /8/. The use of filtrate reduces the fresh water usage in the precoating process and therefore reduces the total water consumption of the filtration plant. A general flowsheet of the filter aid proportioning, mixing, and feeding system is presented in figure 1.

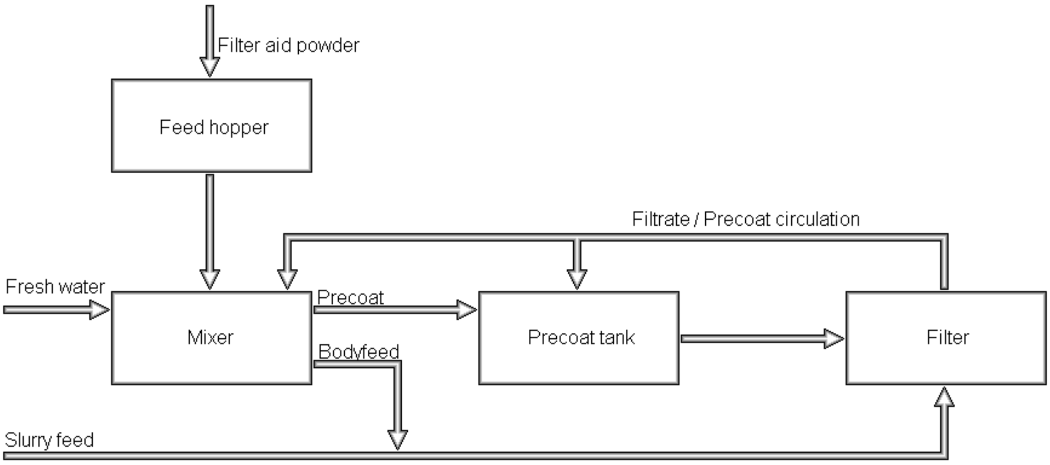


Figure 1. Filter aid proportioning, mixing, and feeding system.

Filter media i.e. filter cloth and accumulated cake retains particles in two ways. According to filtration theory the phenomenon that occurs in the filter aid filtration is mainly cake filtration as the filter cloth acts only as a supporting medium for the accumulating precoat layer. It should be noted that also in-depth or depth filtration occurs, but usually the impurities accumulate for the most part on top of the filter aid layer.

When the filterable particles are larger than the pore sizes of the filter cake, a new layer of cake accumulates, hence the name *cake filtration*. Cake filtration is achieved by two mechanisms simultaneously; complete blocking and bridging. Complete blocking occurs when the filterable particles are larger than the pore sizes of the cake, whereas the bridging occurs when the particles are smaller than the pores. Bridging mechanism occurs when the particles are fed into the filtering element in higher concentration and several particles are attempting to pass simultaneously through the same pores.

In the other phenomenon, *depth filtration*, the particles that are smaller than the pores are trapped inside the interstices of the filter aid particles due to mechanical or surface chemical effects. /9/

When the actual filtration step begins, the cake thickness is increased as the filterable solids accumulate onto the filter aid cake and the total cake, including filter aid and solids, act as a filter media. This filtration phenomenon is explained by the expanded Darcy's law equation (equation 2) /10/.

$$\frac{\Delta P}{L} = \frac{\mu\, q}{k\, A} \tag{1}$$

A	cross-sectional area of the bed
k	permeability of the porous network
L	bed depth
ΔP	pressure difference
q	volume flow rate
μ	liquid viscosity

In cake filtration the Darcy's law (equation 1) is expanded by replacing the volume flow rate q with *dV/dt* as it is presented in the equation 2 /10/.

$$\frac{\Delta P}{L} = \frac{\mu}{k\, A}\frac{dV}{dt} \tag{2}$$

The proportional relation between pressure drop and flow rate is illustrated in figure 2. As can be seen in the graph, the increased volume flow rate ends up in increased pressure drop. If the pressure drop over the filter media increases excessively, the filtration becomes uneconomical and it may lead to problems relating to the filter cloth and its supporting grid. The supporting grid pattern is copied to the filter cloth that leads to a reduced filtration area /10/.

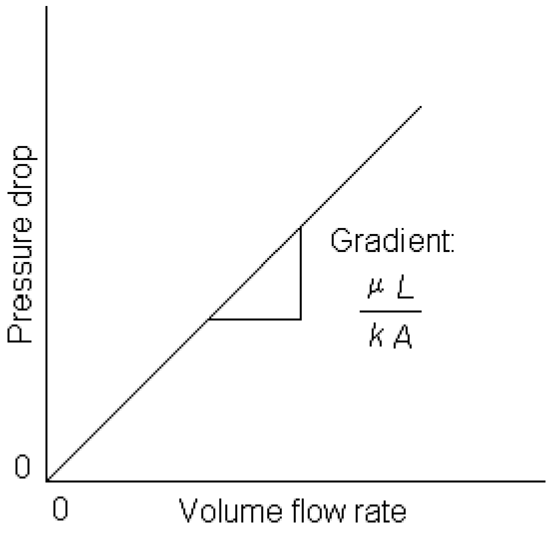


Figure 2. Pressure drop versus volume flow rate /4/.

Darcy discovered that the pressure loss was directly proportional to the volume flow rate, which is presented in figure 2. The proportionality constant is dependent on the permeability *k* (m^2) of the accumulated porous cake. For incompressible filtration the cake concentration remains relatively constant, cake thickness increases proportional to the volume of the filtrated solution, filtrate. As in the case as the assumed way of filtration is carried out with variable pressure and flow rate. The uniform proportional relation between cake and filtrate volumes is presented in figure 3 /10/.

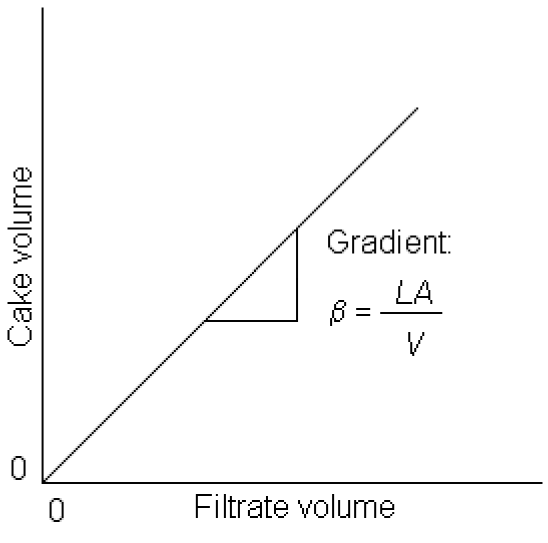


Figure 3. Proportional relation between cake and filtrate volumes /4/.

3. Vertical leaf filter

Larox Scheibler vertical leaf filters are used for the removal and recovery of solids, that are present in low concentration, from process liquids i.e. slurry. The improved quality of the filtrate increases production capacity as well as the quality of plant and refinery products. Filters exploit the phenomena of adsorption filtration to cause micronic and sub-micronic particles to adhere to the fibers of the filter media, despite being small enough to pass through its pores. This activity reduces particle concentration in the filtrate to almost undetectable levels /11/.

The precoat and bodyfeed proportioning, mixing, and feeding system which is developed in this study is designed for a vertical leaf filter family that comprises of 4 filter types (A, C, D, and E -series) with numerous filtration areas and capacities. The main difference in addition to the filtration areas and capacities is that the A-series is a vertical cone filter as the others are horizontally structured. The fact sheets with basic data of the filter families are presented in Appendix I and an example of a typical Scheibler polishing filter flowsheet in figure 4.

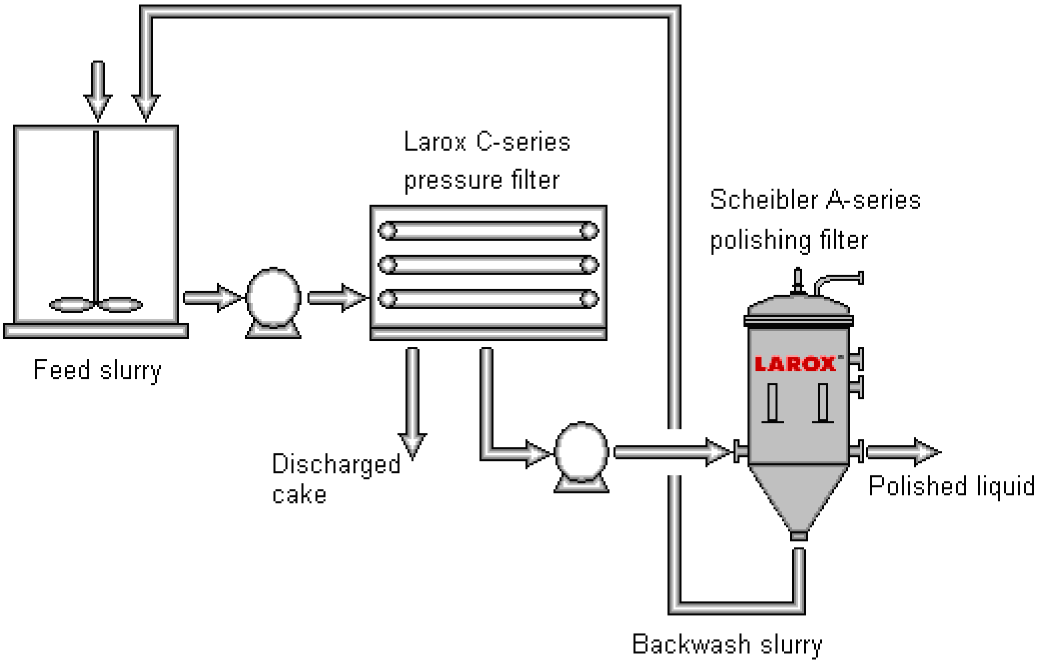


Figure 4. Example of a typical Scheibler polishing filter flowsheet /11/.

The metallurgical industry has been growing significantly in the past decades and at the same time the requirements also for filtration applications have increased. As higher product qualities are required from metal refineries it has resulted in the need for pure electrolyte streams requiring polishing filtration. Also the increasing use of hydrometallurgy has increased the need for polishing filtration equipment that are used to recover valuable products from waste streams, e.g. filtrates from the other filters as it is presented in figure 4 /11/.

The basic principle of a leaf filter is that the pressure vessel is filled with leaf filter elements that can be different in size and shape. A single Scheibler vertical leaf filter is presented in figure 5.

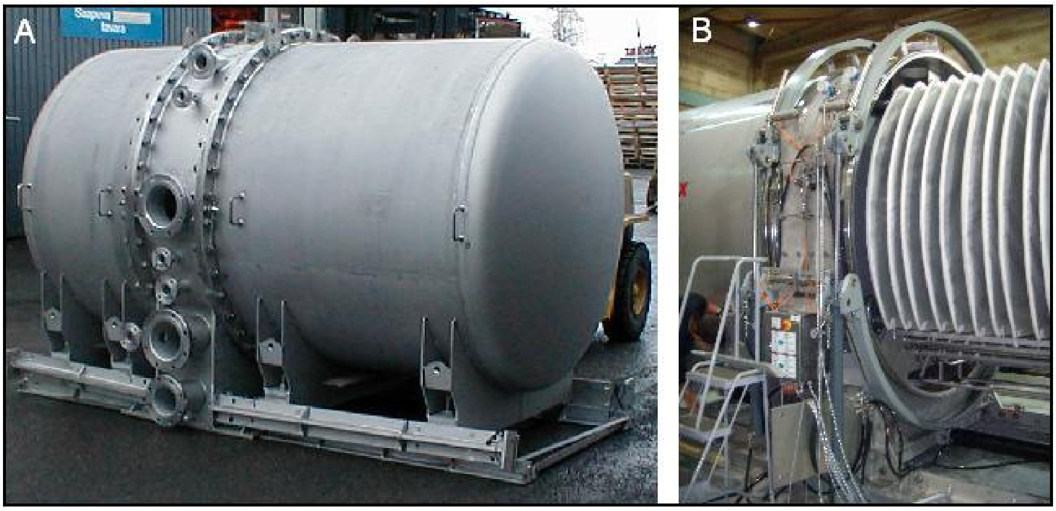


Figure 5. Scheibler vertical leaf filters, A: D-series B: E-series /11/.

These filtering units are usually used for clarification and polishing purposes as the used filter cloths are tight enough to retain microscopic particles without expensive filter aids. This is the case in the majority of applications of these filtering units. When it is possible to operate without filter aids it leads to considerably reduced volumes of total cake solids to be disposed from the site /10/. In certain challenging processes it is still essential to use filter aid materials in order to achieve high efficiencies and purities required by modern industries. The higher environmental awareness and therefore tighter ecological requirements for the fresh water use, water purification and due to that the water reuses are increasing the necessity of these applications. Typical metallurgical applications where polishing filters are used are presented below:

- Copper refineries
    - Electrolyte recirculation
    - Electrolyte decant after de-anoding
    - Anode slimes plant electrolyte return
    - Anode scrap wash water
    - Cathode wash water
    - Wastewater treatment.

- Zinc refineries
    - Solution purification (Cu, Ni/Co, Cd, Sb)
    - Wastewater treatment (precipitated heavy metals recovery).

- Nickel & cobalt refineries
    - Neutral Solution Clarification
    - Barren Liquor Clarification
    - Solution Purification (Fe, Zn, Cu, Al, Mn)
    - Electrowinning solution polishing (catholyte and anolyte).

- Gold/silver Merrill Crowe plants
    - PLS clarifier overflow
    - Post precipitation Au/Ag recovery.

- Metal concentrates
    - Wastewater treatment (precipitated heavy metals recovery)
    - Recirculation of process water /11/.

In these vertical leaf filters the elements are mounted vertically to a manifold, where the filtrate is taken out. The solids that are accumulated onto the filter cloth are discharged from the filtering unit by (back) washing or pulsation. The outcome is that the cake is released from the cloth and is removed from the bottom of the unit. In normal circumstances the filter cloths are washed automatically between the cycles that take several tens of hours. It is economical and efficient to introduce as many filter elements as possible inside the filter unit, as the effective filtering area increases and thus makes the process more efficient and shortens the cycle time. The limiting factor is that there needs to be sufficient space between the elements to be able to drop the cake without the occurrence of bridging between the filter leaves. The minimum recommended distance being around 20 mm prior to back-flushing which determines the maximum thickness of the cake in the end of the filtration step /10/. A schematic figure of a vertical leaf filter and its main connections is presented in figure 6.

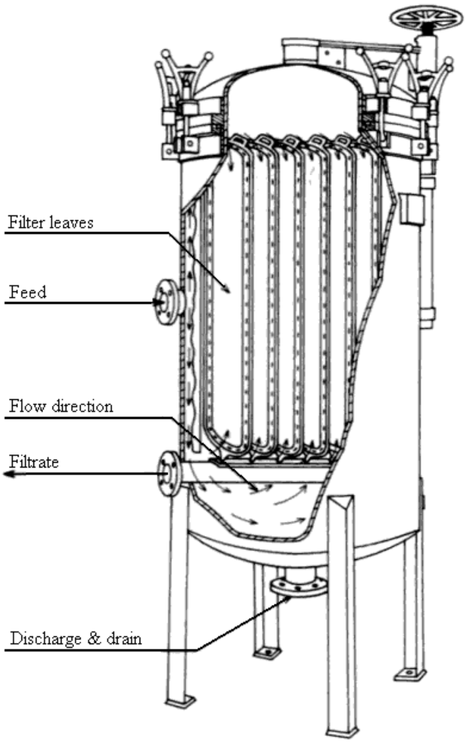


Figure 6. Schematic leaf filter operation principle /12/.

The modelling of the precoat (3) and bodyfeed (4) processes in a leaf filter are the following /10/:

$$A_0 a_p = N(2hw)d_1\rho_b \tag{3}$$

$$a_b V = N(2hw)d_2\rho_b \tag{4}$$

a_b	bodyfeed dosage
A_o	initial filter area
a_p	precoat dosage (mass per unit area)
d_1	depth of precoat deposit
d_2	depth of bodyfeed cake
h	height of a single leaf
N	number of leaves
V	filtrate volume
w	width of a single leaf
ρ_b	bulk density of the precoat

4. Precoating

Precoating is used when the contaminants are gelatinous and sticky which leads to pore blocking, bridge failure and possibly particle bleeding /12/. The main problem prevented by using precoating is the fouling of the filter medium. Also regardless of whether the objective is to prevent clogging or obstruct fines from passing through the filter cloth, the mechanical function is to act as the actual filter medium /13/.

In this study the used filter unit is a vertical leaf filter that is commonly used as a polishing filter as it was noted in chapter 3. The general objective is to remove very small particles from the solution that might be e.g. another filters filtrate. Consequently it is critical to generate an assistant layer in order to improve the pore bridging. Otherwise bridge failure and particle bleeding occurs and the filtration process becomes ineffective as the small particles are not retained effectively by the filter cloth. It should be always remembered that the pore bridging properties are important when choosing a filter aid grade for a specific filter cloth, to be able to optimize the precoating time. The precoating principle is presented in figure 7.

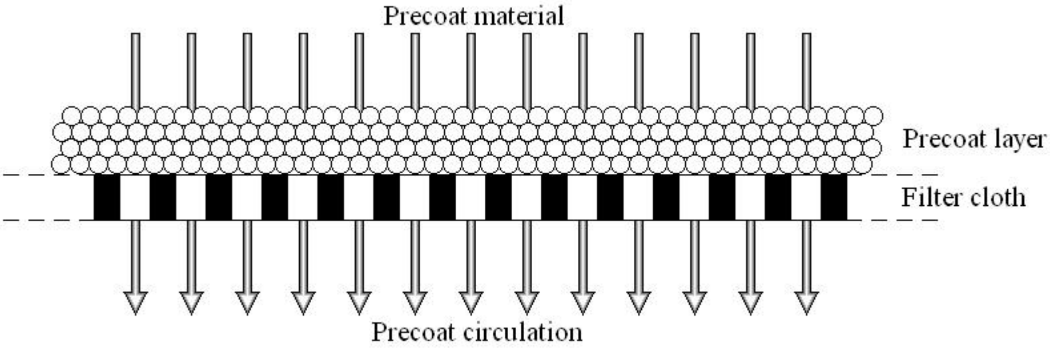


Figure 7. Schematic precoat layer.

Pore blocking, bridge failure and particle bleeding related problems can be avoided by implementing a thin uniform layer of precoat material to the surface of the filter cloth prior to filtration. The thin precoat layer of about 2 – 5 mm is obtained by pumping the precoat solution to the filter unit and circulating it through the filter cloth until sufficient, predetermined layer thickness is produced. A principle of the accumulated precoating layer is presented in figure 7. The filter aid materials have the property of bridging across the openings much larger than their own particle size. /13/

In a typical application for Larox LSF-filters a mixture of precoat solution of concentration about 0.1 – 0.5 % (weight/weight) is recycled through the filter cloth until a predetermined, sufficiently clear filtrate and predetermined cake thickness are achieved. The precoating time for a specific process conditions and equipment is always obtained by experimental testing procedures. Basically it can be said that the precoating step takes about 10 minutes with a flow of ~2 $m^3/h/m^2$ /8/. The time is dependent of the flow, but as well as of the cloth pore size and precoat particle size distribution. As the precoating of the filter cloth is relatively quick step compared to the total filtration cycle, the preparation, consisting of proportioning and mixing, is not usually a critical in a time point of view. /8/

The filter aid layer ensures that the filter cloth is kept separated from the accumulating sticky cake that would otherwise be inconvenient to wash away. As a result of using precoating, when the filter cloth is washed, the cake discharges easily from the surface resulting in faster washing cycles and longer lifetime of the filter cloths. Another reason for the usage of precoating is when clear filtrate is required immediately after the filtration cycle initiates, otherwise recirculation must be employed until a clear filtrate is achieved. This results in prolonged filtration cycles. Therefore the filter aid is needed for good filtration efficiency and better cleaning result that leads to longer life time of used filter media. /14/

The transition from the precoating step to the filtration step should be sequential to prevent the accumulated filter aid cake from cracking and dropping from the filter cloths /8/. This is of great importance when almost incompressible materials such as diatomaceous earth or perlite are used. It is not that critical when cellulose is used as the compressible cake sticks harder onto the cloth /5/. The filter proportioning, mixing and feeding system is explained in chapter 7 and the precoat filtration principle is presented in figure 8.

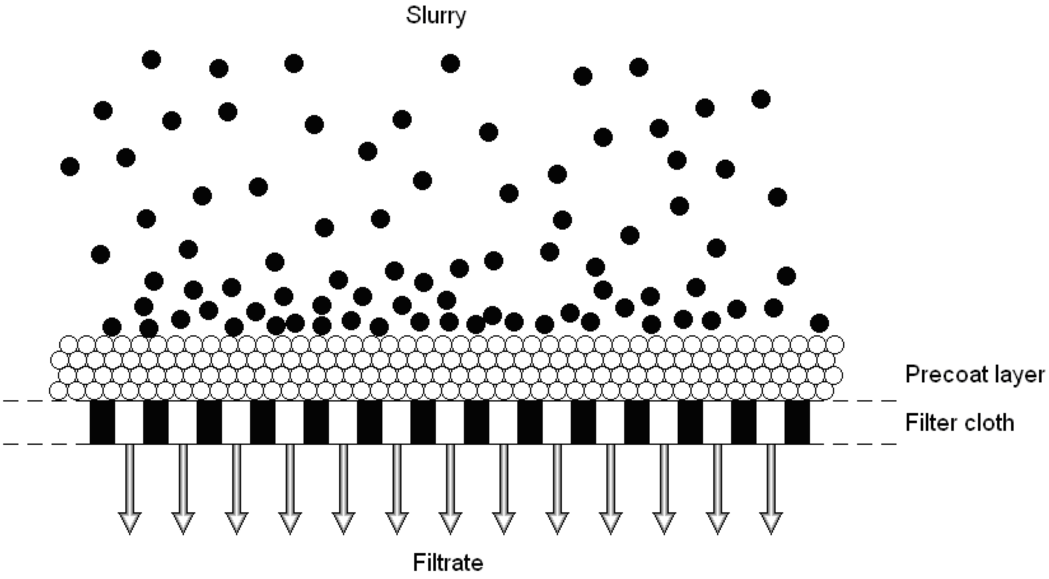


Figure 8. Precoat filtration principle.

4.1 Precoat quantity

The amount of introduced precoat material (diatomaceous earth) should be in the range of 0.48 – 0.73 kg per 1 m^2 according to Wang *et al* /15/. Higher amounts have to be used if the distribution of flow is poor or when a new filter is started up. The lowest precoat amount that Wang *et al.* /15/ suggests (0.48 kg/m^2)

produces a layer of about 1.6 mm in thickness. The same precoat amount is preferred also in other studies, including Cheremisinoff *et al.* /16/ and therefore it can be considered to be reliable. It may be inevitable to use baffles, or to change precoating rate, if lower precoat amounts are to be used /15/.

4.2 Precoat concentration

According to Wang *et al.* /15/ the precoat concentration is dependent primarily of the ratio of filter area to filter and piping volume. If the used precoat concentration is much below 0.3 %, bridging effect is deteriorated as the particles are flowing through the filter cloth. Basically it could be said that the concentration should be as low as possible but not less than 0.3 %, typical value being around 0.5 % /17, 18/.

4.3 Precoating rate

Precoating rate is dependent of the viscosity of the liquid that is used. It is essential to keep the filter aid in suspension but too high rates are causing problems. If too high precoating rate is used it will cause erosion of precoat in the filter and also the pattern of the supporting filter cloth grid is copied which decreases the efficient filtration efficiency /8/. When water is used as a carrier liquid in the precoat solution, a typical precoat rate is 0.04 – 0.08 $m^3/min/m^2$, according to Wang *et al.* /15/. If the viscosity of the solution is higher, lower precoating rate should be used. For viscous liquids the rate might be as low as 0.02 $m^3/h/m^2$. As a general rule the precoating rate should be in the range that gives a differential pressure of 6.8 – 13.8 kilopascals, depending on the source. The velocity in the feed pipeline should be at least 1.4 m/min, according to Wang *et al.* /15, 18/.

4.4 Precoating troubleshooting

According to Wang *et al.* /15/ the filtrate should clear up in from two to 5 minutes, but it does not mean that the precoat is all in place. Therefore the precoating should be continued until the filter shell is relatively clear; usually the time is obtained by experiments. If clarity related problems occur, the reason could be one of the following: improper venting of the filtering unit, precoat erosion, filter cloth blinding, insufficient precoat at top of the leaves, tears in the cloth, worn cloths, leaks between the leaves and the supporting grid, worn seals between leaf and discharge manifold, wrinkles in the cloth, negative pressure on discharge manifold causing flashing inside the leaf. /15/

5. Bodyfeed

If the solids in the filterable solution have a tendency to form a sticky impermeable filter cake, the cake properties may be enhanced by using a precoat substance as a bodyfeed during the filtration cycle. It is advantageous to use bodyfeed if the filterable slurry solution has a low solid content comprising of fine and slimy particles that deteriorates the filtration efficiency and thus makes the operation more challenging. The main objective of the bodyfeeding is to generate pores to the accumulating filter cake which results in faster filtration cycle time /8/. The enhancement is obtained due to higher permeability of the cake which allows using higher flow rate. Also the filtration step time could be prolonged as the accumulating cake remains more permeable for a longer time. The difference could be economically substantial in a long run, as the implemented bodyfeed amounts are relatively low.

When the filtration is started, accompanied with bodyfeed, a new filtering layer is produced continuously and the porous filter aid particles provide countless microscopic channels which act as traps for the solids. Therefore the filtration phenomenon is a mixture of cake filtration and in-depth filtration. The suspended impurities are blocked by these multiform channels but a clear filtrate i.e. carrier liquid is allowed to pass the cloth without clogging it. Conventionally the slurry properties are enhanced by introducing coarse, incompressible solids with large surface area in to the slurry feed in order to produce a highly porous cake matrix /19/. The basic principle is presented in figure 9.

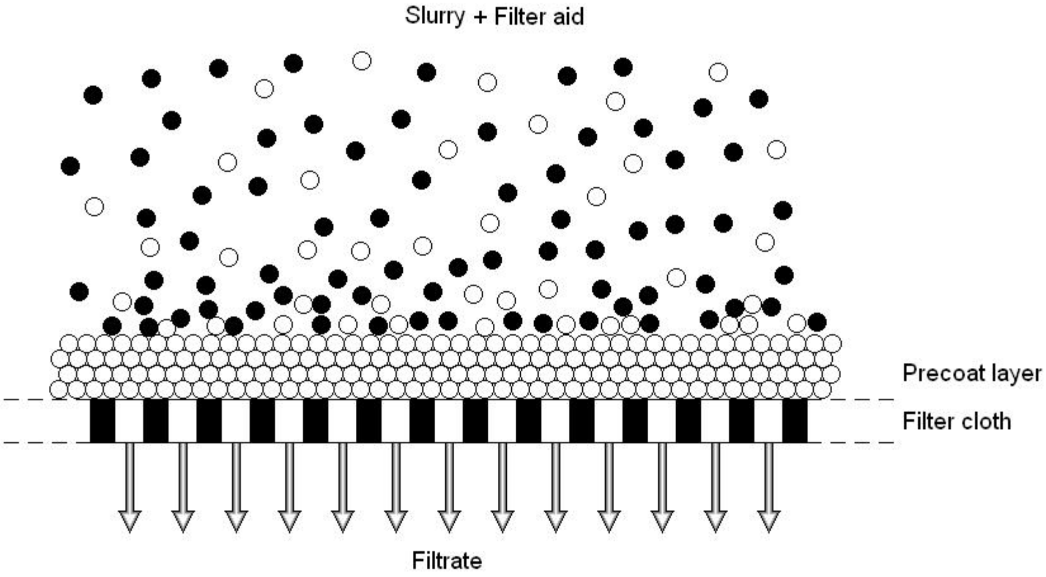


Figure 9. Bodyfeed filtration principle.

Nowadays it is more and more common to use compressible materials, such as organic cellulose. Basically the idea remains similar, the difference being the compressibility when the pressure is increased /5/. These organic filter aids provide many substantial improvements in processes where the use is applicable. The most common filter aid materials and their advantages and disadvantages are explained in chapter 6.

When the filtration step is started the bodyfeed is pumped from the mixing tank with a pump e.g. peristaltic pump into the slurry feed line. The amount that is introduced is determined according to the solid content of the filterable solution. Peristaltic pumps are commonly used because of the capability to act as a dosing unit at the same time, when accompanied with a variable speed drive. This way the bodyfeeding can be carried out reliably, without the use of extra equipment.

Operations based on addition of admixes to the filterable feed solution i.e. bodyfeed, may be described by general equations of filtration with cake formation. As Cheremisinoff *et al.* /16/ discovered a plot of filtration time versus filtrate volume results in an almost parabolic curve that passes through the origin. When plotted on logarithmic coordinates, assuming that the filter medium resistance may be neglected, results in straight line. This linear relationship allows shorter test runs to be used in filtration tests, because the test results can be extrapolated to give results for longer filtration runs. /16/

5.1 Bodyfeed quantity

When the proportion of the introduced bodyfeed is increased, also the throughput is improved rapidly. But it should be noted that introducing amount in excess will not improve the process. As it is illustrated in figure 10, when the amount of bodyfeed is constantly increased it reaches a peak which is the optimum for the process /10/. If the addition of the bodyfeed is too small it merely reduces the total throughput because the bodyfeed is completely surrounded by undissolved solids and therefore the cake permeability is not increased. In this case the introduced bodyfeed increases the thickness of the accumulating cake without increasing porosity. When increasing the amount of bodyfeed from the optimum, the cake permeability is not increased anymore and therefore the total throughput is decreased /15/. By plotting a bodyfeed concentration versus throughput curve, the optimum amount of bodyfeed can be determined straightforwardly for a specific process.

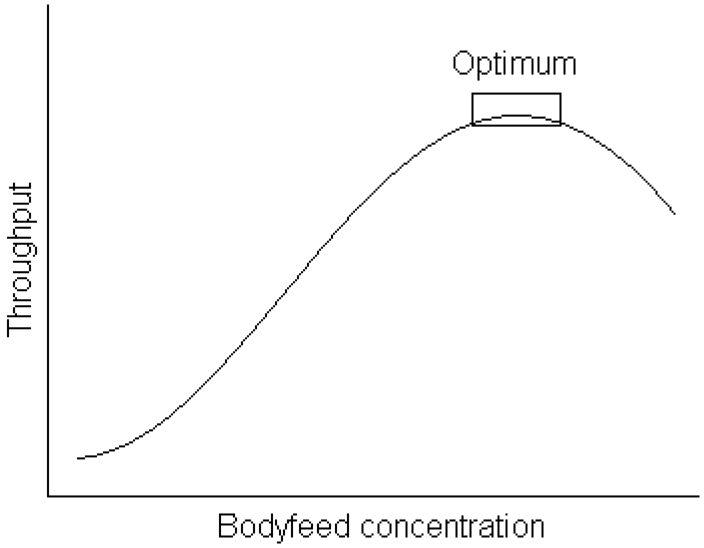


Figure 10. Bodyfeed concentration versus throughput /7/.

As the bodyfeed proportion that is introduced to the filterable solution can be alternated, it has a significant effect to the pressure drop as the constant rate filtration progress continues. Figure 11 shows three different amounts of bodyfeed that are used and their effect on the pressure drop as a function of time. The ideal curve is A as the pressure drop is increasing evenly with time. The curve C indicates an inadequate proportion of bodyfeed, when the pressure increases rapidly and the filtration cycle is shortened. Whereas the curve B indicates a process where the dosage of the bodyfeed is too high which results in excessive build-up of the accumulating cake, and therefore the pressure is increased rapidly in the end of the filtration cycle /10/.

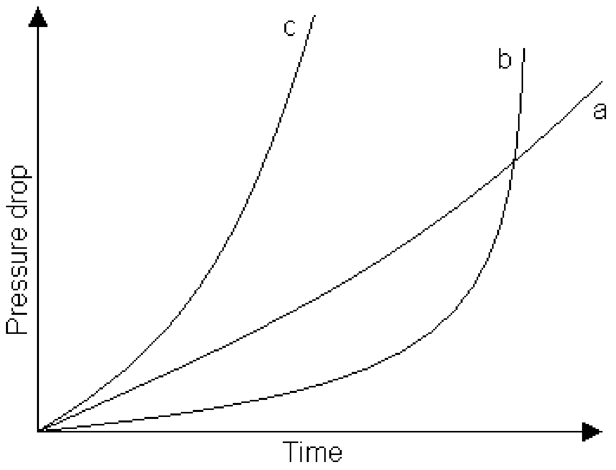


Figure 11. Bodyfeed amounts and their effect to the pressure drop as a function of time /10/.

The sudden increase in the pressure shown on curve b is the result of bridging of the cake between the leaves which leads to decrease in the filter area. This phenomenon should be avoided as it may result also in severe damages to the leaves and loss of clarification /15/.

Bodyfeed quantity in kilograms that is fed into the feed solution is proportional to the dry solids content. The amount depends also of the characteristics of the filterable solid particles. If the particles in the feed solution are nondeformable, the required bodyfeed amount is 1 mg/l for each 1 mg/l of suspended solids in the feed solution. If the feed solution particles are deformable the required bodyfeed quantity may be ten times more than that for nondeformable particles. /1/

5.2 Bodyfeed concentration

Bodyfeed concentration is not as critical factor as it is in precoating. Basically the only limiting factor is maintenance costs of the bodyfeed dosing pump. It is possible to use concentrations of up to 18 % (w/w), but the most economical and efficient concentration is between 5 – 10 % (w/w). When this concentration is exceeded, the pump maintenance costs are increased /15/. It is advisable to mix the desired concentration already to the mixing tank, so that no further diluting is needed. It should be remembered that higher the bodyfeed concentration, smaller-scale equipment can be used and less wetting of the slurry feed occurs.

6. Filter aid materials

Filtration is a separation method where solids are separated from the liquids by forcing the solution to flow through a porous interface and simultaneously accumulating the solids onto the filter cloth surface. Due to this the filtering medium consists of the filter cloth and also of the accumulated cake. Filter aids are extensively used in processes where the filtrated solids form relatively impermeable cake to the flow of filtrate. According to McKetta /20/ the basic need for using filter aid materials is to reduce the overall costs in processes in the field of clarification of valuable liquids and to meet the high clarities required in some liquid products. One could say that filter aid filtration should only be applied for systems where desired product is the filtrate and the filter aid should be acceptable in the accumulated cake. Or if it is not acceptable, it should be possible to repulp the cake and filter it again in order to remove the filter aid from the separated solids /4/. In a certain circumstances the filter aid material must be readily separable from the cake by physical or chemical means /21/. The basic principle of the precoat and bodyfeed accumulation is presented in figure 12.

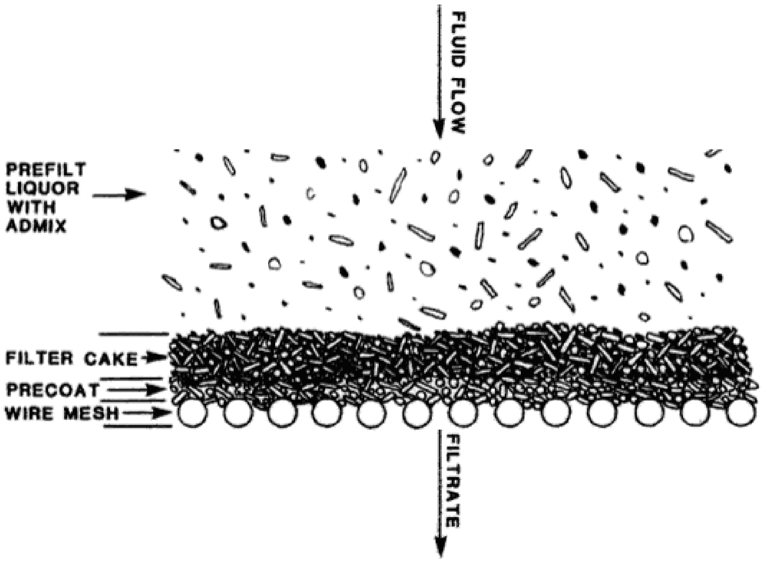


Figure 12. Precoat layer and bodyfeed addition /20/.

Shugar *et al.* /22/ simplified the limitations for the use of filter aid materials into three facts:

1. They cannot be used when the object of the filtration is to collect a solid product, because the precipitate collected also contains the filter aid. Filter aids can be normally used only when the filtrate is the desired product.

2. Because they are relatively inert, they can be used in normally acidic and basic solutions; however, they cannot be used in strongly alkaline solutions or solutions containing hydrofluoric acid.

3. Filter aids cannot be used when the desired substance is likely to precipitate from the solution. /22/

According to Woods /23/ filter aid materials should be considered to be used when particle diameters from 0.8 to 20 µm are to be filtrated. Woods /23/ also presents a general relationship of the particle size to precoat bed permeability: “A fine filter aid is 8 to 20 µm diameter to give precoat bed of permeability 0.05 to 0.5 µm^2; a medium filter aid is 30 to 60 µm diameter to give a precoat bed of permeability 1 to 2 µm^2; a coarse filter aid is 70 to 100 µm diameter to give a precoat bed of permeability 4 to 5 µm^2". /23/

Filter aids are inorganic or organic fibrous materials that are used in combination with filtration hardware to generate a thin (few millimeters) porous layer that intensifies the filtration process. Filtration with filter aid materials is purely mechanical, not chemical in nature. Filter aid that is applied in advance of filtration is called precoat, and its objective is to protect against the penetration of the unwanted solids and premature blinding/pore blocking of the filter media. When the filter aid material is introduced continuously into the slurry feed, it is called bodyfeed which increases the permeability in the accumulating filter cake, restricts solid movement, provides channels for filtrate recovery and extends the filtration cycle length /24/.

6.1 Most commonly used filter aid materials

Diatomite, perlite and cellulose are the most widely used filter aid materials in dynamic process filtration /24/. These materials and their characteristics are presented in the following chapters. The economical factor rules out many potentially useful substances and also the use of sophisticated classifying procedures in filter aid manufacture. It is in some processes reasonable to use a mix of different filter aid materials to produce an optimal solution. For example when a small amount of fibrous material is introduced to perlite or diatomaceous earth filter aid solution, the accumulated cake becomes more compact /16/. Also the total precoating time may be shortened because of the good bridging properties of the fibers.

The most common filter aid materials that are used in solid-liquid separation processes are:

- Inorganic mineral powders
    - Processed diatomaceous earth, known as diatomite
    - Expanded perlite, a glassy aluminum silicate of volcanic origin

- Organic fibrous materials
  - Cellulose
  - Cotton linter

- Organic origin
  - Rice hull ash, a mineral filter aid, introduced in recent years /16/.

A simplified table of the studied filter aid materials and their differences is presented in table II /25/.

Table II. Filter aid materials and their differences /25/.

Property	Filter aid		
	DE	Perlite	Cellulose
Permeability, Darcy	0.05 – 30	0.4 – 6	0.4 – 12
Median pore size, microns	1.1 – 30	7 – 16	–
Compactibility	Low	Medium	High
Trace metal contaminations	Moderate	Moderate	Low
Silicosis concern	Low to high	Low	None

6.1.1 Perlite

Perlite is a generic name for naturally occurring amorphous glassy siliceous volcanic rock that has a relatively high water content and it is available almost throughout the world as is presented in figure 20 /6/. Perlite is formed from rhyolitic volcanic flows and is chemically a sodium potassium aluminium silicate that has to be processed and modified in order to use it as a filter aid material /24, 26/. The reason why it has to be modified is that in the natural state perlite is dense, glassy rock, which in the raw form contains about 3 % of crystal water and has a density of about 1050 kg/m³ /27/, compared to typical expanded perlite that has a bulk density of 30 – 150 kg/m³ /28/.

Perlite is known in industry in two forms. Crude or crushed perlite is prepared by the crushing and screening of perlite into various size fractions. Expanded perlite is perlite after it has been rapidly heated to a high temperature /29/. The most important and unique feature of perlite that differentiates it from other volcanic glasses is its ability to be expanded through this heating process. Crude perlite has to be processed i.e. expanded before it can be used as a precoat material. The reason is that it has one of the most unusual physical properties; it greatly expands when rapidly heated to its softening point which is above 871 °C. It pops in a manner similar to popcorn as the combined water vaporizes and creates countless tiny bubbles which account for the lightweight and other exceptional physical properties of expanded perlite. Perlite expands from four to twenty times its original volume due to the presence of two to six percent combined water in the crude perlite rock /26, 30, 31/. A typical composition of perlite is presented in table III.

Table III. Typical analysis of perlite /28/.

Silicone dioxide	SiO_2	70–75 %
Aluminium oxide	Al_2O_3	12–15 %
Sodium oxide	Na_2O	3–4 %
Potassium oxide	K_2O	3–5 %
Iron oxide	FE_2O_3	0.5–2 %
Magnesium oxide	MgO	0.2–0.7 %
Calcium oxide	CaO	0.5–1.5 %
Loss of ignition (chemical/combined water)		3–5 %

The crude rock is usually from transparent light grey to glossy black but the rapid heating generates snow-white granules composed of many tiny closed air cells or bubbles /27/. These bubbles are milled and classified to produce perlite filter aid /32/. Expanded perlite can be manufactured to weigh as little as 32 kg/m^3. This feature makes it adaptable for numerous applications, including construction, industrial, chemical, and horticultural industries. Since perlite is a form of natural glass, it is classified as chemically inert and has a pH of approximately 6.5 – 7.5 /33/.

Figure 13. Expanded perlite microscope picture /13/.

After heating process, a porous complicated structure with billions of interstices is present, but because its structure is not as complex and tortuous as that of diatomite, perlite suits better for separation of coarse micro particulates from liquids having high solids loading. A microscopic picture of a perlite surface is presented in figure 13. The resulting filter aid is an extremely pure, inert, white, lightweight material having a unique interlocking structure with myriads of microscopic channels. It affords optimum flow rates and sparkling clarity in filtered substances. Perlite does not impart taste, odor or color to filtered liquids. /24, 33, 34/

Perlite filter aids are available in a full range of grades and permeabilities. Perlite is functionally similar to diatomaceous earth, however perlite bulk densities are about half that of diatomite. Kilo for kilo, perlite gives up to 20 % greater filtering capacity resulting in comparable savings in filter aid usage, especially on rotary vacuum precoat filters /35/. Although according to Yang *et al.* /4/ the most important advantage of the perlite over the DE is its relative purity.

The biggest producer in 2005 of the perlite was estimated to be Greece with a production of about 525 000 metric tonnes. Other leading perlite producing countries are USA, Turkey, Japan, Hungary, Armenia, Italy, Mexico, and Philippines. One could say that perlite is mined and expanded throughout the world. /36/

In 2007 the cost of perlite was about US$ 355 per tonne. The year end price for mined perlite in the US has increased since then /36/. The usage and production of the processed perlite has been declined to its lowest level since 1983 /37, 38/.

6.1.2 Diatomaceous earth

Diatomaceous earth which is also called diatomite, D.E. or kieselguhr is the most widely used filter aid material in the world. It has conventionally found its greatest practical applications in swimming pools, iron removal from the ground waters, and industrial and military applications according to Salvato *et al.* /39/. It is an industrial mineral from vegetable origin, composed primarily of the skeletal remains of microscopic aquatic plants, called diatoms, hence the name diatomite. In the geological sense, the name diatomite means sedimentary accumulations that have reached observable thickness and when the accumulation continues, the deposit may have possible commercial potential /7, 40/.

These diatoms have a unique ability to extract silica from water to form their own skeletal structures. When the diatoms die their skeletal remains sink to the bottom of lakes and oceans (marine diatomite) and form a diatomite deposit. Under certain conditions deposits accumulate over millennia and when the water recedes from these areas the deposits become more easily accessible to mining /40, 41/. Diatomaceous earth is commonly used material in the field of filtration as it was said earlier. This is due to the fact that the natural product of diatomite can be modified to meet the requirements and demands of the different and demanding end-use applications. As the particle size and distribution are important factors when selecting and optimizing a filter aid material for a certain process, these factors are modified by crushing, drying and sieving /41/. Typical chemical composition of natural diatomite is presented in table IV.

Table IV. Chemical composition of natural diatomite (oven-dried basis) /7/.

Silicone dioxide	SiO_2	89.75 %
Aluminium oxide	Al_2O_3	3.08 %
Sodium oxide	Na_2O	0.19 %
Potassium oxide	K_2O	0.22 %
Iron oxide	FE_2O_3	1.33 %
Magnesium oxide	MgO	0.11 %
Calcium oxide	CaO	0.41 %
Titanium oxide	TiO_2	0.14 %
Phosphate	P_2O_5	0.04 %
Loss of ignition		4.70 %

Diatomaceous earth is friable, white, soft and powdery siliceous material that has unique physical properties. To the naked eye diatomaceous earth is a fine white powder, but under microscope its unique structure is revealed. This porous structure with complex absorptive and bulking properties makes diatomaceous earth highly desirable for the use as a filter medium /42/. Diatomaceous earth occurs in many shapes when examining an individual particle. The particles of diatomite show up in following form: symmetrical figures resembling disks, rods, cylinders, and snowflakes. Almost all of the particles resemble petrified tumbleweed as they are lacy, web like particles comprising of about 90 % voids and only the rest 10 % is solid fibers /43, 44, 45/. A structure of a marine diatomite (ocean deposit) is presented in figure 14.

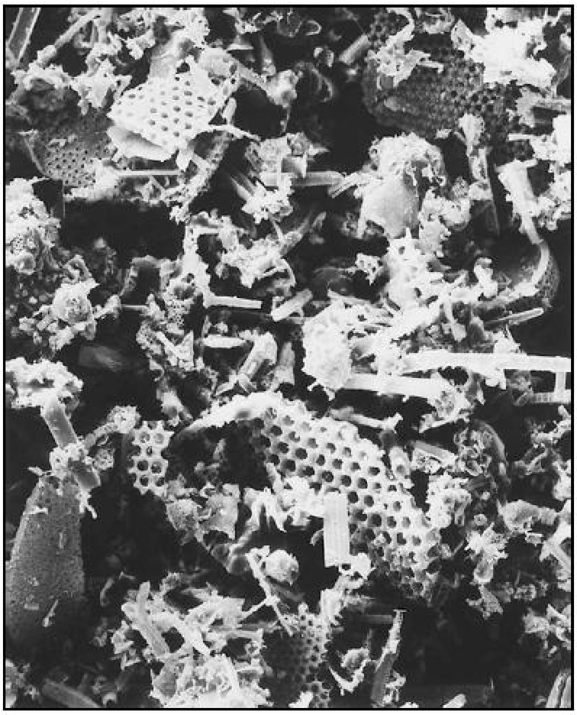


Figure 14. Marine diatomite microscope picture /24/.

Diatomaceous earth, which in its natural form is odourless and non toxic, is selectively mined from open pits, and stockpiled for initial drying in open air. When diatomaceous earth is produced to act as a filter aid material it is first crushed and further dried. Then the material is sized by a series of air separators and cyclones. Without further processing the sized, natural milled, coarse fractions of diatomite can be used as a filter aid material. It is also possible to adjust the properties by calcinations. After crushing, drying, and fractionation processes diatomaceous earth is heated (at above 800 °C) in a kiln in a process called calcination to achieve certain characteristics that improve its performance i.e. optimal particle size distribution and structure. Calcination (divided into straight- and flux -calcinations) changes significantly the physical and chemical properties of diatomite, making it heat resistant and practically insoluble in strong acids. Calcinated diatomaceous filter aid additives have high retention ability with relatively low hydraulic resistance. Technically the thermal processing that is commonly called calcinations is a sintering or agglomeration process. As it was said before, the calcinations can be divided into straight- and flux -calcinations. The difference is the addition of a fluxing agent, e.g. soda ash, prior to heating and also higher temperature of up to 1200 °C. By using a fluxing agent the outcome is white-colored product with even more increased particle size. With these characteristics diatomaceous earth is able to meet the exacting clarity and flow-rate demands of industrial filtration /41, 44, 46, 47, 48/. One disadvantage of the diatomaceous earth is that it may foul filtering liquids by dissolved salts and colloidal clays /4/. The most suitable precoat concentration when DE is used is between 0.3 – 0.6 % (w/w) /20/. Different types of DE and their characteristics are presented in table V.

Table V. Different types of DE filter aids and their properties /47/.

Type of filter aid	Clarification efficiency	Flow rate	Particle size
Natural	Excellent	Poor	Very fine
Straight calcined	Good	Medium	Medium
Flux calcined	Good to medium	High to very high	Medium to coarse

There are thousands of varieties of diatoms throughout the world but not all of them are suitable to be used as a filter aid material according to Saravanamuthu Vigneswaran *et al.* /47/. Diatomite is widespread throughout the world but high-purity; commercially versatile ore deposits are uncommon. Low-purity diatomite is unsuitable to be used as a filter aid material, but can be used in other applications /7/. Two types of diatomite are commercially processed, freshwater origin and seawater origin. Diatomites that are of freshwater origin are tubular and effective in the removal of very fine solids and applications where fast flow rates are required. Both calcined and process-calcined diatomite filter aids are free of organic matter and are non-absorptive. Celatom is an example of a fresh water brand of diatomite. Diatoms from seawater origin are composed of rods, flowers, boats and snowflake shapes. These have the same use as freshwater diatomite, the only difference being the different shapes /43/.

United States is the leading producer of the diatomaceous earth with 687 metric tons in 2007. Other leading perlite producing countries are China, Denmark and Japan. Average value of the diatomite that is used in the field of filtration was US$ 352 per tonne. /48/

6.1.3 Cellulose

As the filtration step is in many industrial applications a quality and cost-determining processing step, filter aid characteristics are being continually improved. The improvement is essential in order to meet the growing demands of cost effectiveness, occupational health and safety, and environmental compatibility. Traditionally the mineral products, diatomaceous earth and perlite, were the most widely used filter aid materials in the world. Nowadays the use of organic filter aids has conquered a huge share of the total consumption. The biggest advantage, and what derives it from other filter aids is the fact that cellulose is of organic origin derived from re-growing raw materials and therefore it can be can be disposed of in an environmentally-friendly manner. It might be even advantageous to utilize the used filter aid material e.g. as an animal feed /5/. Cellulose filter aids are processed to be suitable as a filter aid material. A schematic diagram of Rettenmaier & Söhne's cellulose filter aid manufacturing process is shown in figure 15.

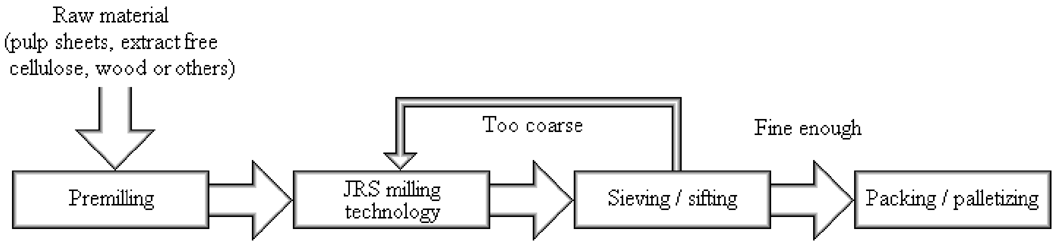


Figure 15. Cellulose filter aid manufacturing process /49/.

Cellulose filter aids are practically ash less and non-abrasive that is beneficial for the auxiliary equipment. Basically the used filter aid can be disposed easily, economically and, in part, even profitably as it was noted before. It is also possible to completely recover valuable processing aids (such as catalysts). And even though cellulose filter aids are more expensive than diatomaceous earth and perlite, in some applications it can still be an economical solution. The general rule is that the cellulose filter aids are up to 50 % more expensive but at the same time the total amount needed is reduced by 50 % /5/. It should be always remembered that mixtures of organic and mineral components are in some applications highly advantageous and advisable solutions /50/.

Disposal difficulties and the new recycling legislations contribute to the steadily increasing use of cellulose as a filter aid. As a naturally regenerating raw material, cellulose meets the requirements of a closed cycle. An important advantage is that cellulose is compressible and can with installation of an additional pressing apparatus be reduced to less than 20 % moisture. Thus no thermal drying is required and the pressed fluid can be utilised and returned to the filtrate. This leads to reduced environmental stress and optimises a cost which is important when the filtrate is the preferred outcome of the separation process. The total efficiency of the filtration process step is also increased as the cake moisture is reduced and thus the waste contains less of the valuable substances. For example a wet cake density of diatomaceous earth is around 300 – 450 g/l compared to cellulose cake 130 – 180 g/l. This is very advantageous when filtrating highly valuable products e.g. wines /5/. The difference between the accumulated cakes of compressible cellulose and incompressible diatomaceous earth is presented in figure 16. If cellulose is incinerated, the advantage is that the cellulose burns practically ash free and as a regenerative raw material it forms a closed CO_2 cycle (application for example: reclaiming of precious metals). In some applications the total energy consumption is reduced as the drying step is improved. This is due to the fact that the cellulose burns away easily and leaves pores that enhance the removal of the moisture /5/. In the area of food filtration the filter cake can be composted or utilised in agricultural applications /43/.

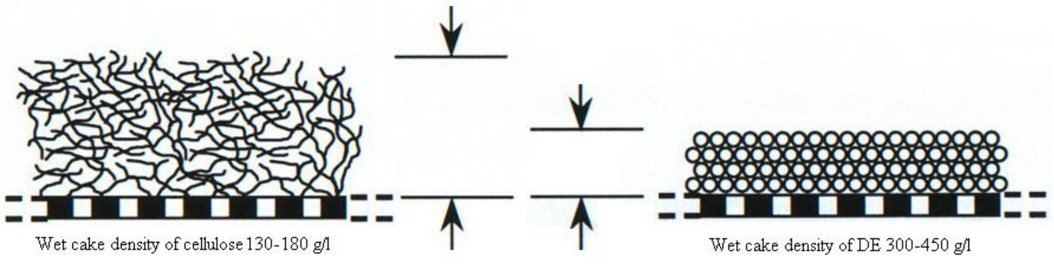


Figure 16. The difference of the filter cakes of DE and cellulose. Same quantities of filter aid in kilos. /49/

The cellulose is the main constituent of wood carbohydrates. It is a polysaccharide consisting of glucose units with high resistance to chemicals. The fiber cell wall contains also hemicelluloce and lignin that binds the fibers together. Generally cellulose, found mainly from the secondary wall, comprises approximately 40 – 50 % of the dry mass of wood and is therefore the main constituent of wood. Chemicals and heat are used to dissolve the lignin and to separate the fibers from each other. The end product of the chemical pulping is called “pulp” and this is usually the raw material for the production of cellulose filter aids. Cellulose structure is presented in figure 17.

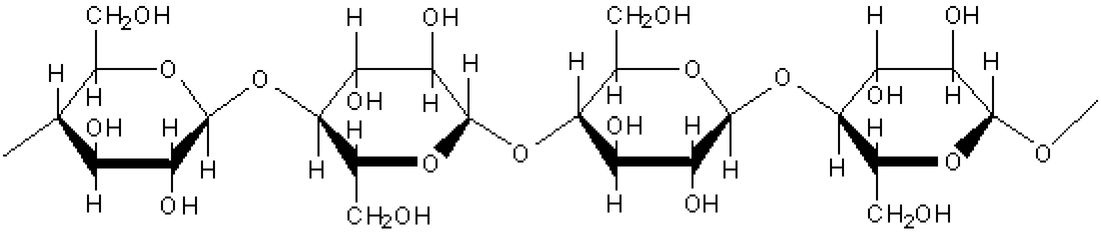


Figure 17. Cellulose structure /51/.

A characteristic of the cellulose fiber has been improved by fibrillating the fibers in order to improve the efficiency. A microcrystalline cellulose material from Germany, Vivapur, has reportedly improved filtration properties compared to regular α-cellulose. Cellulose filter aids are used in applications that demand effectiveness in highly alkalic conditions, above pH 10. One example is chlorine-caustic industry to filter the brine feed to electrolysis membrane separators. Another application of cellulose is in treating machining oils and cutting fluids, to break the emulsion or to trap metal fines. The application of cellulose in pH-values of 4 – 14 can be viewed as problem free. Even the short term use of cellulose in ranges below pH 4 is possible; however, temperature plays a significant part and must be kept as low as possible to avoid a saccharification of wood /24, 43/.

The use of cellulose filter aids is quite straight forward as the filter cloth is precoated pretty easily. The cellulose fibres allow the build up of a very stable filter cake which remains robust even during variations in pressure. This is due to the compressibility of the accumulated cake which is also the reason why cellulose filter aids are frequently mixed with inorganic filter aids, diatomaceous earth and perlite, to increase the accumulated cake performance with this property

/4/. Cellulose filter aid creates a porous mat or paperlike layer on the filter screen or cloth. The fibers bond together and provide a fairly rigid medium. The fibers readily bridge even the coarser septum openings to build up a precoat in a minimum of time. Such a precoat will not crack under usual pressure changes; will plug small leaks in the filter septum; and will often remain on the septum when the pump is stopped. /27/

Cellulose fibers also bridge tears in the filter screen without problems, prevent breaks and increase processing safety. The filter screen can have a larger mesh due to the stable structure of the filter aid layer. This increases the filtration throughput. Although the cellulose filter layer can be compressed in practice this generally causes no problems. The compressibility of the filter aid is only perceivable when the pressure exceeds 2 bar. To avoid unnecessary energy consumption most filtration processes are terminated when pressure differences of 2 bar are reached /52/. An additional characteristic is the swelling property of cellulose. This is, however, hardly perceivable during the build up of a filter cake. Wet density is a very important attribute for the construction of a filter cake. A wet density of 200 g/l means for example that 200 g of the filter aid form a filter cake of 1 mm heights over 1 m^2 of screen. Cellulose filter aids have wet densities ranging from 80 to 300 g/l /43/. The different structure of the cellulose compared to inorganic materials is presented in figure 18.

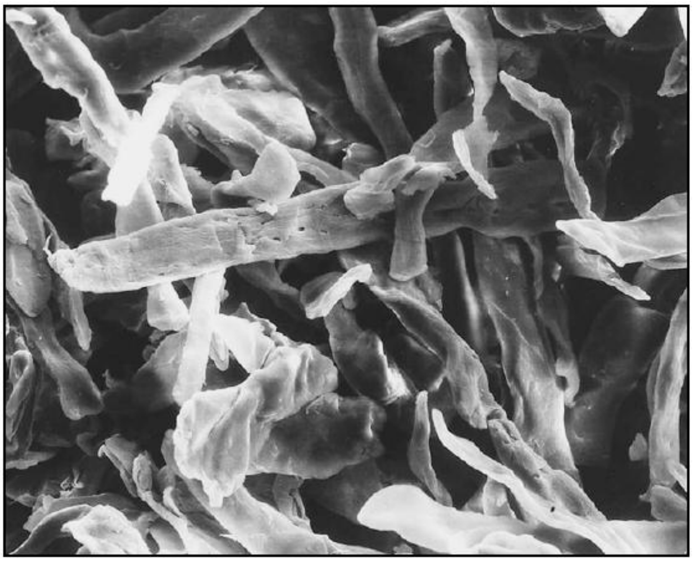


Figure 18. Cellulose microscope picture /24/.

6.2 Comparison of the filter aid materials

As there are many useful filter aid materials with various characteristics, they all have their unique properties and therefore advantages and disadvantages. In this chapter are presented the differences of the materials from the applications, and particularly under its circumstances, point of view. If the application is carried out in exceptional circumstances, it may limit the use of a certain material. The most important factors are listed in the paragraphs below and material comparison is made in one factor at a time.

6.2.1 Resistance of acids and alkalies

The resistance of acids and alkalies is important as a wide range of applications are operating in the fields of slightly acid or alkali conditions. Therefore the stability is of great importance when choosing a right material. Diatomaceous earth is slightly soluble in dilute acids and alkalies and perlite is even more soluble. Cellulose filter aid materials are most stabile as they have an excellent chemical resistance, slightly solubility in dilute and strong alkalies, none in dilute acids /12/. One could say that in the range of 4 – 12 pH conditions the optimal choice is cellulose /43/.

6.2.2 Thermal resistance

Thermal resistance is the biggest obstacle when cellulose is considered to be used according to its maximum operating temperature which is around 200 °C /5/. Both the diatomaceous earth and perlite can be used in higher temperatures as they are produced in roughly 1000 °C as it was noted in chapter 6.1.1. The limited thermal resistance of the cellulose is a disadvantage in some processes but can be also beneficial because of the improved drying of the end product as the cellulose can be burnt away while leaving pores where moisture is released more effectively /5/.

6.2.3 Price

The price is highly dependent of the selected grade and its properties and therefore it is quite impossible to compare reliably. It could be said generally that even though the price per ton is different between the materials, the usage compensates the difference. For example as the cellulose filter aid materials are roughly 50 % more expensive compared to diatomaceous earth and perlite, but the amount to be used is about 50 % less. And when lower volumes are used, the lower are the transportation costs. When comparing the prices of the perlite and diatomaceous earth, the prices per ton are in the same level, but the bulk density of the perlite is lower. This advantageous in reduced transportation costs of the material and also of the disposal /5, 36, 48/. According to Cheremisinoff /53/ the amount of perlite required is typically 30 % less compared to diatomite. That is due to the smaller specific weight /53/.

6.2.4 Size range and availability

Perlite and diatomaceous earth are available in wide size range, and therefore tailored particle size distributions can be used for a specific application. Biggest difference being in perlite is not capable of finest retention of diatomites and cellulose is mainly used as a coarse precoat /12/. At the same time as the diatomite grades are the most fragile, they form the weakest cake in a mechanical strength point of view /54/.

6.2.5 Equipment requirement

The same proportioning, mixing and feeding system can be used with all of the filter aid materials but there are some points where the difference should be remembered, which might be economical in a long run. As the perlite and diatomaceous earth are abrasive materials, valves and pumps are operating under harder circumstances which may lead to higher maintenance costs and more expensive equipment. Cellulose produces practically no abrasion and is manageable from the equipment point of view. When cellulose is used as a filter aid material it is more important to focus on the vibrating element of the feed hopper, as the fibers may not be unloaded as easily as the incompressible perlite and diatomaceous earth /5/. When the filter aid material is successfully unloaded from the feed hopper to the mixing tank, mixing of inorganic materials should be carried out more carefully as too vigorous mixing crushes the spongy particles and results in lower particle sizes than planned. One important and advantageous factor of cellulose is its lower sedimentation speed. When the precoating is started and the solution enters the filtration chamber, fast sedimenting materials may accumulate to the bottom of the filter unit, before the circulation occurs. This phenomenon may be prevented by filling the filter chamber with fresh water or filtrate prior to precoating /5/.

6.2.6 Precoat cycle time

The precoat cycle time is lower when cellulose based filter aid materials are used, as the oblong particles accumulate faster to the filter cloth surface, compared to diatomaceous earth or perlite. It should be remembered that more open filter cloth should be used with cellulose. Even better when the filter cloth is monofilament and calendered that reduces the sticking of the fibers to the filter cloth /5/.

6.2.7 Product loss and disposal

Product loss is an important factor when operating in the field of expensive end-products. For example when cellulose is used, the total amount of the used material is reduced by up to 50 – 70 %. In practice that means that reduced consumption and less sludge which often associates with expensive and time-consuming disposal. Simultaneously the reduced sludge contains less residual filtrate which is advantageous due to reduced product loss. The reduced product loss is achieved due to lower amounts of disposal of the moist filter sludge. Filter sludge, which is made up of organic filter aids, can be quite effectively compressed or even made into briquettes**.** In this manner, a large portion of the valuable residual filtrate can be recovered leading to even further savings. Due to the fibrous structure of organic filter aids, stable and defined compacted material or briquettes are obtained that can often be profitably recycled /5/. Figure 19 presents the different applications where the used filter aid material can be used and utilized.

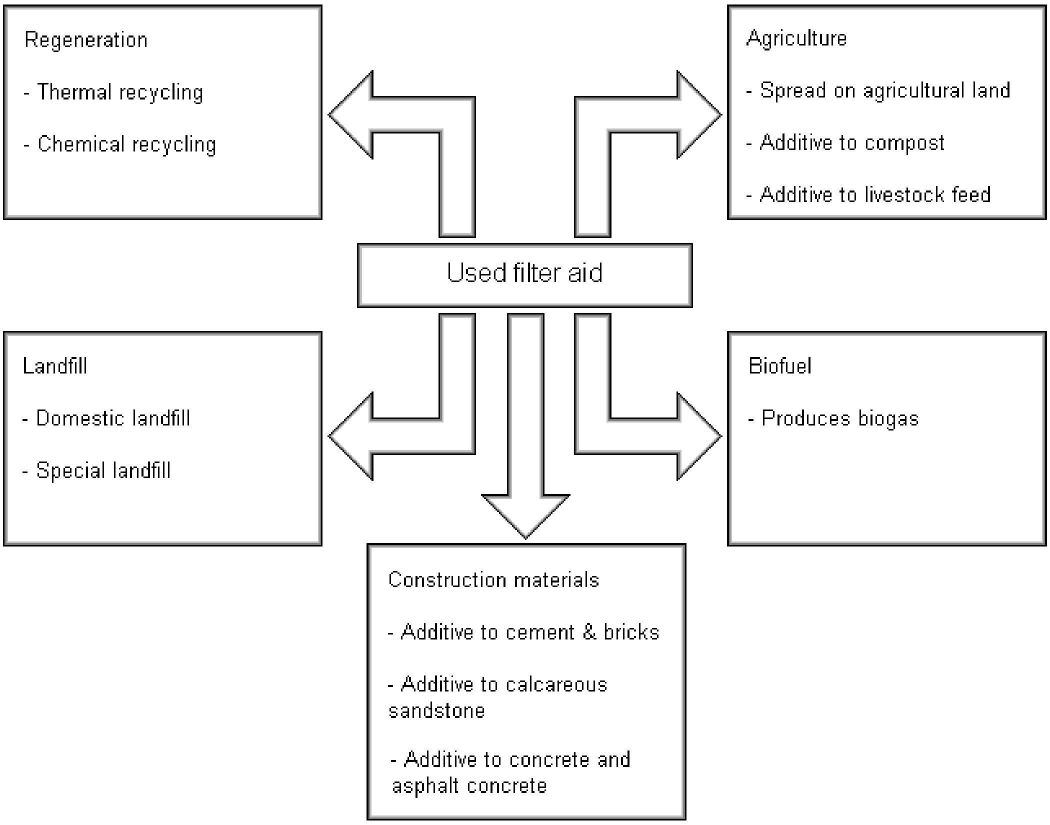


Figure 19. Used cellulose filter aid re-use applications /55/.

6.2.8 Health issues

The inhaling of perlite and diatomaceous earth is dangerous as they are classified as carcinogenic materials and therefore breathing masks should be used when dealing with these materials /46/. Cellulose filter aids can be disposed of in an environmentally friendly manner, and are harmless to workers /28/.

6.3 Economical aspects and availability

As it was noted before, the use of filter aid materials is mainly concentrated to the processes where the filtrate is the preferred outcome of the process and the cake is considered to be waste product /21/. Therefore it is economical to use filter aid products that remain relatively dry after filtration, as the accumulated cake is usually disposed after the cycle. The higher the cake moisture, the higher is the wastage of the valuable product. A very illustrative example is the study that was carried out by Erbslöh Geisenheim AG /56/ where DE and cellulose filter aids were compared in a wine producing application. The result data of the study is presented in table VI below. It was assumed that 1 kg filter aid binds 3 l wine.

Table VI. Erbslöh Geisenheim AG's filter aid study /56/.

Technical aspects	DE	CelluFluxx
Precoating	50 kg coarse DE	5 kg P30/20 kg F45
Corresponds to kg/m^2	1.25	0.625
Continuous dosing, total (kg)	400	175
Filter aid consumption, total (kg)	450	200
Filtrated wine (l)	330 000	420 000
Specific consumption (g/l wine)	1.36	0.48
Filtration cycle (h)	10	12
Pressure difference (bar)	4	4
Filter aid costs (€/kg)	0.65	2.95
Filter aid costs, total (€)	292.50	590
Wine loss (l)	1 350	775
Assumed wine sales price (€/l)	2	2
Receipt loss (€)	2 700	1 550
Waste volume (25 % dry matter)(kg)	1 800	900
Waste disposal costs 100 €/t (€)	180	90
Actual filtration costs (€)	**3 173**	**2 230**

When organic fibers like cellulose are used, the end-product can in some applications be recovered by incinerating /5/. Even though filter aid materials can enhance the filtration process remarkably, they are quite expensive when the whole investment, consisting of the capital investment cost and the operating costs are considered and therefore the necessity should be considered thoroughly, case by case. A simple automatically operating process does not need an own operator and therefore the labour costs are ignored, assuming that the filtration department crew is able to operate it while taking care of their conventional work. Example of simplified operating cost estimation is presented below and the calculations and explanations are presented in chapter 10. The detailed operating costs as a function of filtration area are presented in Appendix II. Table VII presents the used initial data that was used for the calculation.

Table VII. Initial data for cost estimation calculation.

Filtration		Precoat	Bodyfeed	Perlite	Slurry
Area	Cycle	Cake thickness	Bodyfeed amount	Price	DS content
m^2	h	m	$l/m^2/h$	\$/ton	%
100	10	0.003	0.5	355	6

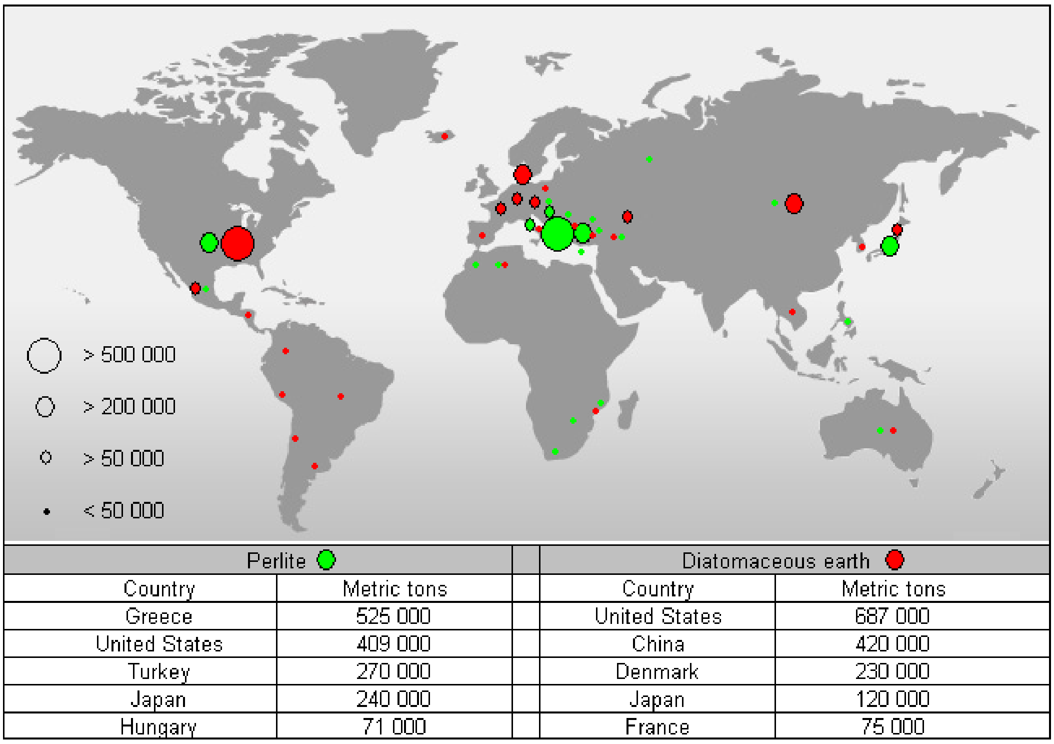
As a result of using this initial data, operating costs of a proportioning, mixing and feeding system where perlite is used as a filter aid material, is presented below. The main expenses consist of raw material i.e. perlite, electricity and maintenance costs. The costs are estimated for one year of operation and the summary is presented in table VIII.

Table VIII. Operating costs summary.

Cost	Price, €
Expanded perlite, raw material	31 600 €
Electricity	8 000 €
Maintenance	5 000 €
Total	44 600 €

The cost of the raw material can be considered to be constant when perlite, diatomaceous earth or cellulose is used. Even though there are differences in the prices of the raw materials, the compensation occurs due to the amount that has to be consumed. As an example, when the cellulose is approximately 50 % more expensive compared to perlite, the consumption can be kept 50 % lower level /5/.

As a result of the relatively low fluctuation of the prices, the most important factor when considering which filter aid material to use is usually its availability as it is uneconomical to transport the materials from other side of the world /8/. The distance is not the only factor affecting to the total transportation price. When for example perlite and diatomaceous earth are compared, the lower specific weight of the perlite advances in lower transportation costs, as the total weight needed to transport is lower. Fortunately the markets of the most used materials have spread almost throughout the world as can be seen in figure 20. As can be seen in the availability map, the only continent with substantial difference is South America where perlite production does not exist. It was not yet possible to find reliable information about cellulose based filter aid producers, as the raw material is used in numerous different applications, and the use as a filter aid material is relatively recently discovered.



Perlite 🟢			Diatomaceous earth 🔴	
Country	Metric tons		Country	Metric tons
Greece	525 000		United States	687 000
United States	409 000		China	420 000
Turkey	270 000		Denmark	230 000
Japan	240 000		Japan	120 000
Hungary	71 000		France	75 000

Figure 20. Top 5 Perlite and diatomaceous earth producing countries in 2007 and world map showing all the important producers /36, 48/.

6.4 Required characteristics of a good filter aid material

The requirements of an effective, practicable and economical filter aid material are that it should have suitable particle size and shape characteristics as well as to be lightweight, sterile, chemically inert under the conditions used and the outcome of the accumulated cake should have a high porosity that sustains free flow of the filterable liquid. The structure and shape as well as optimal dosage of the filter aid particles are critical factors due to the accumulated cake characteristics as irregular particles should form fine interstices between the particles. These billions of interstices allow the carrier liquid to flow through but capture the eligible solids from the solution. The structure of the particles should be prepared in a way that they will not pack too closely as they accumulate to the surface of the filtering cloth. The advantages of the porous media are high initial liquid flow that can be maintained longer. In addition the pore spaces provide traps for the filterable solids and simultaneously leave a high percentage of channels open for liquid flow. Particle size distribution and possibly filter aid mix must be tailored case by case to achieve precoating on medium, coarse cloth and still to meet the demanding requirements in means of desired flow rate and filtrate clarity /6, 10, 16, 21/.

As said earlier also the optimal dosage is very important factor when defining an effective and economical solution. If dosage of the filter aid material is too low, consequently the clarity of the filtration process is unsatisfactory. Too great a dosage results in accumulation of very thick cake which will deteriorate the attainable flow rate through the filter media and therefore increase the total cycle time /6, 10, 16, 21/.

Optimal filter aid selection and mixture is quite demanding as the target is to have a maximum pore size and also to meet the requirements in term of filtrate clarity. It is always a matter of a compromise, between cycle time and effectiveness. The optimal filter aid should meet the following requirements:

1. Filter aid, when used as a precoat material, should provide a thin layer of accumulated solids with high porosity (0.85 – 0.90) over the surface of the filter media. Suspension that is to be filtrated will ideally form a cake over the porous filter aid cake. High porosity of the filter aid cake which is not determined by pore size alone will provide higher filtration rate.

2. Low specific surface which is inversely proportional to particle size is desirable as the hydraulic resistance results from frictional losses produced as liquid flows past particle surfaces. The rate of the particle dispersity and the subsequent difference in specific surface area determines the deviations

in filter aid quality from one material to another. The use of coarser materials results in smaller hydraulic resistance and has less specific surface area than the finer particle sizes, even though the porosity is the same.

3. Narrow fractional composition as the hydraulic resistance is increased when fine particles are used. The use of coarse particles results in deterioration of the separation efficiency i.e. filtrate quality. Air classification is widely used in preparation, where finer size fractions are removed.

4. When an open mesh or cloth is to be used in the filtration, wider size distribution has to be used in order to create a cake effectively. Therefore the used filter aid material should be able to be mixed with coarser particle sizes which results in quicker particle bridging and settling of the filter aid cake. When for example cellulose is added to the perlite or diatomaceous earth solution, the accumulation is accelerated as the oblong organic fibers are first bridging that will capture the finer perlite or diatomaceous particles.

5. Filter aid should be chemically inert to the liquid phase of the filterable solutions in order not to decompose or disintegrate /16/.

It should also be noted that depending on the used mesh or cloth, shape of the particles is also one feature that has to be taken into account. Basically one could say that irregular or angular-shaped particles tend to have better bridging capabilities than spherical particles /16/. At the same time this discrepancy of the shape characteristics can be used as an advantage, like mixing cellulose with incompressible materials /5/.

It is essential to carry out well-aimed laboratory test procedures for every filtration process where filter aids are considered to be used. The used filter aid material has to be specified case by case, even though general guidelines may be used which are presented in this study.

6.5 Selection and optimization of a filter aid material

There are numerous different filter aid materials in the world market. This is advantageous as the filter aid material and its characteristics can be modified to particular application, but at the same time the enormous amount of choices produces a positive optimization problem. It is possible to enhance the total efficiency by choosing a right material with certain characteristics and therefore the selection and optimization of the filter aid material has to be specified case by case by laboratory and field tests.

Conventionally the preselection is made based on their physical (particle size distribution, bulk density), chemical (chemical composition, crystalline silica content), and filtration specifications (cake permeability, filtrate NTU, cake density, removal efficiency of specific sized particles). These characteristics are obtained by water filtration tests and therefore are not consistent with results in actual process. As it is suggested by Li *et al.* /57/ one more aspect should be included in the specifications; pore characteristics of filter aid beds. With this it would be possible to narrow down the possible filter aid materials before the laboratory or field tests are started. It is possible that preselected filter aid materials with great filtration properties and appropriate particle size distribution may not provide desired filtration clarity, when applied to actual process. The outcome of the laboratory tests may be that many possibly working filter aids are found. Li *et al.* /57/ studied the correlations of mean flow pore size (MFP) and envelope surface area (ESA) with d50 particle size, cake permeability, and filtrate turbidity.

- Mean flow pore size is the pressure at which 50 % of the pores are opened during a wet run, i.e. capillary flow porometry using a sample that is wetted with liquid, is called mean flow pressure. It is determined from the wet and dry curves (CFP with un-wetted sample). The mean flow pressure is the pressure at which the total gas flow in a wet run is 50 % of the pressure in dry run of a CFP. MFP can be determined with pore diameter corresponding to the mean flow pressure.

- Envelope surface area is the surface area of all through pores that permit gas flow. It is similar to specific surface are in conventional cake filtration theory which indicates tortuosity and resistance of a filter cake structure during cake filtration. ESA can be determined from the relationship of flow resistance and flow rate during the dry run of a porometry test. /57/

As Li *et al.* /57/ noticed the results are theoretically reasonable. The most interesting result is the decrease of ESA when MFP increases. It is also important that the permeability of the cake decreases as the ESA increases. The correlation between permeability and MFP is not obvious, due to the lack of data. Filtrate turbidity decreases as the MFP and ESA increases. Li *et al*. /57/ explained the correlation of the turbidity and MFP by particle rejection and internal or closed pores. /57/

General rules can be used to be able to start testing from reasonable region and to reach an effective and economical solution in less time. A general rule of thumb is that the finest grades result in highest clarity and lowest flow rate, and therefore precoating cycle time extends.

In most cases the particle size range of undissolved solids is such that a fine grade of filter aid improves the filtrate clarity. Of course it should be noted that at some point the filter aid will remove 100 % of the suspended solids and there is no need to go for finer grades which is uneconomical. The selection is always a compromise between clarity and flow rate. The best suitable filter aid material is a grade that provides the fastest flow rate while maintaining an acceptable clarity level. Usually the clarity is the main target and compromise is made at flow rate’s expense. In this kind of case the solution may be increasing the filtration area by using more filtering units, if the target can not be attained by changing the filter aid material. Filtrate clarity, or the amount of acceptable suspended solids in the filtrate, is controlled basically by four factors /15, 19/:

1. Bodyfeed filter aid grade and amount

2. Precoat filter aid grade and amount

3. Length of the cycle
4. Filtration rate.

The achieved clarity of the filtrate can be determined in a number of ways. The different techniques are listed below /15, 19/:

1. Visual examination
2. Comparing a sample with a standard
3. By using electronic turbidity instruments
4. Filtering a sample on a fine filter paper, and observing the impurities
5. Chemical or biological analysis
6. Gravimetric analysis.

It is almost impossible to state the particle size that is totally removed by filter aid grade. This is due to the fact that filterable solids have different particle sizes and shapes, carrier liquids, filtration conditions and particle characteristics. A needle like particle might easily be removed by the accumulated filter aid cake, if it approaches horizontally. It is still possible that it approaches vertically and goes right through /15, 19/.

The actual selection and optimization of the filter aid material and grade for a specific application is quite a demanding procedure, due to the fact that there are many variables affecting to the final filtration result. Nowadays there are wide varieties of grades with extensive permeability range. Therefore the selection and optimization, if implemented correctly, can lead to massive improvements in the process efficiency, not to mention the economical benefits. Conventionally the grade selection of porous media has been carried out using a stochastic approach, consisting of numerous lab- and bench-scale trial runs. Even though the bench-scale tests are obligatory, the number of test runs can be decreased by using general guidelines. The basic approach can be divided into four criteria: filtrate clarity, product throughput, product yield or recovery and product stability and purity. /24/

Filtrate clarity is a factor that is usually given by the end customer. The required target value should be met or exceeded, importance depending on the application. For example the stringent clarity can extend the life of posterior equipment/process unit, or the shelf life or aesthetics of the final product. Very often when the filtered suspension is waste water or the filter unit is acting as a water purifier, the clarity specification is set by a permit, regulation or water requirement. For example high pressure nozzles of pressure filters, used for cloth washing, require that the water is remarkably clean. Otherwise the nozzles will be instantly clogged. The selected filter aid grade dictates the achievable filtrate clarity, where also the nature of the turbidity removed plays a key role.

The amount of feed solution the filter unit is able to process by a given filtration area is controlled by various factors including the following; selected filter aid material and grade, the introduced amount of filter aid, combined with available differential pressure. In every process condition, a compromise has to be made between the permeability and turbidity removal properties. Different filter aid material families have a curve that defines the trade-off point. Generally one could say that the most effective filter aid materials, in terms of turbidity removal characteristics, are diatomite of marine origin (microscopic picture presented in figure 15). Newest filter aid grade curves present the fact that they enable finer turbidity removal without a sacrifice of permeability. The tightest marine diatomite can remove rigid turbidity below 0.5 µm and deformable turbidity smaller than 0.25 µm. /24/

Product throughput and filtrate clarity are tightly linked when it comes to grade selection. The target of the grade selection is to select a grade that is fine enough in order to obtain the required clarity and still maintain adequate flow rate. As it was noted before, the finer the filter aid grade particle size, lower the flow rate. Also the differential pressure increases rapidly if too fine particles are chose to be used. /24/

Product Yield or Recovery is very important factor when the solids of the filterable slurry are the desired product. Therefore the accumulated cake is washed in order to increase the yield of the filtration. When e.g. cellulose grades are used, the product recovery can be carried out in some processes by burning the used filter aid cake. Product recovery issues can be improved by selecting a more permeable grade of filter aid. As the porosity of the filter aid increases, the surface area and any associated non-specific interactions decrease /24/

Product stability and purity is the fourth criteria. It is important to pay attention to the soluble and insoluble metals as well as other impurities when selecting a filter aid grade. It is extremely important in the field of food, chemical and pharmaceutical industries, as the soluble metals can oxidize the final product. When dealing in these highly demanding applications, finer high purity materials are to be used as filter aid materials. The grades with finer particle sizes are able to eliminate product contamination and degradation issues in the latter processes. Because of these demanding applications, a new filter aid generation has been developed. A patented Celpure is a diatomaceous earth filter aid that undergoes calcinations after purification as the conventional diatomite is not purified. The purification process increases the SiO_2 content from 86 – 93 % (conventional diatomite) to 96 – 98 %. The difference of the structure is presented in figure 21. /24/

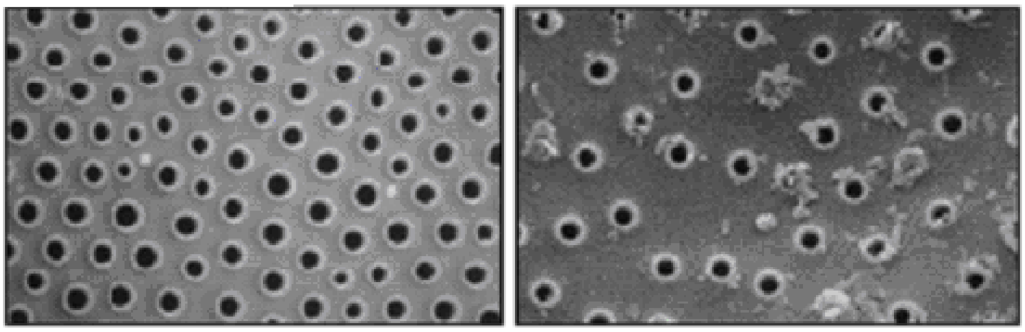

Celpure diatom
Conventional diatom

Figure 21. Celpure diatom versus conventional diatom /58/.

Reduced density of Celpure offers greater filtration capacity with a corresponding reduction in powdered media consumption and reduction in disposal costs. Filtration processes with Celpure grades typically use less media due to a combination of the higher solids loading capacity, lower bulk density and improved flow properties of the media for a given clarity requirement. This improved performance results in longer cycle time lengths and greater amount of liquid being filtered or a reduction in overall processing times compared with conventional grades of diatomite. /24/

6.6 Systematic approach to filter aid grade selection

Systematic method for choosing the right filter aid grade for a specific process is quite demanding as it was noted earlier, due to the fact that there are so many different filter aid materials with various characteristics in the markets. In a solid-liquid separation process the desired outcome is to achieve an optimum clarity and maximum throughput without excessive pressure and product losses, trade-off curves could be used. World minerals R&D developed a systematic method to characterize various filter media types by retention of particles in a model system, using a single leaf test filter. First of all the pore size distribution should be examined of the pre-selected filter aid grades, that provides the range of effective pore diameters from intraparticulate to interparticulate. It should be noted that this may not sufficiently quantify what size of turbidity will be retained by the filter media. /24/

The method and test equipment that was used in the study by the World minerals R&D consisted of the following equipment and materials /24/:

- Lab-scale constant rate filtration test filter: single leaf filter with 20 cm^2 surface area
- Filtered suspension: 0.5 % (weight) suspension of SAE fine dusts (heterogeneous, highly dispersed and non-deformable (rigid) particles with median particle size of 4.16 μm.)
- Filter aid to be applied onto the filter paper septum, 3 mm.
- Filter aid grades: Celite diatoms (see table IX).

Table IX. Diatom types and their characteristics used in a study by World Minerals R&D /24/.

Grade	Type	Permeability, darcy units	Median particle size, µm
Celite 577	Fully Calcined	0.2	14.6
Celite Hyflo Super-Cel	Flux Calcined	1.1	22.3
Celite 535	Flux Calcined	3.1	34.3

Also the following Celpure diatom grades were examined in the study of World Minerals R&D /24/: Celpure 65, Celpure 100, Celpure 300, and Celpure 1000. The number denotes the typical permeability in milliDarcy units. The study presents that the tighter the accumulated filter media i.e. finer the filter aid material particle size, the sharper the particle size cut-off for a feed turbidity with a broad particle size distribution. As it is presented in figure 22, the Celite 577 provided the tightest filter media and therefore the greatest retention of turbidity. From the curve it can be determined which is the point where almost all of the impurities are removed by a specific filter aid cake. This is a point that should not be exceeded; otherwise the accumulated cake is excessively tight, reducing the throughput without increasing the clarity. /24/

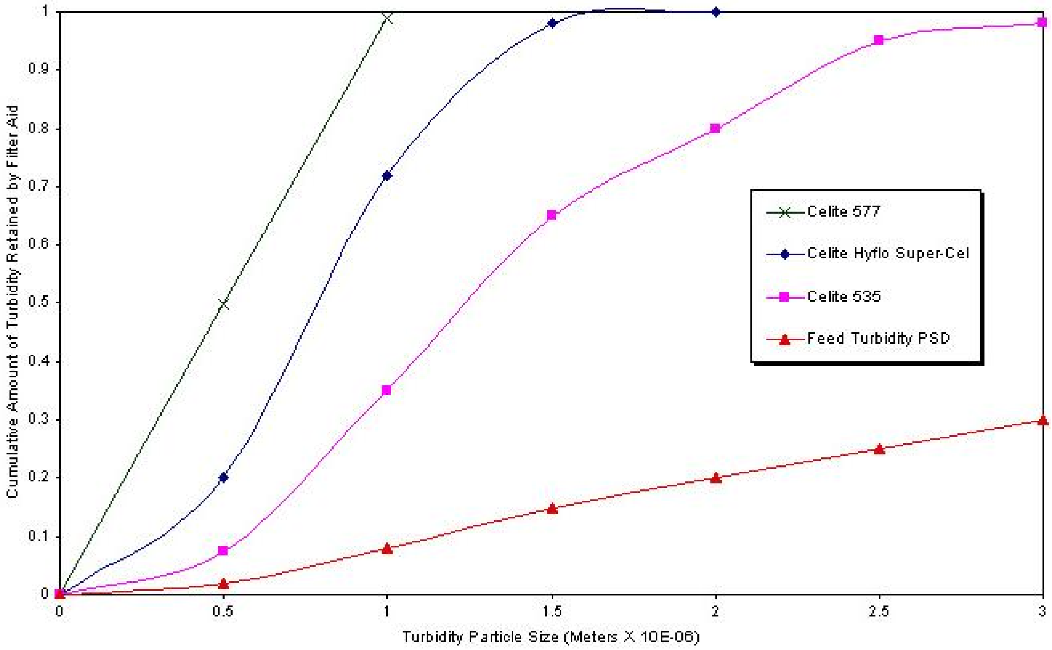


Figure 22. Turbidity particle size versus cumulative amount of turbidity retained by filter aid /24/.

Figure 23 presents the difference between Celite and Celpure trade-off curves for the rigid particles. Celpure grade is able to remove smaller particles without a sacrifice in permeability and has a greater capacity for turbidity particles and colloids as it is presented in figure 23. /24/

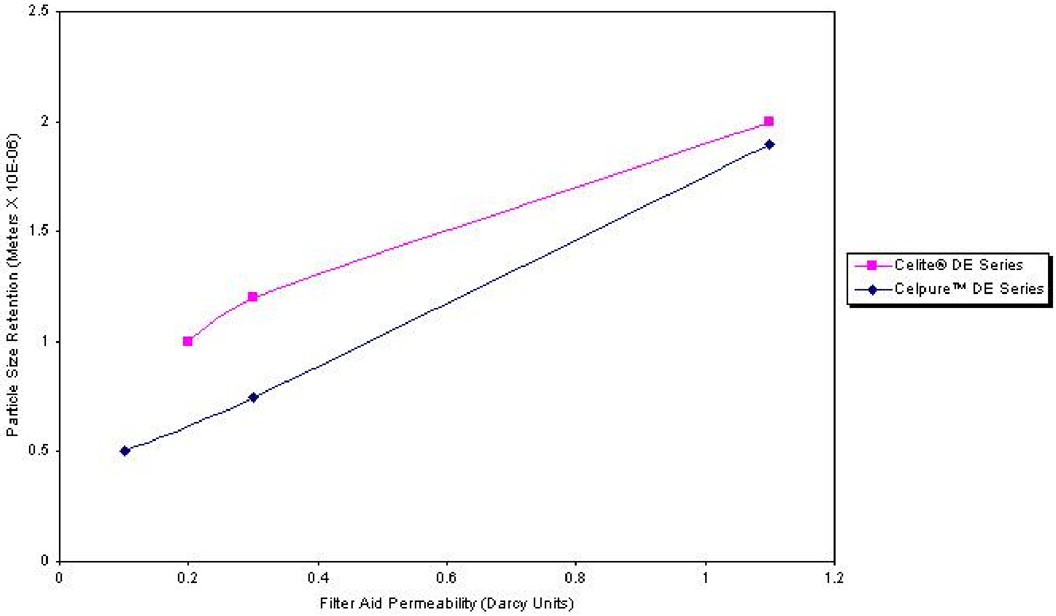


Figure 23. Filter aid permeability versus particle size retention of Celite and Celpure diatoms /24/.

The study shows also that a difference occurs when rigid and deformable turbidity was compared. The outcome was that the deformable particles can bridge over the accumulated filter aid particles and thus reduce the permeability. This advances in improved retention of the impurities, in cases where the excess filtrate clarity is more important than the throughput. Rigid particle studies have shown that conventional diatomite grades are capable of 99 % retention of particulate turbidity below 0.5 µm. The retention of deformable biological turbidity is even finer, going into the colloidal particulate region. It is the intricate structure of diatomite, particularly the enhanced properties of Celpure that accounts for this submicron filtration ability. Celpure grades have improved the performance of conventional diatomite by achieving the same level of particulate retention with a 50 % increase in permeability. /24/

When designing screening studies, rigid particle cut-off curves are useful for narrowing down the grades to consider. An analysis and understanding of the particle size distribution and nature of the turbidity to be removed is still paramount to zeroing in on the porous media to choose. These techniques plus major product advances offer the filtration practitioner new tools to achieve the objectives of a solid-liquid separation process.

7. Filter aid preparation equipment

The goal of this study was to design a proportioning, mixing and feeding system for filter aid materials. The design basis is Larox Scheibler vertical leaf filter family. The design is based on the study of the filter aid materials and also on the previous knowledge of the Larox. Basically the idea was to design the system, denote the equipment sizes, types and specifications for every filtering unit and to estimate the total capital and operational costs of the auxiliary system. Some parts of the study are confidential and therefore are not presented in a detailed way in this thesis work. This chapter, filter aid preparation equipment, gives a general overview of the design process, its procedures and fundaments.

7.1 Mass balance, design criteria, and goal

The first step of the design was to define the amounts of filter aid materials that are needed for a specific process. Also the general requirements and parameters that are used in this kind of applications were studied. This was the basis for the work, but all the initial data were questioned and that is the main reason why the test filtration was carried out, to get the hands-on information.

The basic typifying and enquiring was carried out before the test filtration, which was basically implemented to verify the used assumptions. The initial data used in the calculations are presented in table X.

Table X. Initial data for mass balance calculation.

Initial data		
Precoat material	Expanded perlite	
Pipelines V	1	m^3
Precoat material density	140	kg/m^3
Precoat thickness	0.003	m
Required precoat volume safety factor	1.25	
Preferred flow to the filter	2	m/s
Flux	2	m^3/m^2/h
Precoat		
Minimum flow rate	2	m/s
Maximum flow rate	3.5	m/s
Filtration time	20	h
Defined Mixer DS content	10	%
Water density	1000	kg/m^3
Slurry feed		
Flux	2	m^3/m^2/h
Dry solid content	0.05	5
Dry solid density	2500	kg/m^3
Carrier liquid density	1000	kg/m^3
Mixer safety margin	1	m^3
Filling ratio margin	0.5	m^3

When the mass balance calculation was carried out is was possible to focus on individual equipment and what kind of opportunities and threats are to be confronted. When the equipment sizes and types were figured out, enquiries were sent and meetings were arranged to specify the needed equipment for every filter unit. This way the total capital cost is accurately estimated and all the equipment are typified. The more detailed explanation how the equipment was chosen is presented in the equipment selection chapter 7.3.

7.1.1 Precoat

The mass balance calculation is based on the fact that how thick filter aid cake is needed to cover the filter cloth. The conventionally used thicknesses are in the range of 1 – 5 mm, and therefore 3 mm was chosen to be the initial data and target. It was noted during the laboratory test runs that when perlite or diatomaceous earth is used, the desired cake thickness should be multiplied by two. This modification should be carried out because wet volume of perlite and DE is roughly half of the dry volume. By using the required thickness, multiplied by filtration area, the needed filter aid powder amount was calculated. The accumulated cake is assumed to remain relatively dry to be able to ignore the moisture content and its proportion of the cake volume. When the needed dry solids amount is calculated it was possible to calculate the total volume of filter aid needed for one cycle. It was assumed that the optimal dry solids content of the filter aid solution that is mixed to the mixer is around 10 %. With this information the total volume was calculated and all the data is presented in table XI. Scheibler filter family's A-series with singlex cloths is used as an example in this mass balance chapter.

Table XI. Mass balance calculation; precoat data 1.

A-series	Singlex			Precoat needed for one cycle				
Model	Filtration A m^2	V m^3	DS kg	DS m^3	Water kg	Water m^3	Tot. V m^3	Mixer DS %
A4/6	7.5	1.9	3.2	0.02	31.5	0.03	0.1	10.0
A6/6	11.3	1.9	4.7	0.03	47.3	0.05	0.1	10.0
A6/10	15.0	3.1	6.3	0.05	63.0	0.06	0.1	10.0
As10/10	18.8	3.1	7.9	0.06	78.8	0.08	0.1	10.0
A10/10	22.5	3.1	9.5	0.07	94.5	0.09	0.2	10.0
As13/15	32.5	6.2	13.7	0.10	136.5	0.14	0.2	10.0
As15/15	36.3	6.2	15.2	0.11	152.3	0.15	0.3	10.0
A13/15	40.0	6.2	16.8	0.12	168.0	0.17	0.3	10.0
A15/15	43.8	6.2	18.4	0.13	183.8	0.18	0.3	10.0

When the total volume of 10 % precoat solution is calculated, it is possible to estimate the needed mixer volume. The mixer volume is calculated by the total volume of precoat needed for one cycle plus a safety margin (1 m^3) and filling ratio (0.5 m^3). As such safe margins are used; the smallest mixing tank to be used is 3 m^3, despite the fact that possibly a smaller one could be used with the smallest filters, as this A-series. It is not advisable to use different sizes in every filtering unit, and therefore it was decided that two sizes of mixing tanks should be used, 3 m^3 for the smaller filters and 5m^3 for the bigger ones. It is possible to use only two sizes even though the filter areas of the different filter units differ as much as from 1.9 m^2 (A-series) to 360 m^2 E-series with duplex bag. The reason is that the limiting factor being the precoat volume, not the solids content, as 10 % solution can be used in mixing stage. That is due to the fact that as can be seen in table XI, e.g. for A15/15 singlex 0.3 m^3 of diluted perlite filter aid is enough to produce the required layer, but the total volume has to be higher, roughly more than the filter volume plus the piping volume. Of course also the dry solids content has to be in the range of few percents when introduced to the filtering unit. The required total volume was calculated by adding estimated pipeline volume (1 m^3) and multiplying the sum with a safety factor of 1.25. The safety factor is used because the precoat feeding tank level should not reach the bottom when the circulation of the precoat is on. The required volumes are presented in table XII below. Also the DS content after the precoat is diluted to the final content is shown in table XII.

Table XII. Mass balance calculation; precoat data 2.

A-series	Singlex					
Model	Filtration A m^2	V m^3	Min. mixer V m^3	Required precoat V m^3	Extra water m^3	DS %
A4/6	7.5	1.9	1.6	3.6	3.6	0.1
A6/6	11.3	1.9	1.6	3.6	3.5	0.1
A6/10	15.0	3.1	1.6	5.1	5.0	0.1
As10/10	18.8	3.1	1.6	5.1	5.0	0.2
A10/10	22.5	3.1	1.7	5.1	4.9	0.2
As13/15	32.5	6.2	1.7	9.0	8.7	0.2
As15/15	36.3	6.2	1.8	9.0	8.7	0.2
A13/15	40.0	6.2	1.8	9.0	8.7	0.2
A15/15	43.8	6.2	1.8	9.0	8.6	0.2

The precoat is fed from the precoat tank to the filter with certain dry solids content and with a predetermined flux. The flux that was used in this calculation was 2 $m^3/m^2/h$ and the allowed flow rate range 2 – 3.5 m/s in the feed pipeline. With these parameters it was possible to calculate the feed pipeline size in order to meet the flow rate region. The results of the calculation can be seen in table XIII.

Table XIII. Precoat feed pipeline diameter and flow rate.

A-series	Singlex			
Model	Filtration A m^2	V m^3	Pipeline DN	Flow m/s
A4/6	7.5	1.9	50	2.1
A6/6	11.3	1.9	65	2.8
A6/10	15.0	3.1	65	2.5
As10/10	18.8	3.1	65	3.1
A10/10	22.5	3.1	80	2.5
As13/15	32.5	6.2	100	2.3
As15/15	36.3	6.2	100	2.6
A13/15	40.0	6.2	100	2.8
A15/15	43.8	6.2	100	3.1

7.1.2 Bodyfeed

The bodyfeed amount that is needed for one cycle is determined from a different point of view than the precoat material. That is due to the fact that the amount is proportional to the slurry feed solids content. In general it could be said that the required bodyfeed amount is the same as the accumulating dry solids. The amount of dry solids in the feed solution and the dry solids of bodyfeed are the same. First of all the amount of dry solids of the slurry feed that is introduced to the filter unit was calculated according to the initial data. Total flow to the filtering unit is calculated by the conventional slurry feed flux 2 $m^3/m^2/h$ and filtration area. This is the total filterable solution that is introduced to the filter when the filtration step is on. The dry solids content of the slurry feed that is used in the calculation is 5 % and the carrier liquid is water. By using this information it was possible to calculate the mass flows per area and further the accumulating cake per area. These results are presented in table XIV.

Table XIV. Mass balance calculation, bodyfeed.

A-series Singlex

Model	Filtration A m^2	V m^3	Flow to filter m^3/h	Water $kg/m^2/h$	DS $kg/m^2/h$	DS %	DS $l/m^2/h$	DS l/h	DS/cycle
A4/6	7.5	1.9	15	1960.8	0.98	0.05	0.39	2.9	147.1
A6/6	11.3	1.9	22.5	1960.8	0.98	0.05	0.39	4.4	220.6
A6/10	15.0	3.1	30	1960.8	0.98	0.05	0.39	5.9	294.1
As10/10	18.8	3.1	37.5	1960.8	0.98	0.05	0.39	7.4	367.6
A10/10	22.5	3.1	45	1960.8	0.98	0.05	0.39	8.8	441.2
As13/15	32.5	6.2	65	1960.8	0.98	0.05	0.39	12.7	637.3
As15/15	36.3	6.2	72.5	1960.8	0.98	0.05	0.39	14.2	710.8
A13/15	40.0	6.2	80	1960.8	0.98	0.05	0.39	15.7	784.3
A15/15	43.8	6.2	87.5	1960.8	0.98	0.05	0.39	17.2	857.8

As the amount of dry solids of the slurry feed is known, the amount of bodyfeed needed was calculated. It should be remembered that the bodyfeed is admixed to the slurry feed directly from the mixing tank in at a dry solids content of 10 %. It is not reasonable to dilute the bodyfeed before implementing, because it would dilute the feed solution and reduce the capacity of the filter. And also lower pumping volumes can be used which is economical as the smaller pumps are cheaper and the operating costs are lower as well. The bodyfeed amounts are presented in table XV.

Table XV. Bodyfeed amounts.

A-series Singlex

Model	Filtration A m^2	V m^3	Needed amount of bodyfeed volume (KAP 10) $l/m^2/h$	Bodyfeed l/h
A4/6	7.5	1.9	0.94	7.06
A6/6	11.3	1.9	0.94	10.59
A6/10	15.0	3.1	0.94	14.12
As10/10	18.8	3.1	0.94	17.65
A10/10	22.5	3.1	0.94	21.18
As13/15	32.5	6.2	0.94	30.59
As15/15	36.3	6.2	0.94	34.12
A13/15	40.0	6.2	0.94	37.65
A15/15	43.8	6.2	0.94	41.18

7.2 Literature designs

It is possible to find various different setups that are used in filter aid applications, depending on which kind of setup is preferred. There are generally a few different ways to accomplish the precoating and bodyfeeding setup. Usually in the setups that are found from the literature, separate tanks are used for both precoat and bodyfeed. Both tanks are acting as mixing tanks and storage tank at the same time, and the proportioning of the filter aid powder is not normally presented in figures. Precoat feed is very often carried out by using the same pump that is used for filterable solution feeding. This is advantageous if the filter aid system is designed to serve only one filtering unit, as it is presented in figures 24 and 25. Otherwise the bodyfeed admixing of an ongoing filtration has to be stopped before the cycle ends to be able to precoat the second filter in time. That will cause decreased efficiency, as the bodyfeed is stopped too soon, or the second filter has to wait for the other cycle to end. In some applications it may cause problems if the same pump is used for precoating and slurry feeding as the solution properties may vary notably and therefore the feed circumstances are different.

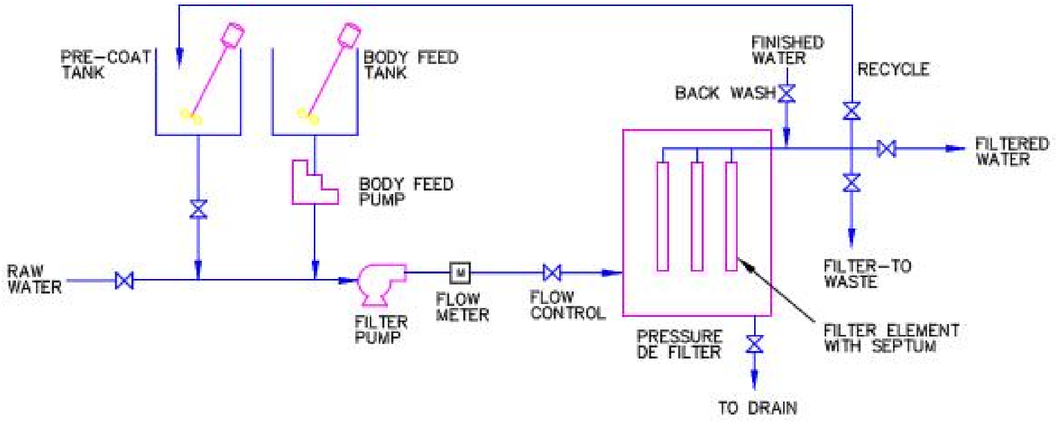


Figure 24. Slow Sand Filtration and Diatomaceous Earth Filtration for Small Water Systems /59/.

These two setups, figures 24 and 25 are generally identical, the only difference being in the arrangement of the bodyfeed pump and the filtrates recycle. In figure 24 the filtrate is not recycled to the bodyfeed tank, where presumably only raw water is used.

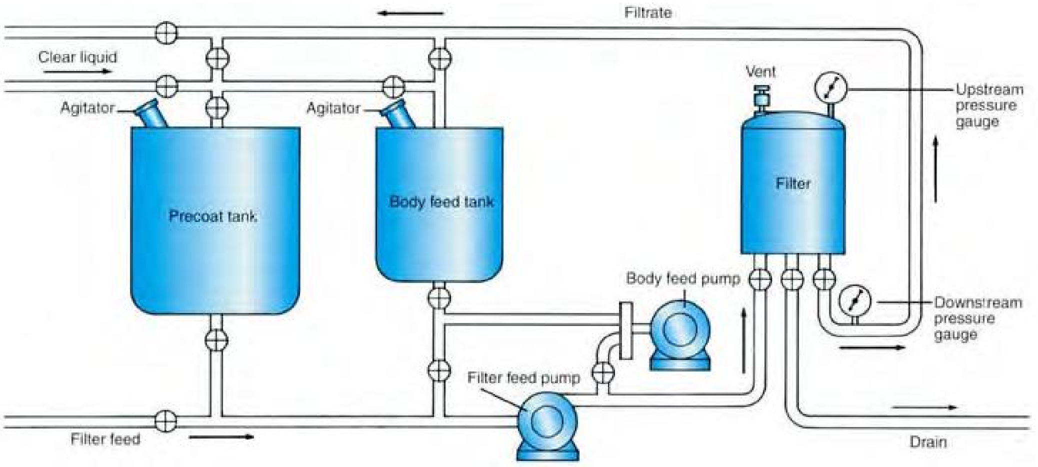


Figure 25. Filter aid setup by Celite corp. /60/

This setup where precoat and bodyfeed are mixed and fed from separate tanks without having a precoat feed pump is commonly used. Also McKetta /20/ presents a similar setup with filtrate circulation line also to the bodyfeed tank, the same way as in it was presented in figure 25. The operational setup of the filter aid system by McKetta /20/ is presented in figure 26.

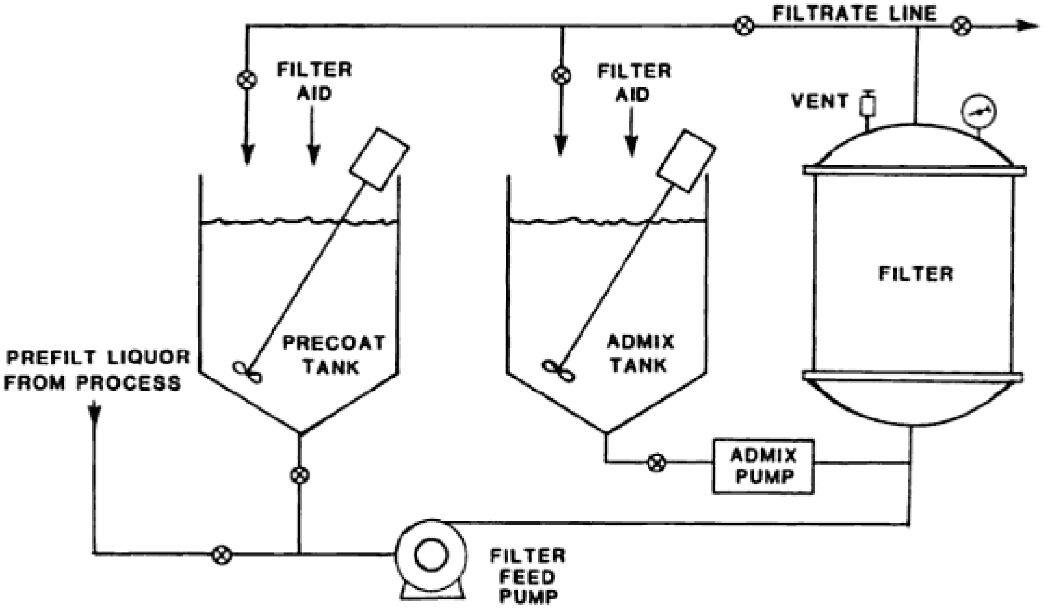


Figure 26. Precoat and bodyfeed operation by McKetta /20/

A setup for water purification by Fulton /61/ is a bit different from the others as it can be seen in figure 27. Third tank is used as a precoat circulation tank but still separate tanks for bodyfeed and precoat are used. This setup is not economical as the amount of pumps and tanks are increased without achieving any improvements.

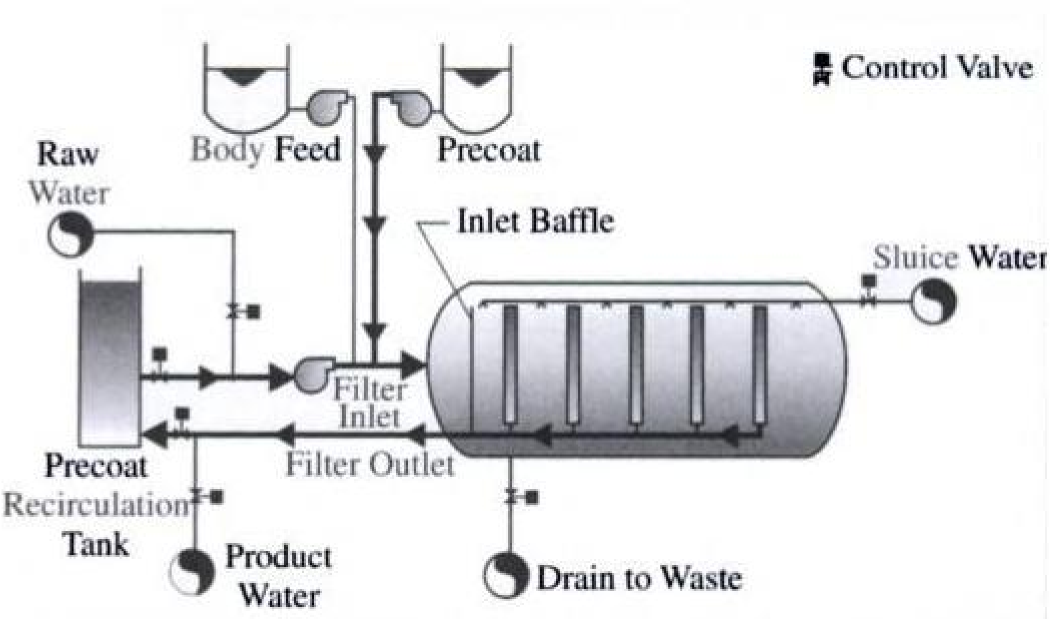


Figure 27. Pressure filter setup 3 by Fulton /61/.

7.3 P&ID and equipment selection

Equipment selection was carried out according to the mass balance calculations, former knowledge, and literature designs. The equipment types and sizes were enquired from suppliers to ensure that proper guidelines were used and right types were selected. It was also advantageous to get the first-hand information about the equipment prices, to be able to optimize the costs. In this chapter are listed all the principles and ideas that were used for designing the filter aid proportioning, mixing and feeding system. The piping and instrumentation diagram was drawn with AutoCad 2006 application and its sections and solutions are discussed in this chapter.

7.3.1 Feed hopper

Feed hopper is the equipment that stores the filter aid powder and proportions the powder to the mixing tank. The hopper cone can be kept quite small by volume as the consumption of the filter aid powder is moderate. The filter aid powder is delivered to the filter plant in so-called big bags, weighing approximately 150 –

300 kg. These bags are unloaded to the silo that is equipped with vibrator and volumetric screw conveyor. The use of vibrator is important to be able to unload the silo reliably with a screw feeder. It is even more important when cellulose is considered to be used as filter aid material /5/. The principle of the feed hopper unit is presented in figure 28.

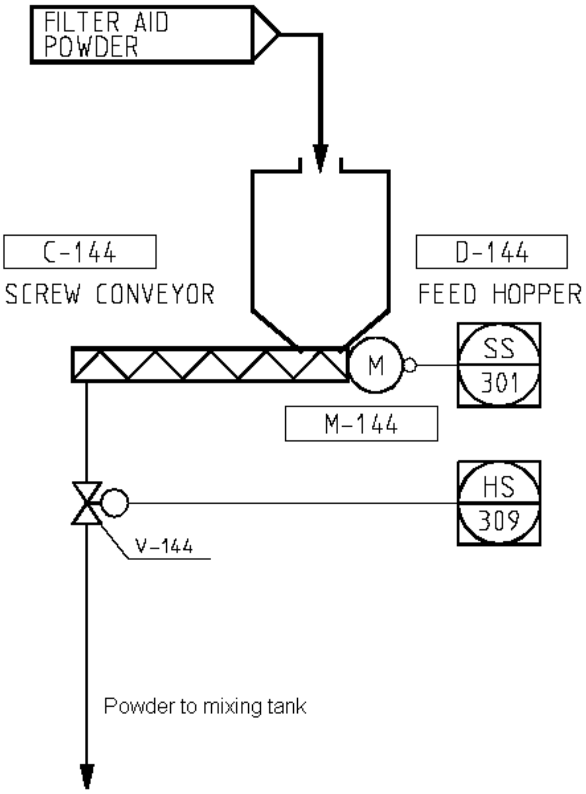


Figure 28. Feed hopper P&ID.

As the screw feeder is operated from the rpm basis there is a possibility that the screw feeder is operating but the powder is stuck in the silo. Another possibility for proportioning, other than volumetric screw, is by using weighing sensors underneath the mixing tank or the silo. This possibility is attractive as an alarm would be always initiated if the powder amount is not increasing or decreasing. But it has also a couple of disadvantages as its measuring accuracy is not suitable, at least for the smaller polishing filters. And the other one is obviously the price.

The volumetric screw conveyor is operating a predetermined time with constant revolutions per minute, reaching a satisfactory exactness. The pipeline that is connecting the screw outlet to the mixing tank has to be closed during the mixing operation and therefore a pinch valve or knife gate valve should be used to prevent the moisture from clogging the screw. It is important as in some applications the filtrate that is used as a carrier liquid, is hot.

7.3.2 Tanks and agitators

The filter aid proportioning, mixing, and feeding system was decided to be arranged with two tanks that are functioning in a bit different way than any of the ones that were found from the literature. One tank, called a mixing tank is operating continuously, providing ~10 % solution for both bodyfeed and precoat purposes. This way, as the only tank where filter aid powder is introduced, the automation of the proportioning can be kept simple and reliable. The tank is equipped with inductive level switches, and a new batch is prepared when the liquid level reaches the LL-limit. When the limit is reached a certain predetermined amount of filter aid powder is introduced to the tank and filtrate circulation valve is opened until the level reaches the H-level. This operation ensures that there is always filter aid solution available when needed. From this tank the bodyfeed with ~10 % concentration is pumped to the slurry feed line. The mixing tank and its connections are presented in figure 29. The arrangement of the mixing tank and the precoat tank is presented in figure 32.

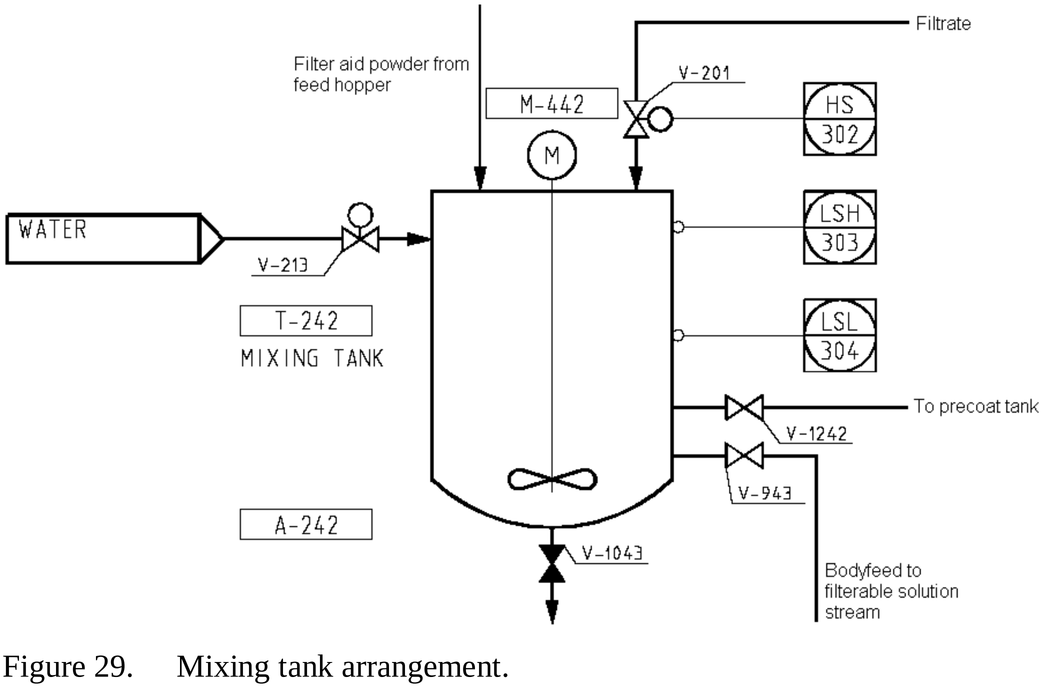


Figure 29. Mixing tank arrangement.

The other tank in the system is for precoat dilution, feeding, and circulation. Before the precoating step is to be started a predetermined amount of filtrate, or raw water, is used to fill the precoat tank. It is done to fasten the precoat step when it is initiated. Now as the precoat tank is filled with liquid, the filtering unit can be filled fast with the precoat feed pump. When the filter is filled the precoat transfer pump starts dosing the filter aid solution to the tank. Precoat tank should be 125 % of the filter's volume, according to Wang *et al* /15/. In this study the precoat tank was dimensioned to be 115 % of the volume of the filtering unit plus the pipelines. The precoat tank is equipped with ultrasonic level measurement unit in order to be able to alternate the water volume, if necessary /15/. The precoat tank and its connections are shown in figure 30.

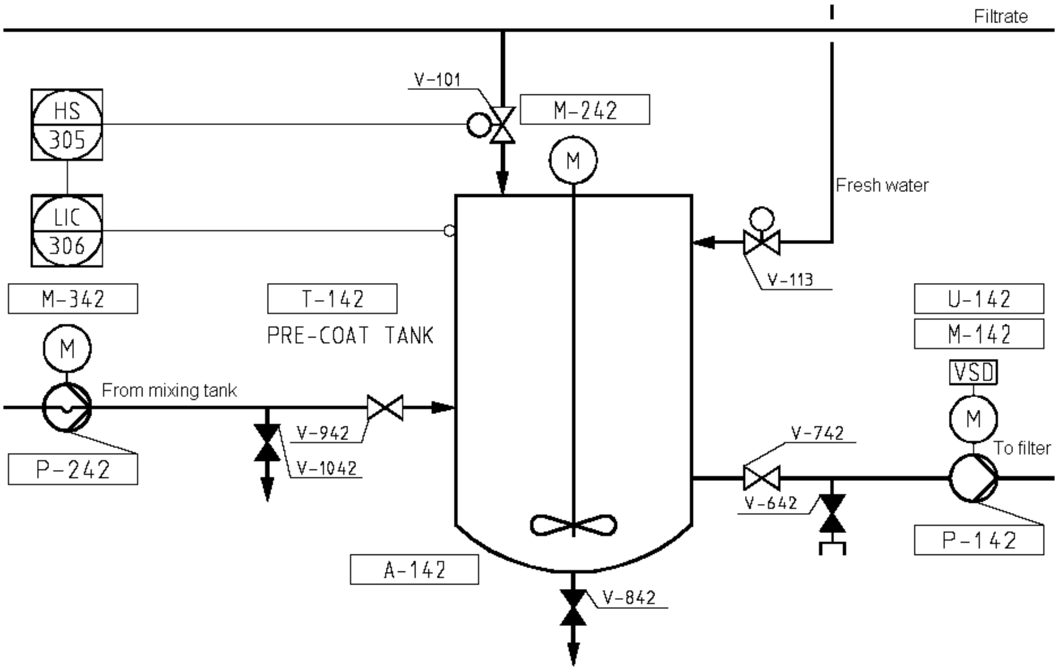


Figure 30. Precoat tank P&ID.

Both tanks are equipped with agitators to mix the solution and to keep the solids suspended in liquid. According to Wang *et a*l. /15/ the agitators should be sweep-arm agitators rotating at approximately 50 rpm or slow speed, large-bladed, propeller-type agitators. It is essential to not use higher rpm than necessary because too high rotational speed can cause damage to the fragile filter aid particles and at the same time consume unnecessarily energy. Filter aid is pretty easy to keep in suspension once it is mixed well. Therefore in this study the mixer tank agitator has a larger motor compared to precoat tank, reducing the operating costs. Wang *et al.* /15/ also noted that the tanks should have dished coned or slanted bottoms in order to be able to keep the heel as minimal as possible during the precoating and circulation. This way the small heel gives a rapid turnover. The circulation line back to the precoat tank should be attached to the bottom of the precoat tank to prevent aeration. If it is necessary, also baffles should be installed to the precoat tank to prevent vortexing /15/.

7.3.3 Pumps

The system consists of three pumps, when one filter solution is used and an extra pump for every additional filter. The designed setup is able to handle multiple filtering units with only one additional pump per filter. The most demanding application for a pump is the precoat feed pump (figure 31). Conventionally centrifugal pumps are used because of their ability to produce flow without pulsations that would disturb the accumulating cake. According to Wang *et al.* /15/ low-speed (1800 rpm) pumps with open impellers should be used to prevent the degradation of the filter aid particles.

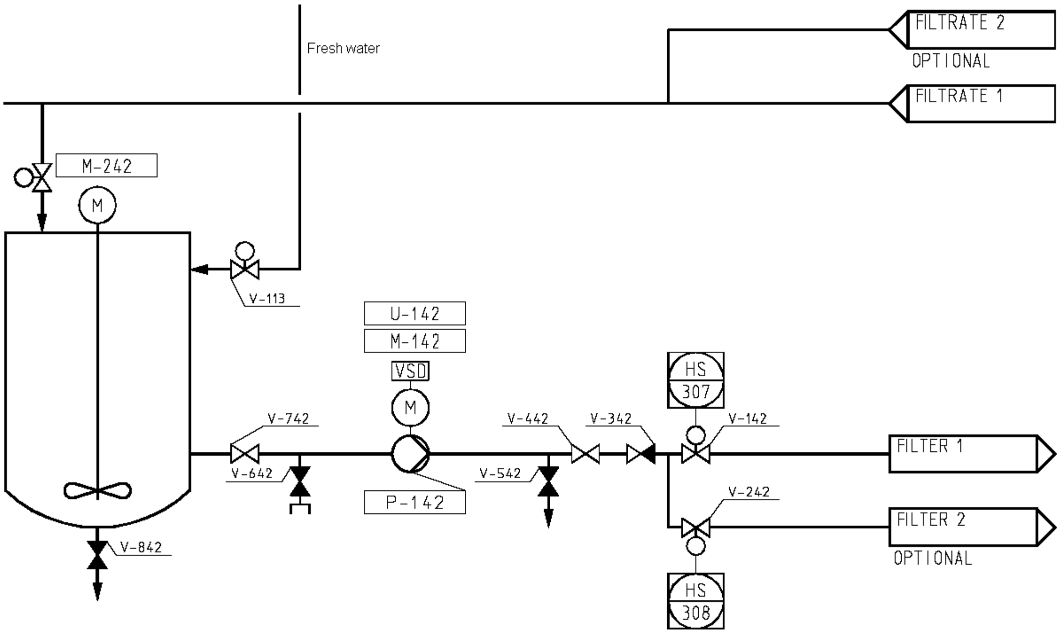


Figure 31. Precoat feed pump arrangement.

When the ~10 % filter aid solution is introduced to the precoating tank, a peristaltic pump is to be used. That is because of its constant feed rate from minute to minute, and therefore the possibility to control the flow simply with the revolutions per minute. The times are always obtained by experiments case by case. The bodyfeed pumps are also peristaltic pump with a smaller capacity. With these pumps it is possible to achieve the required feeding accuracy with reliable operation and low maintenance costs as the pumping volumes are quite low. When the volume flows are increased it is not anymore economical to use peristaltic pumps as the price and size increases quite rapidly after a certain point. All the pumps that are used in this setup are equipped with variable speed drives. The precoat transfer pump and the bodyfeed feed pumps arrangement is presented in figure 32.

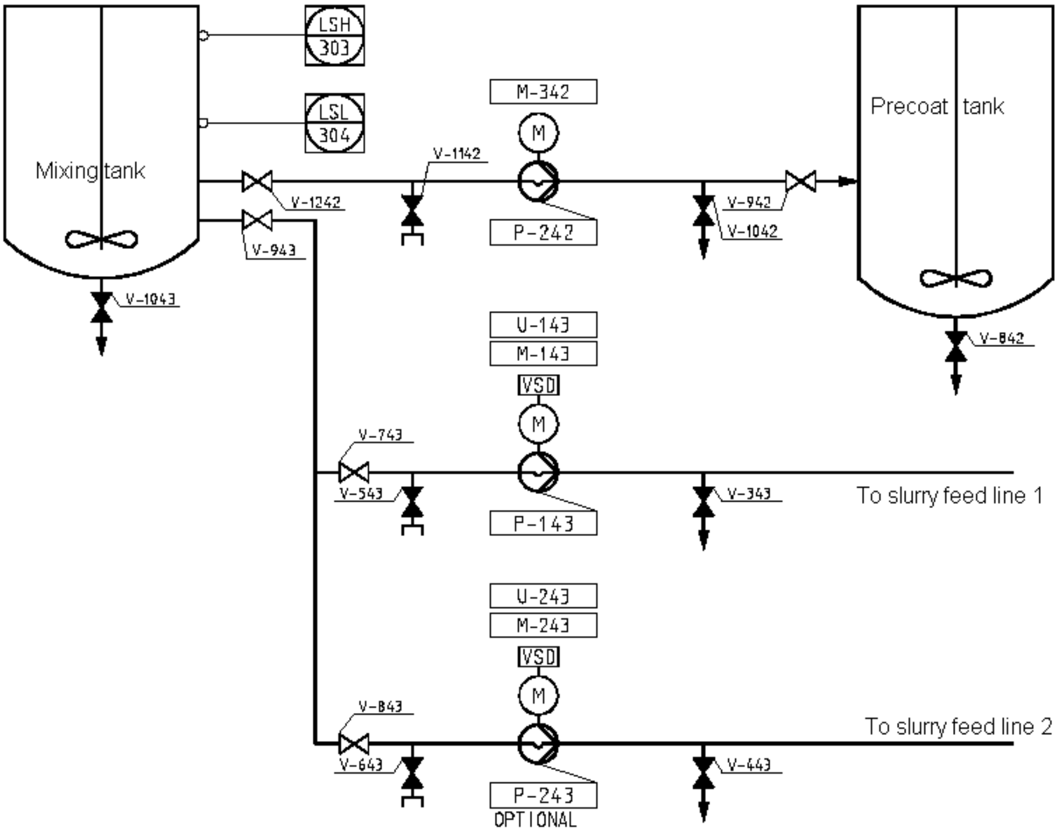


Figure 32. Precoat transfer pump and bodyfeed feed pump arrangement.

7.3.4 Valves

With the use of fragile filter aid materials the demands for the valves are not high and therefore ball valves with stainless steel body can be used. Even though conventionally when dealing with solid materials knife gate or pinch valves should be used as the particles may stuck between the moving parts, e.g. in butterfly valves between the plate and the body. This is not considered to be a problem as the particles are fragile. The valve that is preventing the moisture from reaching the volumetric screw feeder should be valve that has an ability to be fully opened, such as pinch valve or knife gate valve. It is advantageous to use a pinch valve with plastic body, as the stress towards the structure is not significant and therefore more economical solutions can be considered.

8. Process description

Process description is written in three paragraphs; introduction, overall process description and filter aid process control. The idea is to give a full description of the process in two different levels, overall and detailed step-wise way. Positioning and format is based on Larox’s guidelines. The detailed step-wise process description is not presented in this study because of its confidentiality.

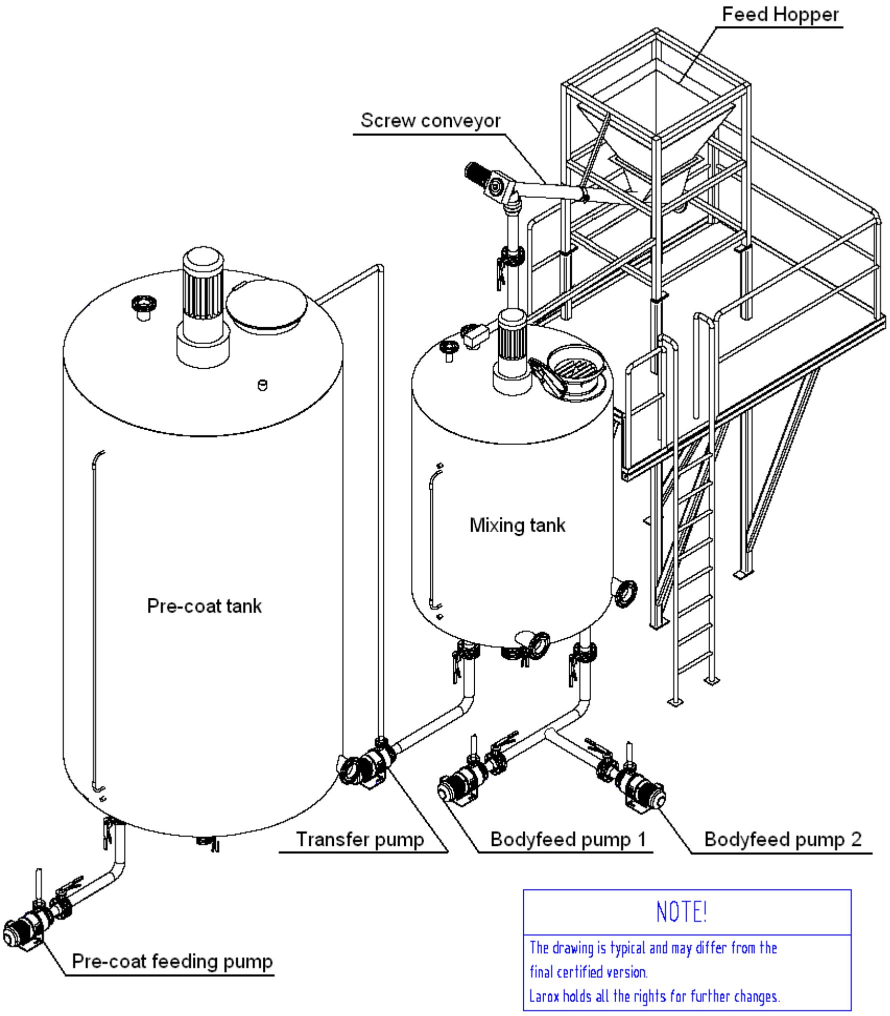
8.1 Process description introduction

This process description describes a filter aid preparation and feeding system for LSF –filtering unit. The filter aid is needed in challenging conditions to improve the filtration efficiency and cleaning and thus extend the operating life of the filter media. Filter aid preparation and feeding system is designed for the use of two different filter aids, precoat and bodyfeed.

Precoating is used before the filtration step initiates. If the solids in the filterable solution have a tendency to clog the filter bag easily, precoat is used on the filter bag to obtain better filtration efficiency and quality. Diatomite or perlite is usually used as a precoating substance. The intention is to create a uniform cake to the overall surface of the filter cloth, with predetermined thickness (< 5 mm). This ensures that the clogging of the filter cloth is reduced and the filtration efficiency is increased.

Bodyfeed is used if the solids in the filterable solution have a tendency to form a sticky impermeable filter cake. The cake properties are enhanced by using the filter aid substance as bodyfeed during the filtration process. The bodyfeed is introduced to the same pipeline as the filterable solution.

The filter aid is delivered in a powder form and therefore it has to be mixed with fresh water in the beginning of the filter aid preparation cycle. It is also possible to use product filtrate instead of water, when the filtration cycle is on. Figure 33 describes the basic configuration of the construction and main equipment of the filter aid preparation and feeding system.



NOTE!

The drawing is typical and may differ from the
final certified version.
Larox holds all the rights for further changes.

Figure 33. Filter aid preparation and feeding system

8.2 Overall process description

The filter aid preparation and feeding system contains the following main equipment: (overall configuration is presented in figure 33).

1. Automatic filter aid powder proportioning unit
    - Feed hopper D-144
    - Screw conveyor C-144
2. Mixing tank T-242
3. Transfer pump P-242
4. Bodyfeed pump 1 P-143
5. Bodyfeed pump 2 P-243 (optional)
6. Precoat tank T-142
7. Precoat feeding pump P-142.
8. Mixing tank agitator A-242
9. Precoat tank agitator A-142

The filter aid preparation and feeding process consists of subtasks that are explained in the following chapters:

- Proportioning and mixing of the filter aid powder
- Precoating
- Bodyfeeding.

The precoating and bodyfeeding are explained generally from the filter aid preparation and feeding system point of view. More detailed description of the precoating and bodyfeeding, and especially the interaction with the LSF filtering unit(s) is described in the filter unit process description.

8.2.1 Proportioning and mixing of the filter aid powder

The filter aid substance, usually diatomite or perlite, is delivered in so-called big bags. Therefore an overhead crane is needed to be able to empty the powder bags into the feed hopper D-144 that is equipped with a shaker. The screw conveyor C-144 is used to unload and proportion the filter aid from the feed hopper D-144 to the mixing tank T-242. The screw conveyor C-144 stops when a predetermined number of revolutions have been reached from the start. The amount of filter aid powder that is introduced to the mixing tank T-242 per cycle is determined by experiments (kilograms of filter aid powder per one revolution of the screw conveyor). The screw conveyor feeds the filter aid powder at a constant speed of revolution and therefore the quantity can be defined and kept constant. When the set number of revolutions is reached the screw conveyor stops and the filter aid powder valve V-144 closes to prevent the moisture from entering the screw.

At first the mixing tank T-242 is filled with fresh water (in the first cycle) through the fresh water inlet valve 2 V-213 or filtrate through the filtrate circulation valve 2 V-201, before the powder is introduced. This way the filter aid powder is mixed efficiently and reliably with the carrier liquid. The mixing tank T-242 is equipped with an agitator A-242 and level switches LSH-303 and LSL-304. The objective is to prepare a filter aid solution to the mixing tank T-242 with a consistency of 10 %. Bodyfeed is introduced to the process in this mixing tank consistency but the final dilution of the precoat is carried out in the precoat tank T-142. The quantity of the powder that is introduced per one precoating cycle is determined according to the filtration area of the filter cloth that is to be coated. This way the cake thickness that is created to the filter cloth is kept constant. The mixing of the precoat/bodyfeed slurry takes a few minutes and the only difference is the dry solid content, because the bodyfeed is not diluted before feeding. There are two possibilities when a new batch of filter aid solution (DS 10 %) is prepared:

1. When the level of the mixing tank T-242 drops to the lower level limit LSL-304
2. When the precoat tank T-142 is filled to high level with fresh water/filtrate before precoating step.

This ensures that both bodyfeed and precoat are continuously available for the process and no interruptions occur.

8.2.2 Precoating

If the solids in the filterable solution have a tendency to clog the filter bag easily, precoat can be used onto the filter bag to obtain better filtration efficiency and quality. Usually diatomite or perlite is used as a precoating substance. Before the filtration cycle starts, the LSF filter should be precoated with a suitable filter aid suspension.

The precoat is prepared in the mixing tank T-242 by mixing the precoat (dosed from bags) with the process filtrate or other suitable liquid if filtrate is not available (first batch). After the precoat suspension is mixed in the mixing tank T-242, it is transferred to the precoat tank T-142 with the precoat transfer pump P-242. Before the transfer the precoat tank T-142 is filled with fresh water or filtrate to a predetermined level. The objective is to first fill the filtering unit with fresh water/filtrate by using the precoat feed pump. When the filter is full filled the water starts to re-circulate back and transferring of the precoat is started.

At first the precoat filter selection valve V-142 (or V-242) is opened and then the precoat feed pump P-142 is started and the filter is filled with water/filtrate. When the liquid level reaches the high level switch in the filter unit, the precoat transfer pump P-242 is started. Simultaneously the fed water/filtrate starts to re-circulate back to the precoat tank, through the filtrate circulation valve 1 V-101. This way the 10 % filter aid solution is introduced slowly to the precoating circuit. The target is to precoat the filter with a solution with increasing consistency in order to create efficient precoating layer. In the precoat tank T-142 the suspension is diluted to a target concentration and volume with the fresh water or filtrate that re-circulates back from the filtering unit.

One LSF polishing filter is always precoated at a time. The filtering unit is full filled with the precoat to ensure that the overall filter cloth is affected with precoat.

When the filtrate is clear (time basis, obtained by experiments), the filtrate circulation valve 1 V-101 is closed and the filtrate outlet valve (not shown in the P&ID) in the filter unit is opened. The slurry inlet valve (not shown in the P&ID) is opened and the slurry feed pump (not shown in the P&ID) is started. After a set time the precoat feed pump P-142 is gradually slowed down and finally stopped after the precoat tank T-142 level is dropped to a predetermined value, and then the precoat filter selection valve V-142 (or V-242) is closed. The transition from the precoat to the filtration needs to be gradual so that the precoat does not fall away from the filter surface.

The amount of precoat that is fed to the filtering unit is regulated from the control panel by changing the speed of the precoat pump P-142. An accurate setpoint for the pump speed is obtained by experiments; recommended flow is ~2 $m^3/m^2/h$.

8.2.3 Bodyfeeding

If the solids in the filterable solution have a tendency to form a sticky impermeable filter cake, the cake properties are enhanced by using a precoat substance as bodyfeed during the filtration cycle. This is carried out by starting the bodyfeed pump 1 P-143 and/or 2 P-243. The mixing tank T-242 acts as a storage tank for the bodyfeed suspension. A fresh batch of bodyfeed suspension is prepared when the lower level limit LSL-304 is reached. The amount of bodyfeed that is fed to the slurry inlet line is regulated from the control panel by changing the rotational speed of the bodyfeed pump 1 P-143 or 2 P-243. The preferred flow rate is obtained by experiments; recommended amount is relative to the dry solid content of the feed solution.

9. Capital costs

Capital costs are calculated according to the enquired prices from the manufacturers. The accurate and actual prices are classified information and therefore only a relative contribution of the prices is presented. The purpose was to examine which are the most expensive equipment in the system that could be in some cases optimized. Capital costs are calculated for a filtering unit that has a filtering surface area of 100 m^2 as it is done also when operating costs are evaluated. The mixer, precoat tank, and pipelines are excluded from the Larox's delivery and therefore excluded also from the calculation. The capital cost percentages are presented in figure 34.

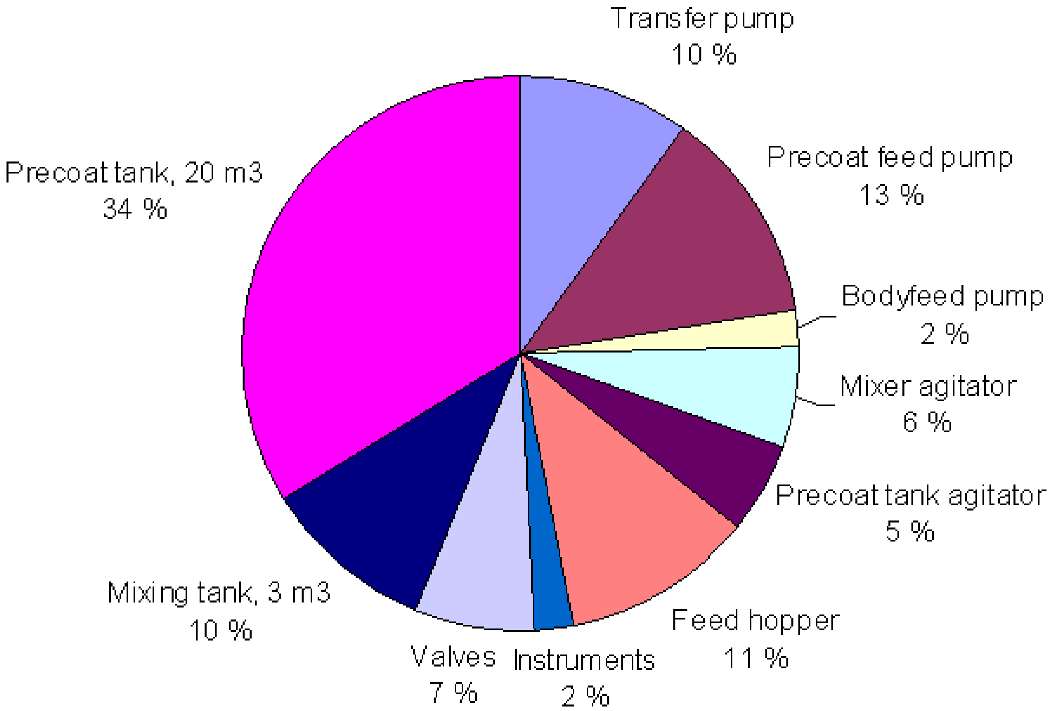


Figure 34. Capital cost percentages.

As can be seen in figure 34 the most expensive equipment are precoat feed pump, feed hopper, and transfer pump. The precoat feed pump size reduction is not desirable as it will prolong the precoating time which results in reduced total filtration capacity. Also the feed hopper that proportions the powder to the mixing tank is simply constructed and therefore the price is economical when considering the whole investment. It is possible to use even smaller pump as a precoat transfer pump without substantially increasing the total precoating time. This is advantageous at least in the larger filtering units, as the price for peristaltic pumps increases notably proportionally with the increased capacity. The optimization of the equipment system is about more than just cutting costs in the factory by improving the filtration step. One crucial insight is that most costs are assigned when the system is designed.

10. Operating costs

As well as optimizing the capital cost of the equipment, also the operating costs are interesting and important when the customer selects whether or not to invest to auxiliary equipment. The main operating cost in filter aid proportioning, mixing and feeding system is obviously the raw material, even when the transport expenses are neglected from the calculation. An indicative operating cost calculation with plotting is carried out in this chapter. The main objective is to produce a figure that indicates the estimated operational costs with a function of filtering area. That is due to the fact that the filtering area is basically directly proportional to the operating costs, because more raw material has to be implemented to the filter and also the required power is increased. By estimating the runtimes for each piece of equipment and calculating their electricity consumption it is possible to notify the critical points for designing and optimization. The calculation excel-sheet with assumptions is presented in Appendix II.

10.1 Raw material costs

At first the raw material operating costs are discussed and calculated in this chapter. The calculation and its initial data are based on the mass balance calculation that is presented in Appendix III. A filter with 100 m^2 filtration area and perlite filter aid was decided to act as a basis for this estimation calculation. The results and used formulas for a 100 m^2 filtering unit filter aid system are presented in this chapter. The initial data for the calculation is presented in table XVI.

Table XVI. Data for example cost estimation calculation for perlite.

Filtration		Precoat	Bodyfeed	Perlite	Slurry
Area	Cycle	Cake thickness	Bodyfeed amount	Price	DS content
m^2	h	m	$l/m^2/h$	\$/ton	%
100	10	0.003	0.5	355	6

Precoat needed for one cycle:

$$0.003\,m \times 100\,m^2 = 0.3\,m^3 \tag{5}$$

$$0.3\,m^3 \times 140\,kg/m^3 = 42\,kg \tag{6}$$

Bodyfeed needed for one cycle:

$$0.5\,l \times 100\,m^2 \times 10\,h = 0.5\,m^3 \tag{7}$$

$$0.5\,m^3 \times 140\,kg/m^3 = 70\,kg \tag{8}$$

Cycles per year, approximated efficiency 0.90 %:

$$\frac{8760}{10} \times 0.9 \approx 789\,cycles \tag{9}$$

Total usage of filter aid per one year:

$$(42\,kg + 70\,kg) \times 789\,cycles = 89\,tons \tag{10}$$

Total price:

$$89\ tons \times 355\$ = 31600\$ \tag{11}$$

$$31600\$ \times 0.78 = 24648 \approx 25000\,€ \tag{12}$$

Total price of the perlite that is used annually, based on the initial data presented in table XVI, is approximately 25 000 €. A plotting versus filtration area is presented in chapter 10.3. The used currency exchange rate was 0.78 on 6.2.2009 /62/.

10.2 Electricity estimation

Another item of expenditure in operating costs is electricity. In this chapter are presented the estimated electricity consumptions and prices. As well as the raw material costs, also electricity price estimation for all the units is presented in Appendix II. Running times and estimated power consumptions and the used formulas are presented below. Running times are obtained from the mass balance calculation and the downtime of the system is estimated to be 10 % annually. The calculation is carried out equipment by equipment and the total costs with figures are presented in chapter 9.3. The electricity price per kWh used in this calculation is 0.10 €/kWh /63/.

Feed hopper (4 kW) is used only when a new batch of filter aid is prepared and therefore the runtime is quite low. With a feed hopper capacity of 10 m^3/h (≈ 0.17 m^3/min) normal runtime per cycle is the following:

$$\frac{0.8\,m^3 / cycle}{0.17\,m^3 / \min} \approx 5 \min / cycle \tag{13}$$

With the runtime per cycle the total running time per year is estimated with downtime of 10 %. With the calculated total runtime and the power consumption, the total energy consumption is estimated:

$$0.083\,h / cycle \times 789\,cycles \approx 65.50\,hours / year \tag{14}$$

$$65.50\,hours / year \times 4\,kW \times 0.10\,€ / kWh = 26.2\,€ \tag{15}$$

Mixer tank agitator (8 kW) is running all the time as the filter aid material has to be kept in motion to prevent the settling. Even though the mixer power consumption can be maintained at a low level due to the behavior of the solution as it is easily mixed, the high total runtime causes the electricity price to be high compared to other equipment. The mixer tank agitator is the most energy consuming equipment in the process and therefore it should be tailored for each process individually. It should be remembered that as low as 50 rpm is sufficient to mix the powder to the carrier liquid.

$$0.90 \times 8760\,h = 7884\,hours/year \tag{16}$$

$$7884\,hours/year \times 8\,kW \times 0.10\,€/kWh = 6307.2\,€ \tag{17}$$

Precoat tank agitator (5 kW) can be stopped in the middle of the cycles in order to save energy and equipment as the precoat step itself is rapid compared to the filtration. It was assumed that the total precoat time from mixing to emptying takes about 15 minutes and this is the time that the precoat tank agitator is running. This way the total running time can be lowered to as low as 200 hours per year, compared to mixing tanks 7884 hours per year. The precoat agitator’s motor can be even smaller than that of mixing tank because at this point the solution is already mixed and in precoat tank the solution is only kept in movement.

$$0.25\,h/cycle \times 789\,cycles \approx 200\,hours/year \tag{18}$$

$$200\,hours/year \times 5\,kW \times 0.10\,€/kWh = 100\,€ \tag{19}$$

Precoat transfer pump (10 kW) is used to transfer the mixed solution to the precoat tank and therefore the running time is pretty low. The system was designed so that the transfer pump is able to transfer the needed volume of filter aid solution to the precoat circulation in 5 – 6 minutes. This way the ~10 % filter aid solution is dosed little by little to the precoat tank where it is diluted and pumped to the filter.

$$0.10\,h/cycle \times 789\,cycles \approx 80\,hours/year \tag{20}$$

$$80\,hours/year \times 10\,kW \times 0.10\,€/kWh = 80\,€ \tag{21}$$

Precoat feed pump (30 kW) is the biggest pump in the system because it has to be able to feed the precoat efficiently to the filtering unit to reduce the downtime from filtration. The system was designed to precoat the filter in 10 – 15 minutes.

$$0.20\,h/cycle \times 789\,cycles \approx 160\,hours/year \tag{22}$$

$$160\,hours/year \times 30\,kW \times 0.10\,€/kWh = 480\,€ \tag{23}$$

Bodyfeed pump (1 kW) is the smallest pump in the system as the bodyfeed volumes are low and more important factor is the capability of accurate dosing. The total runtime is calculated from the total hours that the filtering system is running and reducing the precoating time from it. As can be seen from the results, it is essential to optimize the sizes of the mixer agitator motor as well as bodyfeed pump. If these equipment are over dimensioned, it will cause unnecessary extra costs in electricity consumption.

$$(0.90 \times 8760\,h) - (789\,cycles \times 0.20) = 7726.2\,\frac{hours}{year} \tag{24}$$

$$7726.2\,hours/year \times 1\,kW \times 0.10\,€/kWh = 772.62\,€ \tag{25}$$

10.3 Total operating costs

The results of the previous chapter’s calculations are presented in this chapter with figures and tables. The results are plotted with filtration area because the costs are proportional to filtration are, and with the tables it is possible to evaluate the changing operating costs depending on the selected filtering unit.

The filter aid material consumptions are proportional to the filtration areas as can be seen in figure 35 below.

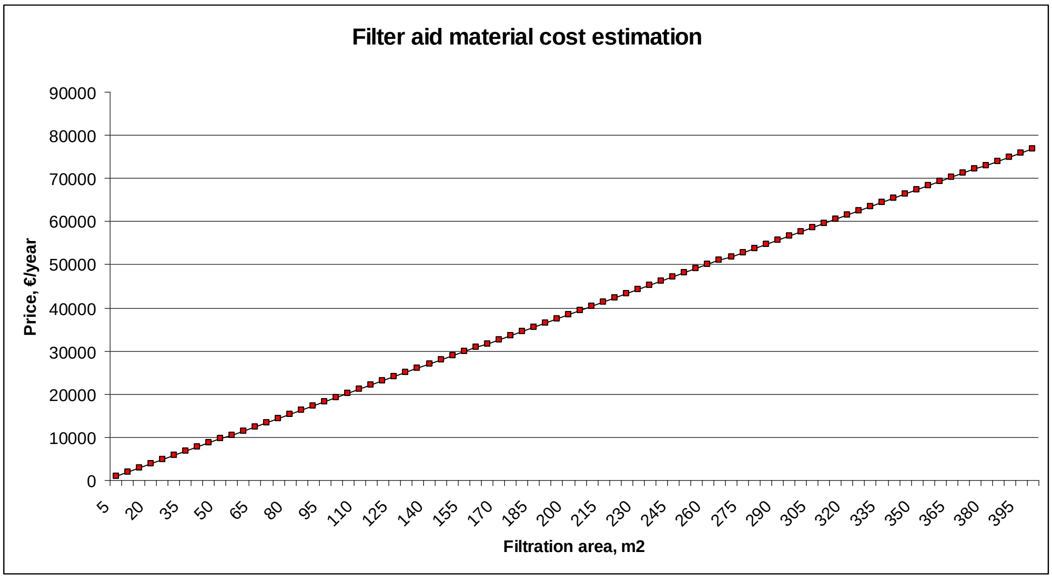


Figure 35. Filter aid material cost estimation.

The other operating costs consist of electricity, lubrication of the peristaltic pumps and other maintenance costs. The electricity prices are estimated according to the defined main equipment electricity consumptions that are used in different filter sizes. The motor sizes were enquired from the equipment manufacturers, but should only be used as guidelines. Summary of electricity consumption for a filter unit with a filtration area of 100 m^2 is presented in table XVII.

Table XVII. Summary of electricity consumption.

Equipment	Motor size, kW	Average running time, h/year	Power consumption, kWh/year	Price/year, €
Feed hopper	4 kW	65.50	262	26.2
Mixer tank agitator	8 kW	7884	63072	6307
Precoat tank agitator	5 kW	200	1000	100
Precoat transfer pump	10 kW	80	800	80
Precoat feed pump	30 kW	160	4800	480
Bodyfeed pump	1 kW	7884	7884	788
TOTAL	58 kW	-	77818	7781

Also the other operating costs than filter aid material, are proportional to the filtration area. The more detailed calculation is presented in Appendix II. In figure 36 below is presented the proportionality of the electricity costs versus filtration area:

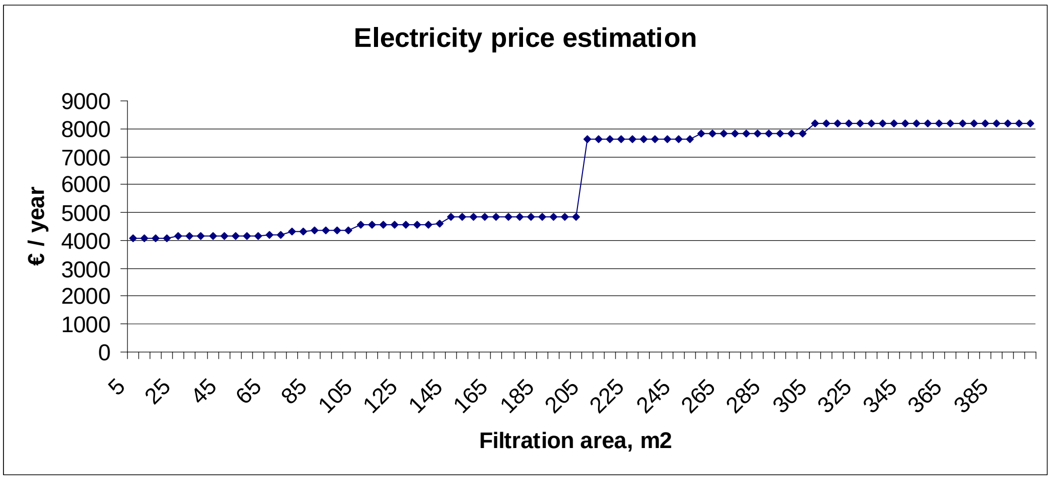


Figure 36. Electricity price as a function of filtration area.

As can be seen in table XVII indicating electricity prices, the most significant electricity consumer is the mixer agitator as it has to be operating almost all the time. When the filtration area is above 220 m^2 a larger mixing tank has to be used with larger agitator and motor. This increases significantly the electricity price as it is presented in figure 36. Other equipment are operating only periodically and therefore the costs are not remarkable. Total annual operating costs consist of filter aid material, electricity of the main equipment and maintenance expenses. The total annual operating costs are presented in figure 37.

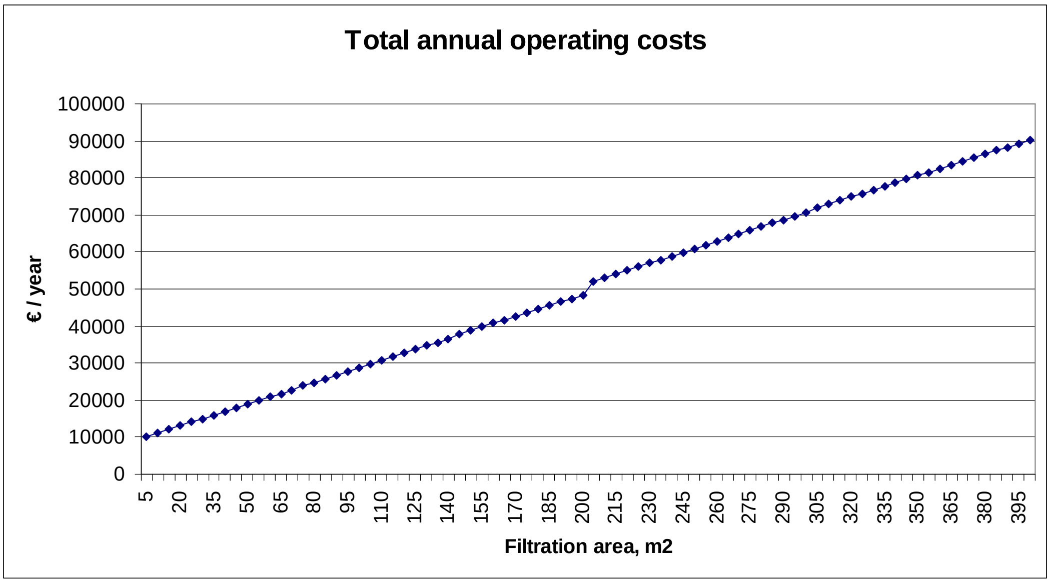


Figure 37. Total annual operating costs as a function of filtration area.

11. Filter aid test procedure

The filter aid test procedure was carried out in the facilities of Lappeenranta University of Technology. The test was carried out by using Larox LSF R2 –test filter to study the behaviour of the different precoat materials and their influences on accumulation of the filter aid cake with different fluxes on different cloths. The obtained data was examined and compared to the values found from the literature and previous assumptions.

11.1 Target of the filter aid test procedure

The main purpose and outcome of the supplementary practical test work was to define suitable procedure for precoat layer creation, depending on the material and its characteristics and the used cloth permeability by replicating the designed system. Another reason for the test work was to expose problems systematically and by using empirical methods to decide what matters, rather than uncritically accepting pre-existing ideas and assumptions of what matters. One could say that the more radical and revolutionary innovations tend to emerge from R&D, while more incremental innovations may emerge from practice. But in this case the empirical part supports the designing. The test was carried out as lean laboratory test which is focused on testing products and materials to deliver results in the most efficient way by using less effort, less resources and less time to test the samples.

As it was noted earlier in this study the selection of the filter aid material should always be determined with laboratory and field tests, but with the results of this study the pre-screening of the possible filter aid materials is made more straight forward. The basic initial idea was to alternate the flux between 1 – 3 $m^3/m^2/h$ with six different precoat materials; DE Celite 503, DE Celite 577, Cellulose Arbocel B-600, Cellulose Filtracel EFC-450, and Perlite Harborlite. These materials were used to create a precoat cake to the LSF R2- test filter that was equipped with six different filter cloths. The test work started with pre-studies with multiple test runs to cut-off unnecessary tests. The initial concept was to alternate the concentration in order to examine the effect of bridging phenomenon, but frankly the concentration is dependent of the used filtration area to volume ratio, and is therefore neglected from the test work. The volume of the needed precoat solution dictates the concentration as the amount of dry solids is a parameter that has to be kept constant, but the total volume has to exceed the volume of a filter unit and pipelines.

11.2 Test equipment

Test equipment and the used filter cloths and materials used in the complementary practical study are presented in this chapter.

11.2.1 LSF R2 test filter

The Larox polishing filtration test filter LSF R2 represents the Larox polishing filtration technology. It is designed for testing purposes of different polishing filtration applications. The test results of LSF R2 filter provides accurate and reliable sizing information for production size LSF polishing filtering units. Normally the LSF R2 test filter contains two filtration elements, each with a filtration area of 1.125 m^2 (triplex cloth). In this study the used filter cloths have smaller filtration area of about 0.624 m^2 because when precoating is studied it is reasonable to use singlex cloths. The filter is normally used with two elements, but other options are with only one element or half of the element. Initially the intention was to use two elements in this study in order to model actual process conditions. But a compromise had to be made because the feeding pump capacity was inadequate for two filter cloths when high fluxes wanted to be tested. A setup of the Larox R2 test filtering unit and auxiliaries is presented below in figure 38 /64/.

Figure 38. Test filtration setup.

11.2.2 Filter elements

The filter element consists of the supporting grid and filter cloth. Four different cloths with different permeabilities were used. The cloths P107 and P126 were used for the testing of perlite and diatomaceous earth grades and the P132 and P133 were used for cellulose test runs. With cellulose filter aids more open cloths are used because of the better bridging properties compared to perlite and DE. All the used cloths were 100 % polypropylene with mono-mono yarns. It is essential to use mono-mono cloths to prevent clogging and blinding that may cause problems with more complicated cloths. Calendered cloths are beneficial with cellulose filter aids, as the structure is more compact and thus the washing of the cloth is easier. That is due to the fact that the filter aids won’t stick overly between the yarns. In this study the only cloth that is not calendered is the P133. The test procedure cloths and their characteristics are presented in table XVIII.

Table XVIII. Filter cloths used in test procedure /65/.

No.	Air Permeability m³/m²/min @ 200 Pa	Weight g/m²	Thickness mm	Yarns warp-weft
P107	6.5	300.0	0.6	mono-mono
P108/ P126	2.1	265.0	0.5	mono-mono satin weave
P132	12.0	380.0	0.7	mono-mono
P133	45.0	370.0	0.7	mono-mono

11.2.3 Filter aid materials

As it was noted before the used filter aid materials were Perlite Harborlite, DE Celite 503, DE Celite 577, Celite Hyflo Super-Cel, Cellulose Arbocel B-600, Cellulose Filtracel EFC-450. The cellulose filter aid materials were provided by Finnpool, a resailer of the J Rettenmaier & Söhne filter aid products. Perlite and diatomaceous earth filter aids were provided by Larox, purchased for previous tests. The filter aid materials that were used in the testing were selected due to their different characteristics. Particle size distributions and microscopic pictures were taken to examine and understand the behaviour in the tests and their influence to the results. The particle size distribution figures and average statistics are presented in Appendix IV.

Particle size analysis was carried out in the facilities of Lappeenranta University of Technology. The used equipment was Beckman Coulter LS13 320 Laser Diffraction Particle Size Analyzer with Aqueous Liquid Module (ALM).

The data of the particle size analysis is presented in table XIX.

Filter aid	Mean µm	S.D. µm	<10 % µm	<25 % µm	<50 % µm	<75 % µm	<90 % µm
Celite 503	44.64	33.81	8.355	19.00	38.03	62.44	89.06
Celite 577	30.10	30.45	4.662	9.855	21.03	39.73	62.80
Hyflo Super-Cel	37.43	33.96	6.249	14.14	28.40	50.13	76.37
Harborlite	64.35	44.17	15.09	29.63	54.95	90.78	129.1
Arbocel B-600	47.18	34.42	10.88	21.27	38.45	66.49	97.42
Filtracel EFC-450	73.62	65.91	8.752	24.66	54.98	104.2	166.7

11.3 Test procedure

The test procedure consisted of two parts. The reason was that usually the most valuable contribution is often made at the earliest stage of a project and therefore the test procedure and the necessity of the parameters were critically thought in the beginning by carrying out preparatory tests before the actual test procedure. The test procedure is explained below in a stepwise manner.

1. Filter cloths were attached to the support grids with necessary cleats
2. Elements were mounted to the filtering unit, o-ring condition was checked
3. Precoat mixer/feeding vessel was filled with 90 litres of fresh water
4. The filtering unit inlet valves V-1 and air vent valve V-4 were opened and the feeding pump was started
5. 90 litres of fresh water was introduced to the system
6. The chamber was filled with fresh water and when filled to top, circulation through the air vent valve occurred
7. The air vent valve was closed and filtrate valve V-3 was opened.
8. Precoat mixer A-1 was started and the feeding pump’s rotational speed was adjusted to a desired value.
9. The mixer agitator was started
10. The filter aid material (weighted amount) was manually dosed to the precoat vessel during one minute

11. Samples were taken from the mixer in every 60 seconds and turbidity test was carried out in the laboratory
12. When the predetermined time had passed the feeding pump was stopped and the drain valve was opened to ensure that the cake remained on the cloth
13. The accumulated cake was examined and evaluated visually
14. The filter cloth, filtering unit, and mixer were washed and another cycle was started from the point 3.

The amount of filter aid that was used in one cycle was calculated by multiplying the filtration area with preferred cake thickness, in this study 3 mm. In the pre-test runs it was discovered that this conventional way of calculating is not totally correct and leads to insufficient cake formation. The reason for this is that the filter aid materials consists of highly porous particles and therefore the wet volume, is twice lower compared to dry volume. It was noted that to obtain a predetermined and adequate cake thickness of ~3 mm, the filter aid amount has to be roughly doubled. The weighted filter aid powder was fed to the mixer in one minute and the first sample was taken one minute after introducing the powder. The total time of a test run was 15 minutes, so 14 samples were taken from every test run for turbidity test. Turbidities were measured with Hach 2100 AN IS Turbidimeter (ISO method 7027) in the paper laboratory of LUT.

Piping and instrumentation diagram of the test equipment is presented in Appendix V.

11.4 Test results

The test runs were carried out in the facilities of Lappeenranta University of Technology. In the following chapters are presented the most important results that were obtained during the intensive test run period. The results are divided into chapters according to the used filter cloth and also the different materials and their usage are being analyzed. Also some general remarks were made during the test period.

The most important general observation was that it was possible to use higher flux (> 3 $m^3/m^2/h$) than what has been conventionally used. In these test runs the accumulated cake was visually uniform even with higher flux. It was possible to use this higher flux with all the materials, even though when the finest materials (DE Celite 577 and DE Hyflo Super-Cel) were used on tightest cloth it was clearly seen that the flux 3 $m^3/m^2/h$ was the maximum as the pattern of the grid was slightly copied. The pattern copying can be notified also during the precoating as the pressure difference increases slightly (0.2 – 0.5 bar). This phenomenon is presented in the following figure 39.

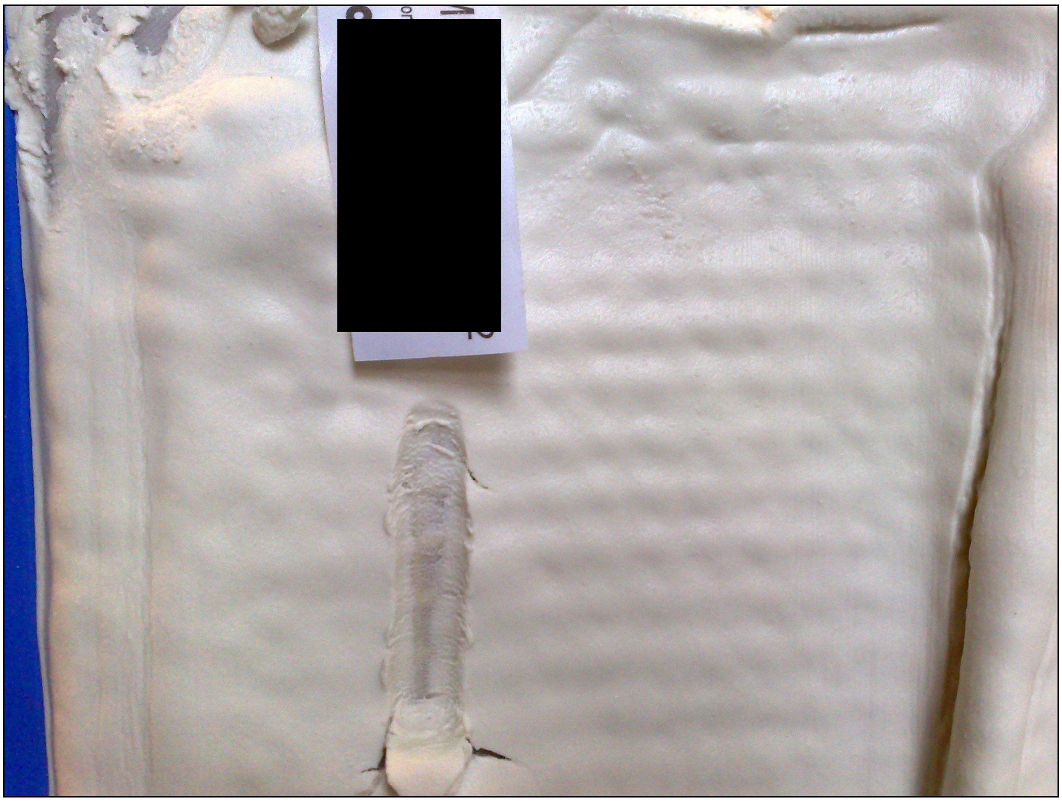

[redacted]

Figure 39. DE Hyflo Super-Cel and P108/P126 cloth.

But it was also noted during the test runs that when cellulose filter aids were used with the cloths of higher permeabilities, the flux 4 $m^3/m^2/h$ did not cause any problems. By using the flux 4 $m^3/m^2/h$ the cake was accumulated evenly in less than 10 minutes without any problems. The accumulated uniform cake of Arbocel

B-600 onto to the P133 cloth is presented below in figure 40. The cavity occurred during the removal of the filter element from the filter unit.

[redacted]

Figure 40. Arbocel B-600 and P133 cloth.

In the following chapters are presented the results obtained during the test runs. The results are divided into chapters according to which cloth is used and also the used materials and their behaviour is explained in the following chapters. All the test runs and results are presented in Appendix VI.

11.4.1 Cloth P108/P126

The testing was started with the densest cloth (air permeability 2.1 $m^3/m^2/min$) that was meant to be used with perlite and diatomaceous earth grades. The results of the test runs with the flux 3 $m^3/m^2/h$ are presented in table XX and in figure 41.

Table XX. Test run 1 – 4 results, turbidity vs. time.

Test run 1		Test run 2		Test run 3		Test run 4	
Perlite Harborlite		DE Celite 503		DE Celite 577		DE Hyflo Super-Cel	
Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3
Density, kg/m^3	147	Density, kg/m^3	240	Density, kg/m^3	208	Density, kg/m^3	225
DS, kg	0,55	DS, kg	0,9	DS, kg	0,8	DS, kg	0,85
Water, kg	180	Water, kg	180	Water, kg	180	Water, kg	180
DS % (w/w)	0,31	DS % (w/w)	0,50	DS % (w/w)	0,44	DS % (w/w)	0,47
Min	NTU	Min	NTU	Min	NTU	Min	NTU
2	1147	2	4310	2	4022	2	4353
3	1113	3	2578	3	3108	3	3722
4	616	4	2136	4	1527	4	3176
5	454	5	2117	5	1507	5	2507
6	351	6	1324	6	935	6	907
7	279	7	787	7	690	7	787
8	86	8	358	8	477	8	358
9	82	9	340	9	256	9	345
10	75	10	190	10	202	10	178
11	45	11	182	11	185	11	164
12	28	12	78,3	12	166	12	126
13	19,5	13	60,7	13	130	13	85,2
14	-	14	-	14	79,1	14	56,5
15	-	15	-	15	45,1	15	41,3

The test results show that the perlite accumulates quickest onto the surface and the optimal precoating time with the flux 3 $m^3/m^2/h$ is about 8 minutes as the turbidity is not changing remarkably after that point. It is not a problem if all of the filter aid material is not on the cloth surface, if adequate cake is accumulated. When Celite 503 was used the needed precoating time is longer, for about 11 minutes. The smaller the particles, the longer it takes for the mixer turbidity to reduce, as can be seen that Celite 577 and Hyflo Super-Cel requires about 13 minutes to efficiently accumulate onto the cloth surface.

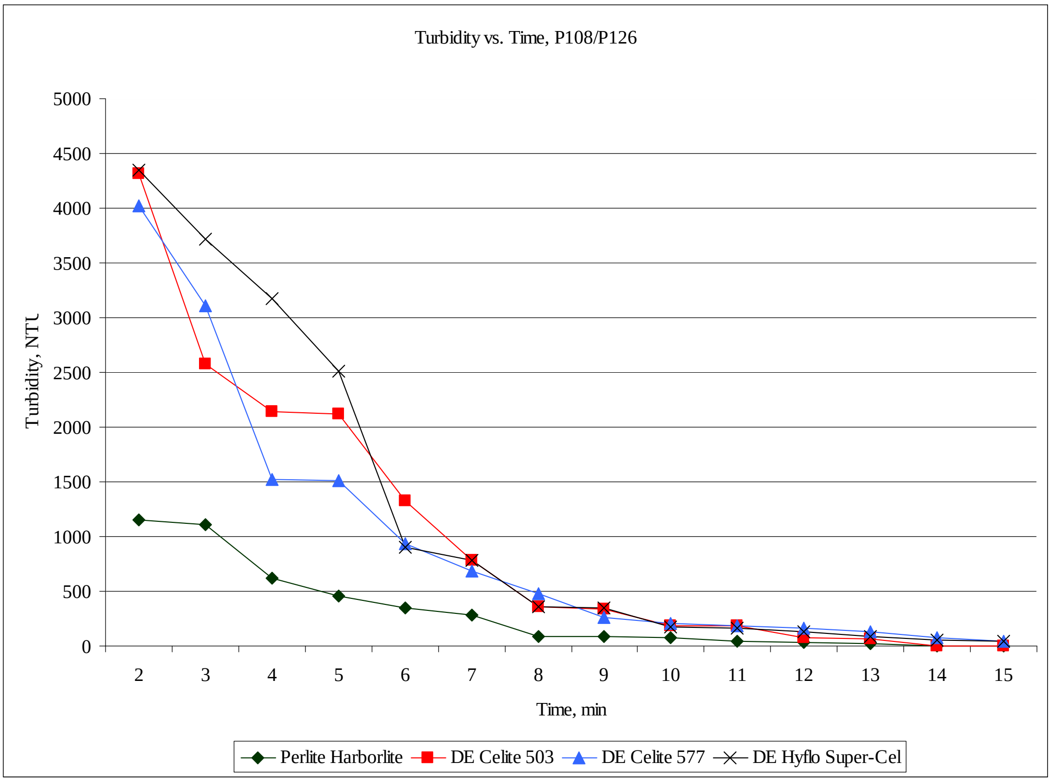


Figure 41. Test runs 1 - 4 turbidity vs. time.

11.4.2 Cloth P107

The test runs 9 – 12 were carried out with using another cloth with a bit higher permeability (6.5 $m^3/m^2/min$) which was also used only with perlite and diatomaceous earth grades. The results of the test runs with the flux 3 $m^3/m^2/h$ are presented in table XXI and in figure 42.

Table XXI. Test run 9 – 12 results, turbidity vs. time.

Test run 9		Test run 10		Test run 11		Test run 12	
Perlite Harborlite		DE Celite 503		DE Celite 577		DE Hyflo Super-Cel	
Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3
Density, kg/m^3	147	Density, kg/m^3	240	Density, kg/m^3	208	Density, kg/m^3	225
DS, kg	0,55	DS, kg	0,9	DS, kg	0,8	DS, kg	0,85
Water, kg	180	Water, kg	180	Water, kg	180	Water, kg	180
DS % (w/w)	0,31	DS % (w/w)	0,50	DS % (w/w)	0,44	DS % (w/w)	0,47
Min	NTU	Min	NTU	Min	NTU	Min	NTU
2	1232	2	4024	2	4332	2	4036
3	1087	3	3656	3	3579	3	4028
4	674	4	3100	4	1516	4	3164
5	463	5	1322	5	1372	5	2380
6	227	6	1097	6	995	6	916
7	213	7	528	7	677	7	873
8	184	8	345	8	316	8	425
9	114	9	243	9	225	9	402
10	81	10	173	10	216	10	215
11	55	11	149	11	149	11	195
12	27	12	110	12	106	12	152
13	13,9	13	76	13	84	13	121
14	7,3	14	61	14	55	14	51
15	6,9	15	43	15	31	15	38

The test results show that again the perlite accumulates quickest onto the cloth surface and the optimal precoating time with the flux 3 $m^3/m^2/h$ is about 9 minutes as the turbidity is not changing remarkably after that point. In the same way that with the denser cloth but now the accumulation takes roughly a minute longer. When Celite 503 was used the needed precoating time is longer, for about 12 minutes. It can be clearly seen that when the cloth is more open i.e. has a higher permeability, the precoating time is slightly prolonged. Even though the time difference is not significant and may be in some cases compensated with increased flux. For some reason the Celite 577 accumulates in less time when wider cloth is used, which was not expected.

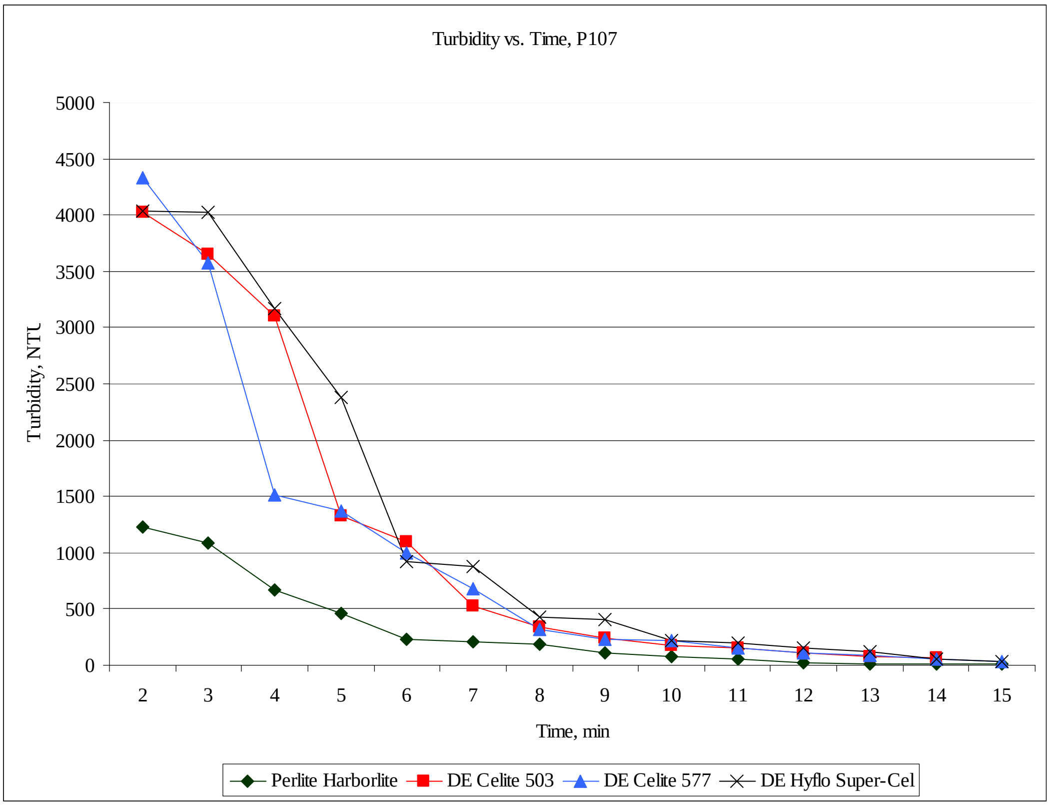


Figure 42. Test runs 9 – 12, turbidity vs. time.

11.4.3 Cloth P132

The cellulose test runs were started with denser cellulose cloth P132 (air permeability 12 $m^3/m^2/min$). The needed amount of cellulose that needs to be used in a single run was tested in the pre-studies. A rule of thumb according to literature is that half the weight of cellulose compared to DE gives the same cake thickness. This general guideline was tested in the pre-studies and found to be usable. At first it was surprising that so small amount of weighted cellulose, about 2 liters (0.5 kg) could generate a filter aid cake with a thickness of about 3 mm. This feature is beneficial because the transportation costs are lower, which compensates the price difference of cellulose compared to the cheaper filter aid grades, perlite and DE.

The turbidity results versus time are presented in table XXII and in figure 43.

Table XXII. Test run 17 – 18 results

Test run 17 Arbocel B-600		Test run 18 Filtracel EFC-450	
Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3
Density, kg/m^3	250	Density, kg/m^3	250
DS, kg	0,5	DS, kg	0,5
Water, kg	180	Water, kg	180
DS % (w/w)	0,28	DS % (w/w)	0,28
Min	NTU	Min	NTU
2	1607	2	2634
3	1349	3	2458
4	930	4	1531
5	897	5	1121
6	549	6	384
7	260	7	372
8	139	8	309
9	126	9	136
10	63	10	130
11	59	11	92
12	37	12	67
13	31	13	47
14	22,0	14	33
15	13	15	26

As can be seen from the results the optimum precoating time is around 10 minutes with both cellulose grades. It should be remembered that a lot wider cloth is used compared to perlite and DE test runs. Therefore higher flux may be used as the accumulated cake and the supporting cloth remain more permeable. This is a beneficial property of the cellulose filter aid grades, as the precoating time could be significantly reduced, leading towards higher capacities. The huge difference in the starting point turbidity is due to the fact that Filtracel EFC-450 cellulose is not bleached, and is therefore brownish.

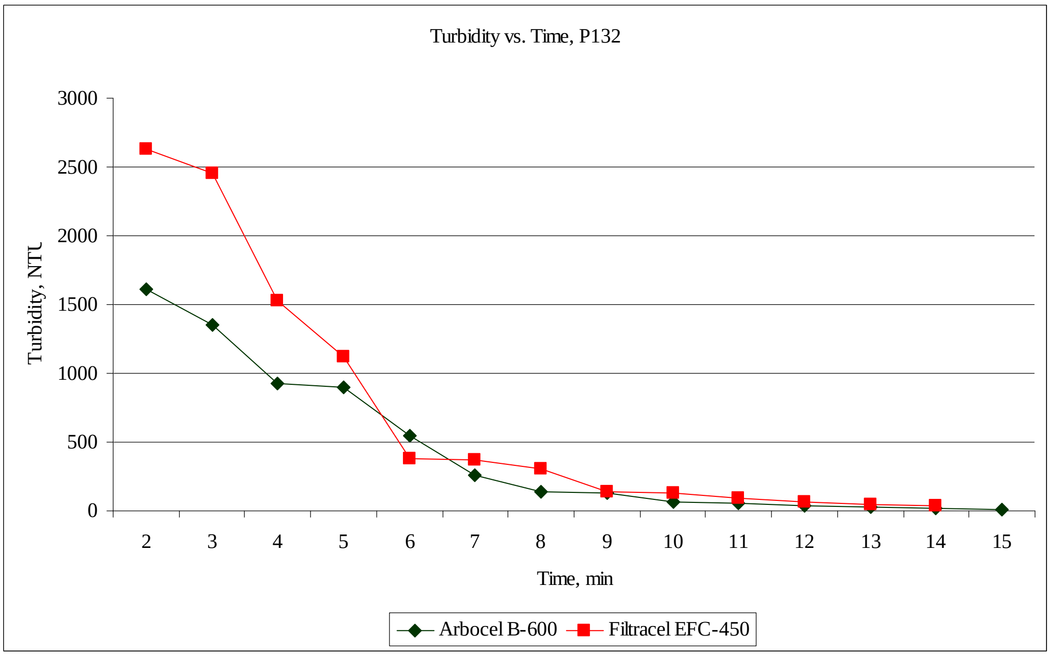


Figure 43. Test runs 17 – 18, turbidity vs. time.

11.4.4 Cloth P133

The cloth with highest permeability (air permeability 45 $m^3/m^2/min$) was tested last. It is interesting to notice that the precoating time is not prolonged, even though a lot wider cloth is used. This verifies the fact that both of these cloths could be easily and effectively used in a full scale operation. It seems that the cloth has to be excessively wide to encounter problems that arouse if the particles are too small compared to the cloth openings. According to these laboratory tests it seems that cellulose grades are easier to use with different filter cloths compared to perlite and DE grades.

The turbidity results versus time are presented in table XXIII and in figure 44.

Table XXIII. Test run 19 – 20 results

Test run 19		Test run 20	
Arbocel B-600		Filtracel EFC-450	
Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3
Density, kg/m^3	250	Density, kg/m^3	250
DS, kg	0,5	DS, kg	0,5
Water, kg	180	Water, kg	180
DS % (w/w)	0,28	DS % (w/w)	0,28
Min	NTU	Min	NTU
2	1351	2	2949
3	1191	3	1768
4	830	4	1278
5	534	5	1037
6	312	6	439
7	232	7	415
8	103	8	326
9	97	9	137
10	77	10	129
11	58	11	59
12	37	12	58
13	19	13	47
14	17,0	14	31
15	11	15	23

As can be seen from the results the optimum precoating time is around 9 - 10 minutes with both cellulose grades. It is not advisable to continue precoating any longer than that as the turbidity is not remarkably reduced after this point.

It is possible to reduce the precoating time to around 7 minutes when even higher flux 4 $m^3/m^2/h$ is used. This was tested in the final cellulose test run, which was visually examined. The accumulated cake is presented in figure 40.

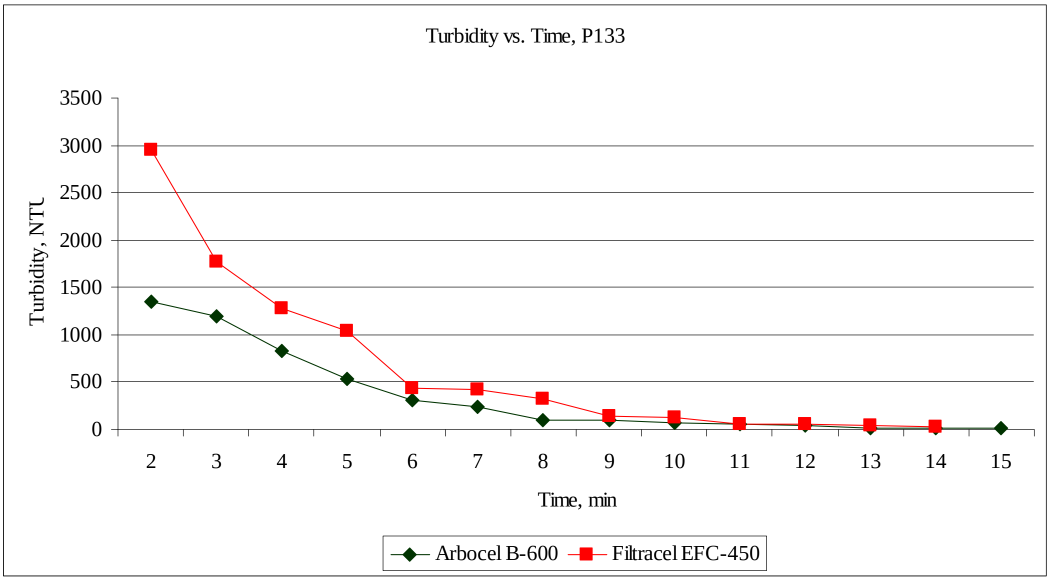


Figure 44. Test runs 19 – 20, turbidity vs. time.

11.4.5 Perlite

Perlite is very light filter aid material, which is beneficial when considering transportation costs, but disadvantageous in use. Perlite is carcinogenic and very easily dusting material and therefore respirator mask should be used. When perlite is introduced to the filtering unit, especially when lower fluxes are used, the material flows in the surface of the carrier liquid. This was seen when the filtering unit was opened after precoating, and an example is presented in figure 45.

Figure 45. Perlite

The accumulated cake was uniform but wetter than DE cakes. As the perlite is highly porous material no increase in pressure difference occurred. The first test run was carried out with the flux 3 $m^3/m^2/h$ and another one with lower flux of 2 $m^3/m^2/h$. It takes roughly one third longer to reach the same turbidity level when lower flux was used. The same occurred also with the diatomaceous earth test runs, and therefore the results are presented and plotted only of the perlite test runs 1 and 5. Perlite test runs 1 and 5 results presented in table XXIV.

Table XXIV. Perlite test runs on P108/P126 cloth.

Test run 1		Test run 5	
Perlite Harborlite		Perlite Harborlite	
Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	2
Density, kg/m^3	147	Density, kg/m^3	147
DS, kg	0,55	DS, kg	0,55
Water, kg	180	Water, kg	180
DS % (w/w)	0,31	DS % (w/w)	0,31
Min	NTU	Min	NTU
2	1147	2	1132
3	1113	3	1121
4	616	4	812
5	454	5	623
6	351	6	456
7	279	7	303
8	86	8	250
9	82	9	170
10	75	10	146
11	45	11	94
12	28	12	72
13	19,5	13	49
14	-	14	-
15	-	15	-

As the accumulated cake was uniform without grid pattern copying it is advisable to use a flux up to a 3 $m^3/m^2/h$ in order to reduce the precoating time by a third.

These results plotted to a diagram are presented in figure 46.

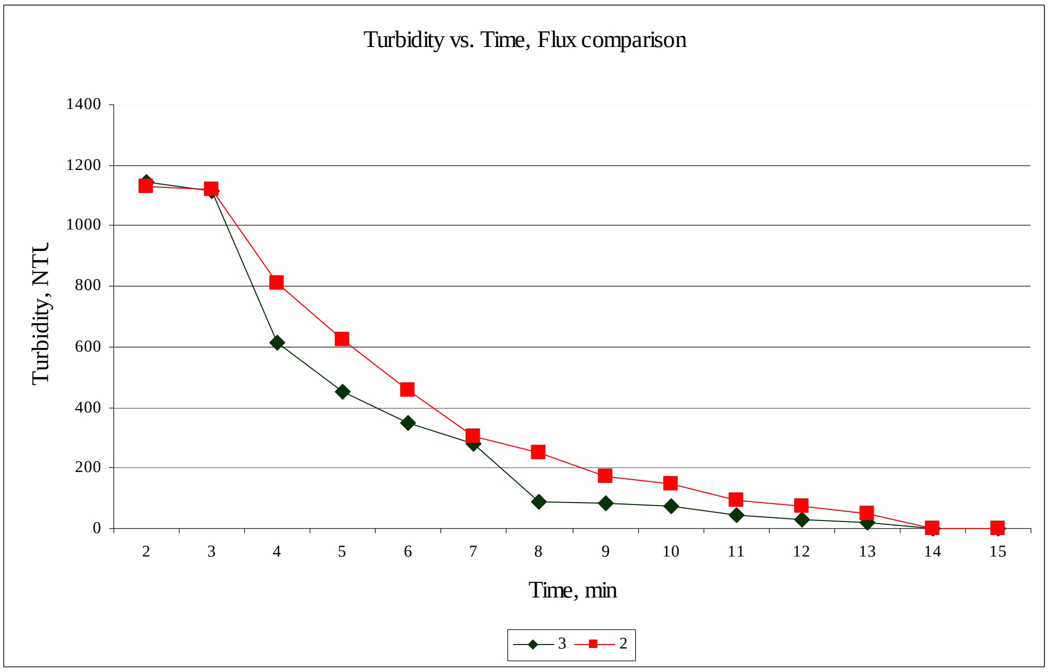


Figure 46. Test runs 1 and 5, turbidity vs. time.

11.4.6 Diatomaceous earth

Diatomaceous earth filter aid materials used in the test procedure were a bit heavier (higher density) than the perlite grade. Regardless of that the dusting is also a problem with DE, and personal respiratory mask should always be used when handling these materials. All the accumulated cakes of diatomaceous earth grades were dryer than that of perlite. When smaller filter aid material with smaller particle size was used with denser cloth, a change in differential pressure occurred. As a consequence also the grid pattern was slightly copied to the accumulated cake. The copying was not severe (figure 39) and it was not considered to affect to filtration efficiency. But when the mean particle size is under 40 µm it is advisable to use a maximum flux of 2.5 $m^3/m^2/h$. It was clearly seen that the pressure difference will increase if too dense cloth is used with filter aid material that produces tight and impermeable cake. The final test was carried out to study the behaviour of filter cloth permeability and its influence to the precoating time. For this DE Celite 503 was chosen to be used with a wider cloth, initially meant to be used with cellulose filter aid grades, P132 (air permeability 12). The result was surprising as the total precoating time was not prolonged even though a lot wider cloth was used. It can be seen from the result table and plotting that the cloth’s influence is pretty significant in the beginning, but as the cake accumulates, the cake itself starts to catch the filter aid particles. The results are presented in table XXV and in figure 47.

Table XXV. DE Celite 503 test runs on P108/P126, P107 and P132 cloth.

Test run 2		Test run 10		Test run 21	
Cloth: P108/P126		Cloth: P107		Cloth: P132	
DE Celite 503		DE Celite 503		DE Celite 503	
Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3
Density, kg/m^3	240	Density, kg/m^3	240	Density, kg/m^3	240
DS, kg	0,9	DS, kg	0,9	DS, kg	0,9
Water, kg	180	Water, kg	180	Water, kg	180
DS % (w/w)	0,50	DS % (w/w)	0,50	DS % (w/w)	0,50
Min	NTU	Min	NTU	Min	NTU
2	4310	2	4024	2	3474
3	2578	3	3656	3	3406
4	2136	4	3100	4	3276
5	2117	5	1322	5	1449
6	1324	6	1097	6	1060
7	787	7	528	7	828
8	358	8	345	8	349
9	340	9	243	9	343
10	190	10	173	10	178
11	182	11	149	11	173
12	78,3	12	110	12	139
13	60,7	13	76	13	86.8
14	-	14	61	14	55
15	-	15	43	15	47.6

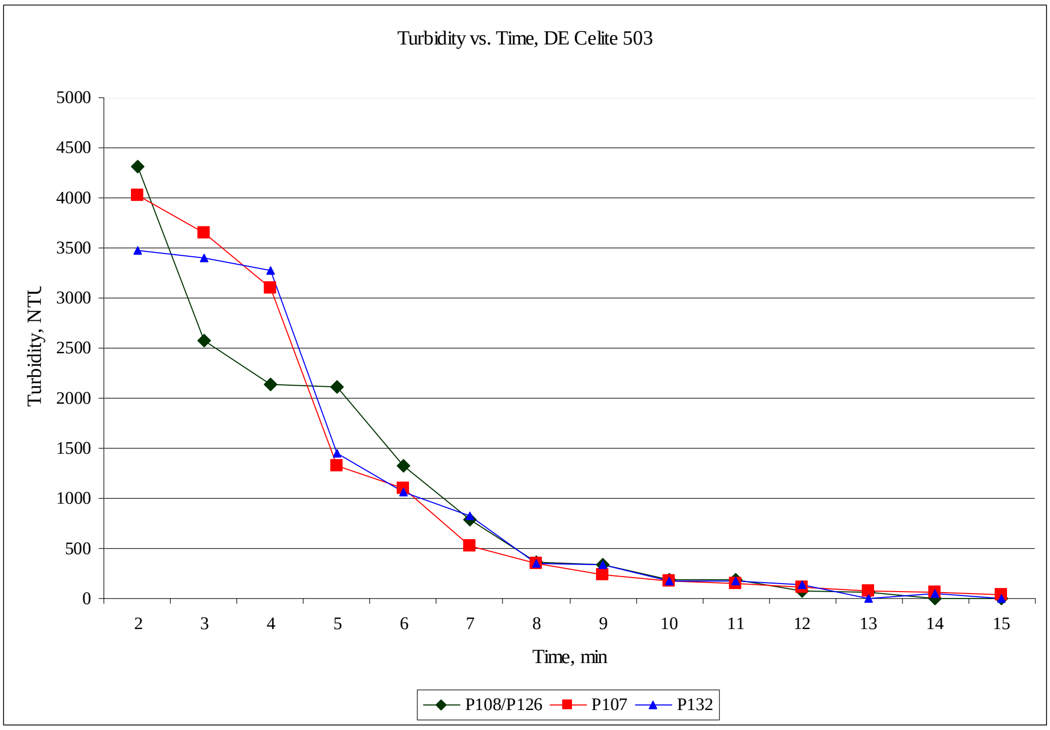


Figure 47. Test runs 2, 10, and 21; turbidity vs. time.

11.4.7 Cellulose

Cellulose filter grades were easier to handle as the inhaling of the dust was not as harmful as it is with perlite and DE. Especially Arbocel B-600 grade was very easy to use and fewer kilograms had to be used, compared to perlite and DE. The accumulated cake was uniform and grid pattern was not copied even with the flux 4 $m^3/m^2/h$. The other grade, Filtracel EFC-450, was a bit more difficult to use. When the powder was fed to the mixer, it foamed slightly and did not mix very easily. Therefore mixers speed of revolutions had to be increased in order to mix the powder effectively before it enters the filtering unit. This may be also problem in larger scale, as the amounts are increased, and the time is more relevant factor.

12. Conclusions and future recommendations

In this thesis work a filter aid proportioning, mixing, and feeding system was designed to serve Scheibler LSF polishing filters. The work consisted of literature search, designing, and supplementary laboratory test work. This section presents the conclusions concerning the designed system developed in this thesis and presents recommendations for possible future enhancements.

It is recommended that future enhancements should be made to the filter aid system as further research is completed at full scale. The forthcoming research should be structured so that results are obtained from a full scale operation with filtration efficiency included. The chosen filter aid material has paramount importance to the filtration efficiency but it seems that the material does not have a significant impact on the operating parameters.

The supplementary laboratory test work indicated that the filter cloth permeability does not have a remarkable effect on cake accumulation, if operated in the normal region of under ~ 20 $m^3/m^2/min$ for perlite and DE grades and under ~ 50 $m^3/m^2/min$ for cellulose grades. The most interesting feature that was discovered was the fact that the flux could be increased to as high as 4 $m^3/m^2/h$ which reduces the total precoating time to half compared to conventionally used flux parameter of 2 $m^3/m^2/h$. This increased flux should be further examined in full scale operation case by case, especially when filter aid materials with higher permeabilities are used. This is extremely beneficial in processes where more permeable cellulose materials can be used. Reduced flux has to be used if the process requires use of filter aid material with low permeability (< 2 Darcies) or small mean particle size (< 40 µm). In these cases the pressure difference increases and copying of the supporting grid may cause problems as the total filtration area is reduced. Although the grid was slightly copied in the laboratory tests, it was not considered to be a problem.

Another interesting observation was that the conventional way of evaluating the needed precoat amount for a single cycle was inaccurate due to the fact that the wet volume is significantly different than dry volume. Therefore the accumulated cake would end up being insufficient in thickness. The needed amount of precoat material can be simply calculated by multiplying the filter area by the desired thickness and furthermore multiplying the amount by two. As it was noted in the literature sources when cellulose is used the needed kilograms are roughly half of that of perlite or DE, still providing the same cake thickness.

The designed filter aid auxiliary system is simple and efficient to serve even multiple filter installations economically. It should be noted that the precoat feed pump should not be under dimensioned if the target is to optimize the precoating time. The most important piece of equipment when optimizing operating costs is the mixing tank agitator. That is due to the fact that the agitator has to be working all the time to provide homogenous filter aid solution continuously without interruptions. As it was discovered in the laboratory tests the filter aid materials are very easily mixed with very low rpm’s and therefore low energy. A reduced motor size could decrease the operating costs and therefore the mixer agitator and its power demand should be further discussed with equipment suppliers.

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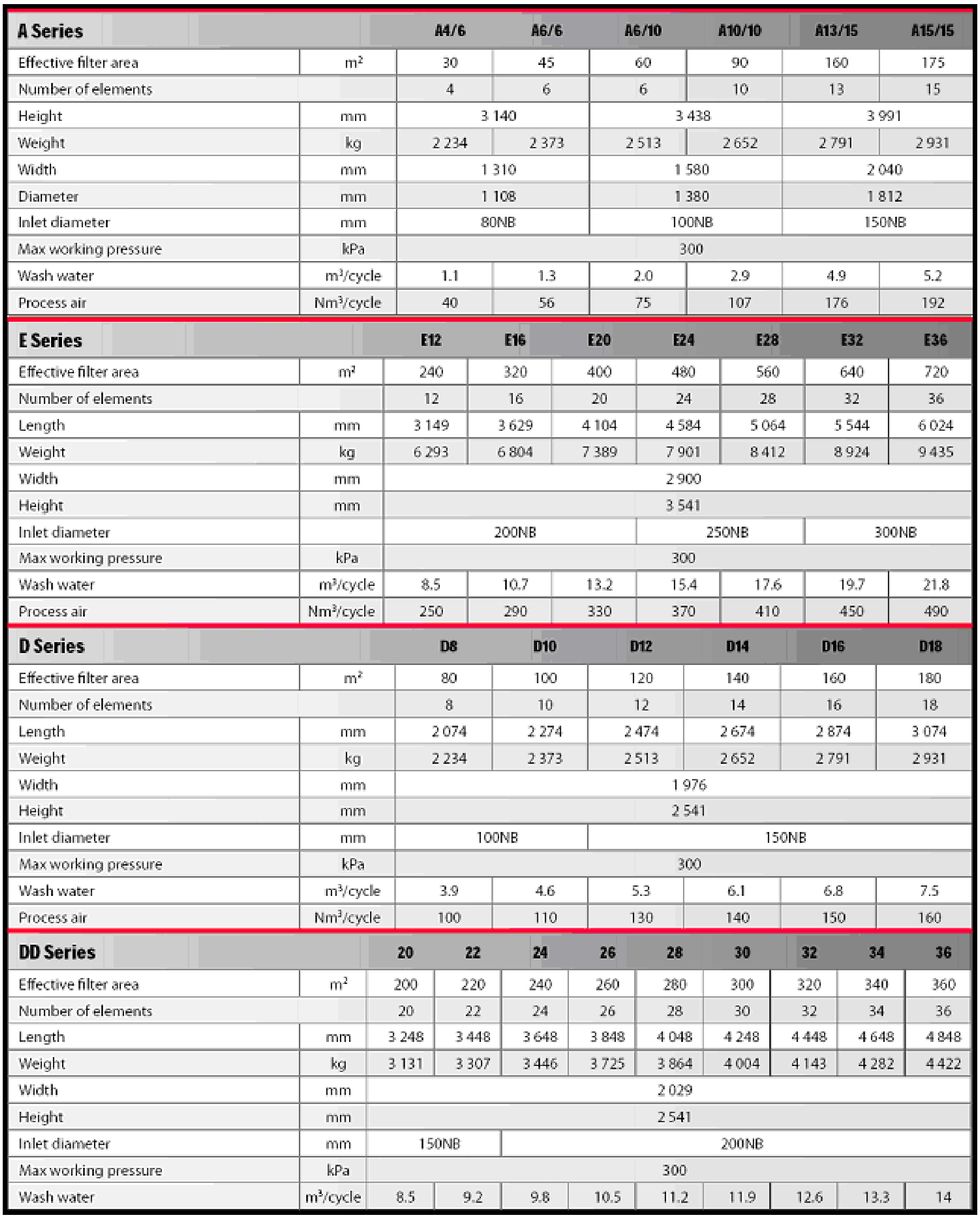
Scheibler filter family

APPENDIX I



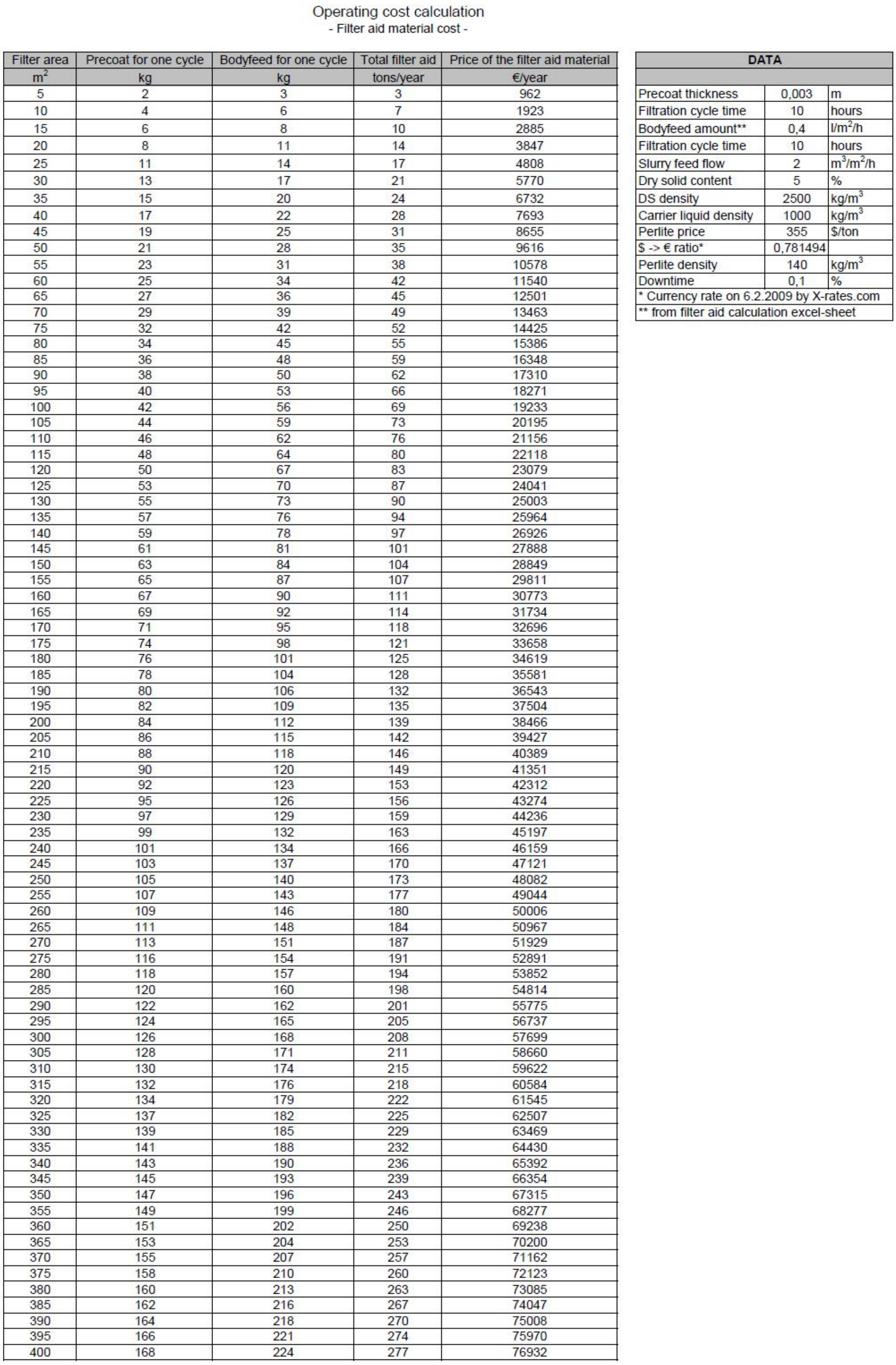
A Series		**A4/6**	**A6/6**	**A6/10**	**A10/10**	**A13/15**	**A15/15**
Effective filter area	m^2	30	45	60	90	160	175
Number of elements		4	6	6	10	13	15
Height	mm	3 140		3 438		3 991	
Weight	kg	2 234	2 373	2 513	2 652	2 791	2 931
Width	mm	1 310		1 580		2 040	
Diameter	mm	1 108		1 380		1 812	
Inlet diameter	mm	80NB		100NB		150NB	
Max working pressure	kPa	300					
Wash water	m^3/cycle	1.1	1.3	2.0	2.9	4.9	5.2
Process air	Nm^3/cycle	40	56	75	107	176	192

E Series		**E12**	**E16**	**E20**	**E24**	**E28**	**E32**	**E36**
Effective filter area	m^2	240	320	400	480	560	640	720
Number of elements		12	16	20	24	28	32	36
Length	mm	3 149	3 629	4 104	4 584	5 064	5 544	6 024
Weight	kg	6 293	6 804	7 389	7 901	8 412	8 924	9 435
Width	mm	2 900						
Height	mm	3 541						
Inlet diameter		200NB			250NB		300NB	
Max working pressure	kPa	300						
Wash water	m^3/cycle	8.5	10.7	13.2	15.4	17.6	19.7	21.8
Process air	Nm^3/cycle	250	290	330	370	410	450	490

D Series		**D8**	**D10**	**D12**	**D14**	**D16**	**D18**
Effective filter area	m^2	80	100	120	140	160	180
Number of elements		8	10	12	14	16	18
Length	mm	2 074	2 274	2 474	2 674	2 874	3 074
Weight	kg	2 234	2 373	2 513	2 652	2 791	2 931
Width	mm	1 976					
Height	mm	2 541					
Inlet diameter	mm	100NB		150NB			
Max working pressure	kPa	300					
Wash water	m^3/cycle	3.9	4.6	5.3	6.1	6.8	7.5
Process air	Nm^3/cycle	100	110	130	140	150	160

DD Series		**20**	**22**	**24**	**26**	**28**	**30**	**32**	**34**	**36**
Effective filter area	m^2	200	220	240	260	280	300	320	340	360
Number of elements		20	22	24	26	28	30	32	34	36
Length	mm	3 248	3 448	3 648	3 848	4 048	4 248	4 448	4 648	4 848
Weight	kg	3 131	3 307	3 446	3 725	3 864	4 004	4 143	4 282	4 422
Width	mm	2 029								
Height	mm	2 541								
Inlet diameter	mm	150NB		200NB						
Max working pressure	kPa	300								
Wash water	m^3/cycle	8.5	9.2	9.8	10.5	11.2	11.9	12.6	13.3	14

Operating cost tables APPENDIX II (1/3)

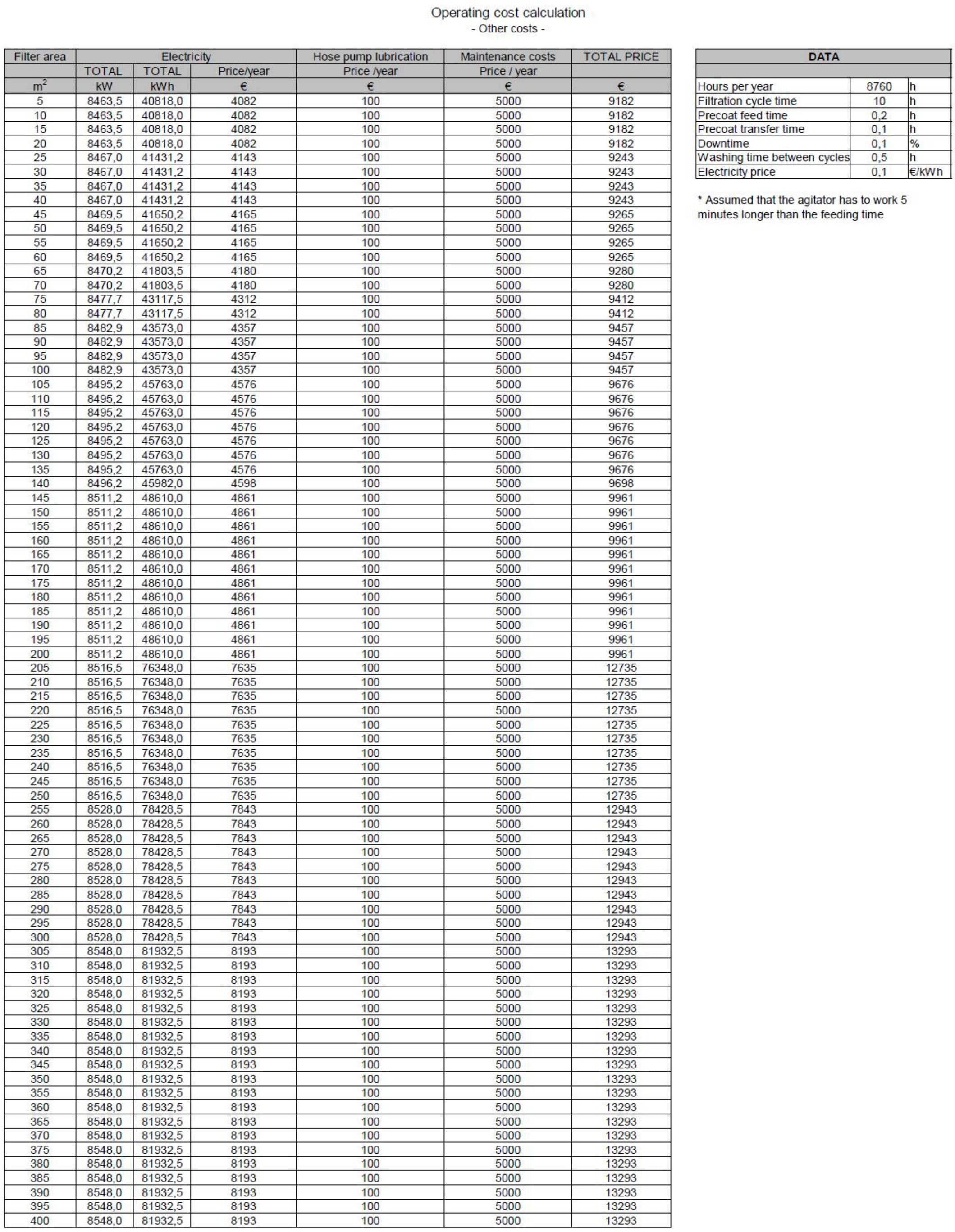


Operating cost calculation

- Filter aid material cost -

Filter area	Precoat for one cycle	Bodyfeed for one cycle	Total filter aid	Price of the filter aid material
m^2	kg	kg	tons/year	€/year
5	2	3	3	962
10	4	6	7	1923
15	6	8	10	2885
20	8	11	14	3847
25	11	14	17	4808
30	13	17	21	5770
35	15	20	24	6732
40	17	22	28	7693
45	19	25	31	8655
50	21	28	35	9616
55	23	31	38	10578
60	25	34	42	11540
65	27	36	45	12501
70	29	39	49	13463
75	32	42	52	14425
80	34	45	55	15386
85	36	48	59	16348
90	38	50	62	17310
95	40	53	66	18271
100	42	56	69	19233
105	44	59	73	20195
110	46	62	76	21156
115	48	64	80	22118
120	50	67	83	23079
125	53	70	87	24041
130	55	73	90	25003
135	57	76	94	25964
140	59	78	97	26926
145	61	81	101	27888
150	63	84	104	28849
155	65	87	107	29811
160	67	90	111	30773
165	69	92	114	31734
170	71	95	118	32696
175	74	98	121	33658
180	76	101	125	34619
185	78	104	128	35581
190	80	106	132	36543
195	82	109	135	37504
200	84	112	139	38466
205	86	115	142	39427
210	88	118	146	40389
215	90	120	149	41351
220	92	123	153	42312
225	95	126	156	43274
230	97	129	159	44236
235	99	132	163	45197
240	101	134	166	46159
245	103	137	170	47121
250	105	140	173	48082
255	107	143	177	49044
260	109	146	180	50006
265	111	148	184	50967
270	113	151	187	51929
275	116	154	191	52891
280	118	157	194	53852
285	120	160	198	54814
290	122	162	201	55775
295	124	165	205	56737
300	126	168	208	57699
305	128	171	211	58660
310	130	174	215	59622
315	132	176	218	60584
320	134	179	222	61545
325	137	182	225	62507
330	139	185	229	63469
335	141	188	232	64430
340	143	190	236	65392
345	145	193	239	66354
350	147	196	243	67315
355	149	199	246	68277
360	151	202	250	69238
365	153	204	253	70200
370	155	207	257	71162
375	158	210	260	72123
380	160	213	263	73085
385	162	216	267	74047
390	164	218	270	75008
395	166	221	274	75970
400	168	224	277	76932

DATA		
Precoat thickness	0,003	m
Filtration cycle time	10	hours
Bodyfeed amount**	0,4	$l/m^2/h$
Filtration cycle time	10	hours
Slurry feed flow	2	$m^3/m^2/h$
Dry solid content	5	%
DS density	2500	kg/m^3
Carrier liquid density	1000	kg/m^3
Perlite price	355	$/ton
$ -> € ratio*	0,781494	
Perlite density	140	kg/m^3
Downtime	0,1	%
* Currency rate on 6.2.2009 by X-rates.com		
** from filter aid calculation excel-sheet		



Operating cost calculation

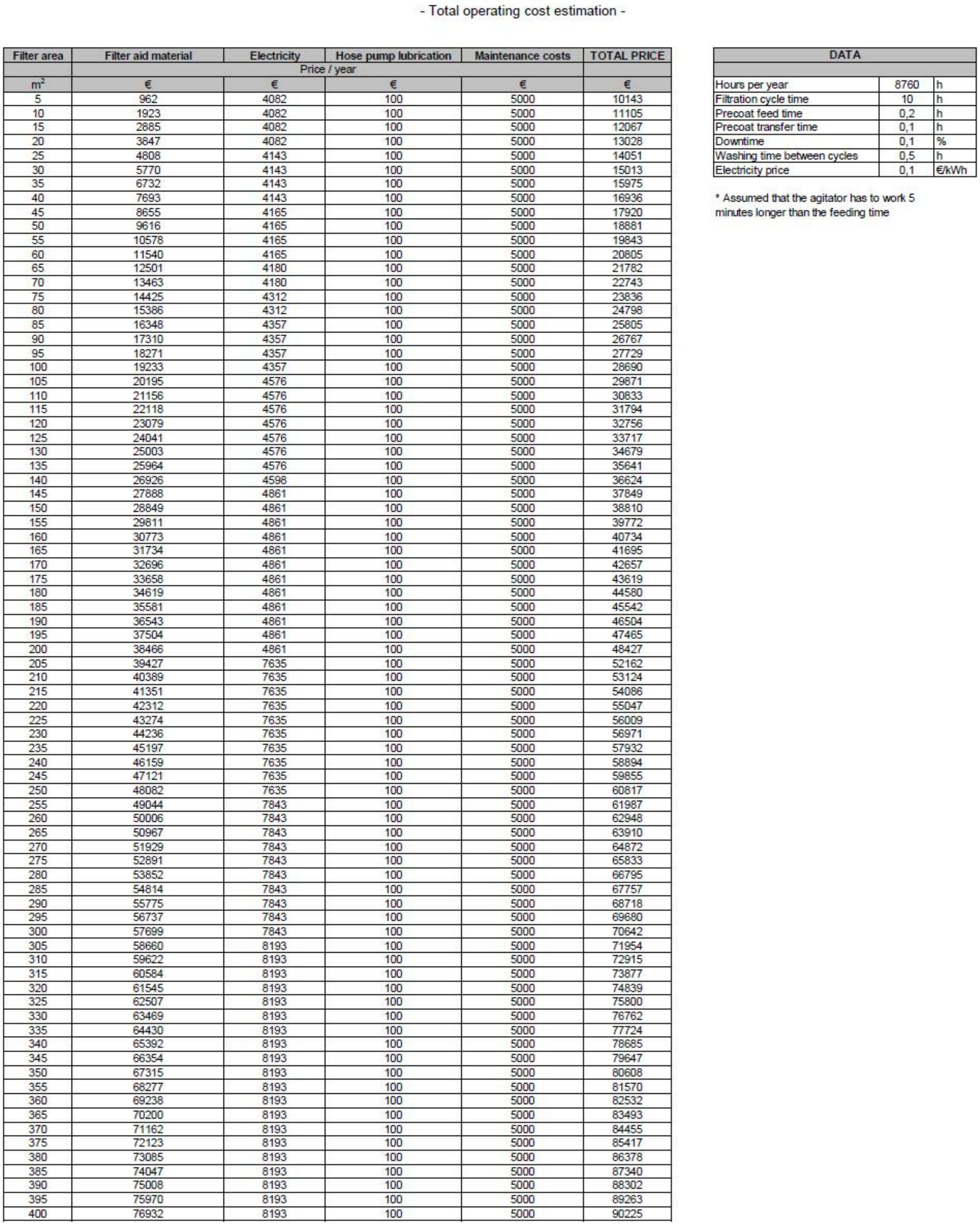
- Other costs -

Filter area	Electricity			Hose pump lubrication	Maintenance costs	TOTAL PRICE
	TOTAL	TOTAL	Price/year	Price /year	Price / year	
m^2	kW	kWh	€	€	€	€
5	8463,5	40818,0	4082	100	5000	9182
10	8463,5	40818,0	4082	100	5000	9182
15	8463,5	40818,0	4082	100	5000	9182
20	8463,5	40818,0	4082	100	5000	9182
25	8467,0	41431,2	4143	100	5000	9243
30	8467,0	41431,2	4143	100	5000	9243
35	8467,0	41431,2	4143	100	5000	9243
40	8467,0	41431,2	4143	100	5000	9243
45	8469,5	41650,2	4165	100	5000	9265
50	8469,5	41650,2	4165	100	5000	9265
55	8469,5	41650,2	4165	100	5000	9265
60	8469,5	41650,2	4165	100	5000	9265
65	8470,2	41803,5	4180	100	5000	9280
70	8470,2	41803,5	4180	100	5000	9280
75	8477,7	43117,5	4312	100	5000	9412
80	8477,7	43117,5	4312	100	5000	9412
85	8482,9	43573,0	4357	100	5000	9457
90	8482,9	43573,0	4357	100	5000	9457
95	8482,9	43573,0	4357	100	5000	9457
100	8482,9	43573,0	4357	100	5000	9457
105	8495,2	45763,0	4576	100	5000	9676
110	8495,2	45763,0	4576	100	5000	9676
115	8495,2	45763,0	4576	100	5000	9676
120	8495,2	45763,0	4576	100	5000	9676
125	8495,2	45763,0	4576	100	5000	9676
130	8495,2	45763,0	4576	100	5000	9676
135	8495,2	45763,0	4576	100	5000	9676
140	8496,2	45982,0	4598	100	5000	9698
145	8511,2	48610,0	4861	100	5000	9961
150	8511,2	48610,0	4861	100	5000	9961
155	8511,2	48610,0	4861	100	5000	9961
160	8511,2	48610,0	4861	100	5000	9961
165	8511,2	48610,0	4861	100	5000	9961
170	8511,2	48610,0	4861	100	5000	9961
175	8511,2	48610,0	4861	100	5000	9961
180	8511,2	48610,0	4861	100	5000	9961
185	8511,2	48610,0	4861	100	5000	9961
190	8511,2	48610,0	4861	100	5000	9961
195	8511,2	48610,0	4861	100	5000	9961
200	8511,2	48610,0	4861	100	5000	9961
205	8516,5	76348,0	7635	100	5000	12735
210	8516,5	76348,0	7635	100	5000	12735
215	8516,5	76348,0	7635	100	5000	12735
220	8516,5	76348,0	7635	100	5000	12735
225	8516,5	76348,0	7635	100	5000	12735
230	8516,5	76348,0	7635	100	5000	12735
235	8516,5	76348,0	7635	100	5000	12735
240	8516,5	76348,0	7635	100	5000	12735
245	8516,5	76348,0	7635	100	5000	12735
250	8516,5	76348,0	7635	100	5000	12735
255	8528,0	78428,5	7843	100	5000	12943
260	8528,0	78428,5	7843	100	5000	12943
265	8528,0	78428,5	7843	100	5000	12943
270	8528,0	78428,5	7843	100	5000	12943
275	8528,0	78428,5	7843	100	5000	12943
280	8528,0	78428,5	7843	100	5000	12943
285	8528,0	78428,5	7843	100	5000	12943
290	8528,0	78428,5	7843	100	5000	12943
295	8528,0	78428,5	7843	100	5000	12943
300	8528,0	78428,5	7843	100	5000	12943
305	8548,0	81932,5	8193	100	5000	13293
310	8548,0	81932,5	8193	100	5000	13293
315	8548,0	81932,5	8193	100	5000	13293
320	8548,0	81932,5	8193	100	5000	13293
325	8548,0	81932,5	8193	100	5000	13293
330	8548,0	81932,5	8193	100	5000	13293
335	8548,0	81932,5	8193	100	5000	13293
340	8548,0	81932,5	8193	100	5000	13293
345	8548,0	81932,5	8193	100	5000	13293
350	8548,0	81932,5	8193	100	5000	13293
355	8548,0	81932,5	8193	100	5000	13293
360	8548,0	81932,5	8193	100	5000	13293
365	8548,0	81932,5	8193	100	5000	13293
370	8548,0	81932,5	8193	100	5000	13293
375	8548,0	81932,5	8193	100	5000	13293
380	8548,0	81932,5	8193	100	5000	13293
385	8548,0	81932,5	8193	100	5000	13293
390	8548,0	81932,5	8193	100	5000	13293
395	8548,0	81932,5	8193	100	5000	13293
400	8548,0	81932,5	8193	100	5000	13293

DATA		
Hours per year	8760	h
Filtration cycle time	10	h
Precoat feed time	0,2	h
Precoat transfer time	0,1	h
Downtime	0,1	%
Washing time between cycles	0,5	h
Electricity price	0,1	€/kWh

* Assumed that the agitator has to work 5 minutes longer than the feeding time

Operating cost tables APPENDIX II (3/3)



- Total operating cost estimation -

Filter area	Filter aid material	Electricity	Hose pump lubrication	Maintenance costs	TOTAL PRICE
	Price / year				
m^2	€	€	€	€	€
5	962	4082	100	5000	10143
10	1923	4082	100	5000	11105
15	2885	4082	100	5000	12067
20	3847	4082	100	5000	13028
25	4808	4143	100	5000	14051
30	5770	4143	100	5000	15013
35	6732	4143	100	5000	15975
40	7693	4143	100	5000	16936
45	8655	4165	100	5000	17920
50	9616	4165	100	5000	18881
55	10578	4165	100	5000	19843
60	11540	4165	100	5000	20805
65	12501	4180	100	5000	21782
70	13463	4180	100	5000	22743
75	14425	4312	100	5000	23836
80	15386	4312	100	5000	24798
85	16348	4357	100	5000	25805
90	17310	4357	100	5000	26767
95	18271	4357	100	5000	27729
100	19233	4357	100	5000	28690
105	20195	4576	100	5000	29871
110	21156	4576	100	5000	30833
115	22118	4576	100	5000	31794
120	23079	4576	100	5000	32756
125	24041	4576	100	5000	33717
130	25003	4576	100	5000	34679
135	25964	4576	100	5000	35641
140	26926	4598	100	5000	36624
145	27888	4861	100	5000	37849
150	28849	4861	100	5000	38810
155	29811	4861	100	5000	39772
160	30773	4861	100	5000	40734
165	31734	4861	100	5000	41695
170	32696	4861	100	5000	42657
175	33658	4861	100	5000	43619
180	34619	4861	100	5000	44580
185	35581	4861	100	5000	45542
190	36543	4861	100	5000	46504
195	37504	4861	100	5000	47465
200	38466	4861	100	5000	48427
205	39427	7635	100	5000	52162
210	40389	7635	100	5000	53124
215	41351	7635	100	5000	54086
220	42312	7635	100	5000	55047
225	43274	7635	100	5000	56009
230	44236	7635	100	5000	56971
235	45197	7635	100	5000	57932
240	46159	7635	100	5000	58894
245	47121	7635	100	5000	59855
250	48082	7635	100	5000	60817
255	49044	7843	100	5000	61987
260	50006	7843	100	5000	62948
265	50967	7843	100	5000	63910
270	51929	7843	100	5000	64872
275	52891	7843	100	5000	65833
280	53852	7843	100	5000	66795
285	54814	7843	100	5000	67757
290	55775	7843	100	5000	68718
295	56737	7843	100	5000	69680
300	57699	7843	100	5000	70642
305	58660	8193	100	5000	71954
310	59622	8193	100	5000	72915
315	60584	8193	100	5000	73877
320	61545	8193	100	5000	74839
325	62507	8193	100	5000	75800
330	63469	8193	100	5000	76762
335	64430	8193	100	5000	77724
340	65392	8193	100	5000	78685
345	66354	8193	100	5000	79647
350	67315	8193	100	5000	80608
355	68277	8193	100	5000	81570
360	69238	8193	100	5000	82532
365	70200	8193	100	5000	83493
370	71162	8193	100	5000	84455
375	72123	8193	100	5000	85417
380	73085	8193	100	5000	86378
385	74047	8193	100	5000	87340
390	75008	8193	100	5000	88302
395	75970	8193	100	5000	89263
400	76932	8193	100	5000	90225

DATA		
Hours per year	8760	h
Filtration cycle time	10	h
Precoat feed time	0,2	h
Precoat transfer time	0,1	h
Downtime	0,1	%
Washing time between cycles	0,5	h
Electricity price	0,1	€/kWh

* Assumed that the agitator has to work 5 minutes longer than the feeding time

Mass balance tables, A & C -series

Precoat

A-series	Singlex													
Model	Filtration area	Volume	DS (kg)	DS (m^3)	Water (kg)	Water (m^3)	Water + DS (m^3)	Mixer KAP	Min. Mixer Volume	Needed precoat (V)	Extra water (m^3)	KAP (precoat tank)	Pipeline (DN)	Flow (m/s)
A4/6	7,5	1,9	6	0,05	63,0	0,06	0,11	10,00	1,61	3,6	3,5	0,2	50	2,12
A6/6	11,25	1,9	9	0,07	94,5	0,09	0,16	10,00	1,66	3,6	3,5	0,3	65	2,83
A6/10	15	3,07	13	0,09	126,0	0,13	0,22	10,00	1,72	5,1	4,9	0,3	65	2,51
As10/10	18,75	3,07	16	0,11	157,5	0,16	0,27	10,00	1,77	5,1	4,8	0,3	65	3,14
A10/10	22,5	3,07	19	0,14	189,0	0,19	0,32	10,00	1,82	5,1	4,8	0,4	80	2,49
As13/15	32,5	6,17	27	0,20	273,0	0,27	0,47	10,00	1,97	9,0	8,5	0,3	100	2,30
As15/15	36,25	6,17	30	0,22	304,5	0,30	0,52	10,00	2,02	9,0	8,4	0,3	100	2,56
A13/15	40	6,17	34	0,24	336,0	0,34	0,58	10,00	2,08	9,0	8,4	0,4	100	2,83
A15/15	43,75	6,17	37	0,26	367,5	0,37	0,63	10,00	2,13	9,0	8,3	0,4	100	3,09

	Duplex													
Model	Filtration area	Volume												
A4/6	15	1,9	13	0,09	126,0	0,13	0,22	10,00	1,72	3,6	3,4	0,4	65	2,51
A6/6	22,5	1,9	19	0,14	189,0	0,19	0,32	10,00	1,82	3,6	3,3	0,5	100	2,39
A6/10	30	3,07	25	0,18	252,0	0,25	0,43	10,00	1,93	5,1	4,7	0,5	100	2,12
As10/10	37,5	3,07	32	0,23	315,0	0,32	0,54	10,00	2,04	5,1	4,5	0,6	100	2,65
A10/10	45	3,07	38	0,27	378,0	0,38	0,65	10,00	2,15	5,1	4,4	0,8	100	3,18
As13/15	65	6,17	55	0,39	546,0	0,55	0,94	10,00	2,44	9,0	8,0	0,6	150	2,04
As15/15	72,5	6,17	61	0,44	609,0	0,61	1,04	10,00	2,54	9,0	7,9	0,7	150	2,28
A13/15	80	6,17	67	0,48	672,0	0,67	1,15	10,00	2,65	9,0	7,8	0,8	150	2,52
A15/15	87,5	6,17	74	0,53	735,0	0,74	1,26	10,00	2,76	9,0	7,7	0,9	150	2,75

C-series	Singlex													
Model	Filtration area	Volume	DS (kg)	DS (m^3)	Water (kg)	Water (m^3)	Water + DS (m^3)	Mixer KAP	Min. Mixer Volume	Needed precoat (V)	Extra water (m^3)	KAP (precoat tank)	Pipeline (DN)	Flow (m/s)
C6	7,5	0,89	6	0,05	63,0	0,06	0,11	10,00	1,61	2,4	2,3	0,3	50	2,12
C8	10	1	8	0,06	84,0	0,08	0,14	10,00	1,64	2,5	2,4	0,3	50	2,83
C10	12,5	1,24	11	0,08	105,0	0,11	0,18	10,00	1,68	2,8	2,6	0,4	65	2,09
C12	15	1,56	13	0,09	126,0	0,13	0,22	10,00	1,72	3,2	3,0	0,4	65	2,51
C14	17,5	1,8	15	0,11	147,0	0,15	0,25	10,00	1,75	3,5	3,2	0,4	65	2,93
C16	20	2,03	17	0,12	168,0	0,17	0,29	10,00	1,79	3,8	3,5	0,5	65	3,35
C18	22,5	2,26	19	0,14	189,0	0,19	0,32	10,00	1,82	4,1	3,8	0,5	80	2,49
C20	25	2,49	21	0,15	210,0	0,21	0,36	10,00	1,86	4,4	4,0	0,5	80	2,76
C22	27,5	2,82	23	0,17	231,0	0,23	0,40	10,00	1,90	4,8	4,4	0,5	80	3,04
C24	30	3,05	25	0,18	252,0	0,25	0,43	10,00	1,93	5,1	4,6	0,5	80	3,32

	Duplex													
Model	Filtration area	Volume												
C6	15	0,89	13	0,09	126,0	0,13	0,22	10,00	1,72	2,4	2,1	0,6	65	2,51
C8	20	1	17	0,12	168,0	0,17	0,29	10,00	1,79	2,5	2,2	0,7	65	3,35
C10	25	1,24	21	0,15	210,0	0,21	0,36	10,00	1,86	2,8	2,4	0,8	80	2,76
C12	30	1,56	25	0,18	252,0	0,25	0,43	10,00	1,93	3,2	2,8	0,8	80	3,32
C14	35	1,8	29	0,21	294,0	0,29	0,50	10,00	2,00	3,5	3,0	0,9	100	2,48
C16	40	2,03	34	0,24	336,0	0,34	0,58	10,00	2,08	3,8	3,2	0,9	100	2,83
C18	45	2,26	38	0,27	378,0	0,38	0,65	10,00	2,15	4,1	3,4	1,0	100	3,18
C20	50	2,49	42	0,30	420,0	0,42	0,72	10,00	2,22	4,4	3,6	1,0	125	2,26
C22	55	2,82	46	0,33	462,0	0,46	0,79	10,00	2,29	4,8	4,0	1,0	125	2,49
C24	60	3,05	50	0,36	504,0	0,50	0,86	10,00	2,36	5,1	4,2	1,1	125	2,72

			Precoat tank volume							Bodyfeed		
A-series	Singlex		Precoat tank volume					Feed solution, cake accumulation		Bodyfeed		
Model	Filtration area	Volume	<5 m^3	<10m^3	<20m^3	<30m^3	>30m^3	Flow to the filter (m^3/h)	DS ($l/m^2/h$)	Needed amount of Bodyfeed V (KAP 10), $l/m^2/h$	Bodyfeed l/h	Filter aid DS ($l/m^2/h$)
A4/6	7,5	1,9	1					15	0,39	0,94	7,06	0,39
A6/6	11,25	1,9	1					22,5	0,39	0,94	10,59	0,39
A6/10	15	3,07		1				30	0,39	0,94	14,12	0,39
As10/10	18,75	3,07		1				37,5	0,39	0,94	17,65	0,39
A10/10	22,5	3,07		1				45	0,39	0,94	21,18	0,39
As13/15	32,5	6,17		1				65	0,39	0,94	30,59	0,39
As15/15	36,25	6,17		1				72,5	0,39	0,94	34,12	0,39
A13/15	40	6,17		1				80	0,39	0,94	37,65	0,39
A15/15	43,75	6,17		1				87,5	0,39	0,94	41,18	0,39
	Duplex											
Model	Filtration area	Volume										
A4/6	15	1,9	1					30	0,39	0,94	14,12	0,39
A6/6	22,5	1,9	1					45	0,39	0,94	21,18	0,39
A6/10	30	3,07		1				60	0,39	0,94	28,24	0,39
As10/10	37,5	3,07		1				75	0,39	0,94	35,29	0,39
A10/10	45	3,07		1				90	0,39	0,94	42,35	0,39
As13/15	65	6,17		1				130	0,39	0,94	61,18	0,39
As15/15	72,5	6,17		1				145	0,39	0,94	68,24	0,39
A13/15	80	6,17		1				160	0,39	0,94	75,29	0,39
A15/15	87,5	6,17		1				175	0,39	0,94	82,35	0,39
C-series	Singlex		Precoat tank volume					Feed solution, cake accumulation		Bodyfeed		
Model	Filtration area	Volume	<5 m^3	<10m^3	<20m^3	<30m^3	>30m^3	Flow to the filter (m^3/h)	DS ($l/m^2/h$)	Needed amount of Bodyfeed V (KAP 10), $l/m^2/h$	Bodyfeed l/h	Filter aid DS ($l/m^2/h$)
C6	7,5	0,89	1					15	0,39	0,94	7,06	0,39
C8	10	1	1					20	0,39	0,94	9,41	0,39
C10	12,5	1,24	1					25	0,39	0,94	11,76	0,39
C12	15	1,56	1					30	0,39	0,94	14,12	0,39
C14	17,5	1,8	1					35	0,39	0,94	16,47	0,39
C16	20	2,03	1					40	0,39	0,94	18,82	0,39
C18	22,5	2,26	1					45	0,39	0,94	21,18	0,39
C20	25	2,49	1					50	0,39	0,94	23,53	0,39
C22	27,5	2,82	1					55	0,39	0,94	25,88	0,39
C24	30	3,05		1				60	0,39	0,94	28,24	0,39
	Duplex											
Model	Filtration area	Volume										
C6	15	0,89	1					30	0,39	0,94	14,12	0,39
C8	20	1	1					40	0,39	0,94	18,82	0,39
C10	25	1,24	1					50	0,39	0,94	23,53	0,39
C12	30	1,56	1					60	0,39	0,94	28,24	0,39
C14	35	1,8	1					70	0,39	0,94	32,94	0,39
C16	40	2,03	1					80	0,39	0,94	37,65	0,39
C18	45	2,26	1					90	0,39	0,94	42,35	0,39
C20	50	2,49	1					100	0,39	0,94	47,06	0,39
C22	55	2,82	1					110	0,39	0,94	51,76	0,39
C24	60	3,05		1				120	0,39	0,94	56,47	0,39

Precoat

D-series	Single-flange, Duplex														
Model	Filtration area	Volume	DS (kg)	DS (m^3)	Water (kg)	Water (m^3)	Water + DS (m^3)	Mixer KAP	KAP 10 -> precoat tank. Tot V	Min. Mixer Volume	Needed precoat (V)	Extra water (m^3)	KAP (precoat tank)	Pipeline (DN)	Flow (m/s)
D8	40	4,45	34	0,24	336,0	0,34	0,58	10,00	0,58	2,08	6,8	6,2	0,5	100	2,83
D10	50	4,96	42	0,30	420,0	0,42	0,72	10,00	0,72	2,22	7,5	6,7	0,6	125	2,26
D12	60	5,47	50	0,36	504,0	0,50	0,86	10,00	0,86	2,36	8,1	7,2	0,7	125	2,72
D14	70	5,98	59	0,42	588,0	0,59	1,01	10,00	1,01	2,51	8,7	7,7	0,7	125	3,17
D16	80	6,49	67	0,48	672,0	0,67	1,15	10,00	1,15	2,65	9,4	8,2	0,8	150	2,52
D18	90	7	76	0,54	756,0	0,76	1,30	10,00	1,30	2,80	10,0	8,7	0,8	150	2,83
	Single-flange, Singlex														
Model	Filtration area	Volume													
D8	29	4,45	24	0,17	243,6	0,24	0,42	10,00	0,42	1,92	6,8	6,4	0,4	80	3,21
D10	36	4,96	30	0,22	302,4	0,30	0,52	10,00	0,52	2,02	7,5	6,9	0,4	100	2,55
D12	43	5,47	36	0,26	361,2	0,36	0,62	10,00	0,62	2,12	8,1	7,5	0,5	100	3,04
D14	50	5,98	42	0,30	420,0	0,42	0,72	10,00	0,72	2,22	8,7	8,0	0,5	125	2,26
D16	58	6,49	49	0,35	487,2	0,49	0,84	10,00	0,84	2,34	9,4	8,5	0,5	125	2,63
D18	65	7	55	0,39	546,0	0,55	0,94	10,00	0,94	2,44	10,0	9,1	0,6	125	2,94
	Double-flange, Duplex														
Model	Filtration area	Volume													
D8	40	4,54	34	0,24	336,0	0,34	0,58	10,00	0,58	2,08	6,9	6,3	0,5	100	2,83
D10	50	5,05	42	0,30	420,0	0,42	0,72	10,00	0,72	2,22	7,6	6,8	0,6	125	2,26
D12	60	5,56	50	0,36	504,0	0,50	0,86	10,00	0,86	2,36	8,2	7,3	0,6	125	2,72
D14	70	6,07	59	0,42	588,0	0,59	1,01	10,00	1,01	2,51	8,8	7,8	0,7	125	3,17
D16	80	6,58	67	0,48	672,0	0,67	1,15	10,00	1,15	2,65	9,5	8,3	0,7	150	2,52
D18	90	7,09	76	0,54	756,0	0,76	1,30	10,00	1,30	2,80	10,1	8,8	0,8	150	2,83
D20	100	7,63	84	0,60	840,0	0,84	1,44	10,00	1,44	2,94	10,8	9,3	0,8	150	3,14
D22	110	8,13	92	0,66	924,0	0,92	1,58	10,00	1,58	3,08	11,4	9,8	0,9	150	3,46
D24	120	8,64	101	0,72	1008,0	1,01	1,73	10,00	1,73	3,23	12,1	10,3	0,9	200	2,12
D26	130	9,15	109	0,78	1092,0	1,09	1,87	10,00	1,87	3,37	12,7	10,8	0,9	200	2,30
D28	140	9,66	118	0,84	1176,0	1,18	2,02	10,00	2,02	3,52	13,3	11,3	0,9	200	2,48
D30	150	10,17	126	0,90	1260,0	1,26	2,16	10,00	2,16	3,66	14,0	11,8	1,0	200	2,65
D32	160	10,68	134	0,96	1344,0	1,34	2,30	10,00	2,30	3,80	14,6	12,3	1,0	200	2,83
D34	170	11,19	143	1,02	1428,0	1,43	2,45	10,00	2,45	3,95	15,2	12,8	1,0	200	3,01
D36	180	11,7	151	1,08	1512,0	1,51	2,59	10,00	2,59	4,09	15,9	13,3	1,0	200	3,18
	Double-flange, Singlex														
Model	Filtration area	Volume													
D8	29	4,54	24	0,17	243,6	0,24	0,42	10,00	0,42	1,92	6,9	6,5	0,4	80	3,21
D10	36	5,05	30	0,22	302,4	0,30	0,52	10,00	0,52	2,02	7,6	7,0	0,4	100	2,55
D12	43	5,56	36	0,26	361,2	0,36	0,62	10,00	0,62	2,12	8,2	7,6	0,5	100	3,04
D14	50	6,07	42	0,30	420,0	0,42	0,72	10,00	0,72	2,22	8,8	8,1	0,5	125	2,26
D16	58	6,58	49	0,35	487,2	0,49	0,84	10,00	0,84	2,34	9,5	8,6	0,5	125	2,63
D18	65	7,09	55	0,39	546,0	0,55	0,94	10,00	0,94	2,44	10,1	9,2	0,6	125	2,94
D20	72	7,63	60	0,43	604,8	0,60	1,04	10,00	1,04	2,54	10,8	9,8	0,6	125	3,26
D22	79	8,13	66	0,47	663,6	0,66	1,14	10,00	1,14	2,64	11,4	10,3	0,6	150	2,48
D24	86	8,64	72	0,52	722,4	0,72	1,24	10,00	1,24	2,74	12,1	10,8	0,6	150	2,70
D26	94	9,15	79	0,56	789,6	0,79	1,35	10,00	1,35	2,85	12,7	11,3	0,7	150	2,96
D28	101	9,66	85	0,61	848,4	0,85	1,45	10,00	1,45	2,95	13,3	11,9	0,7	150	3,18
D30	108	10,17	91	0,65	907,2	0,91	1,56	10,00	1,56	3,06	14,0	12,4	0,7	150	3,40
D32	115	10,68	97	0,69	966,0	0,97	1,66	10,00	1,66	3,16	14,6	12,9	0,7	200	2,03
D34	122	11,19	102	0,73	1024,8	1,02	1,76	10,00	1,76	3,26	15,2	13,5	0,7	200	2,16
D36	130	11,7	109	0,78	1092,0	1,09	1,87	10,00	1,87	3,37	15,9	14,0	0,7	200	2,30

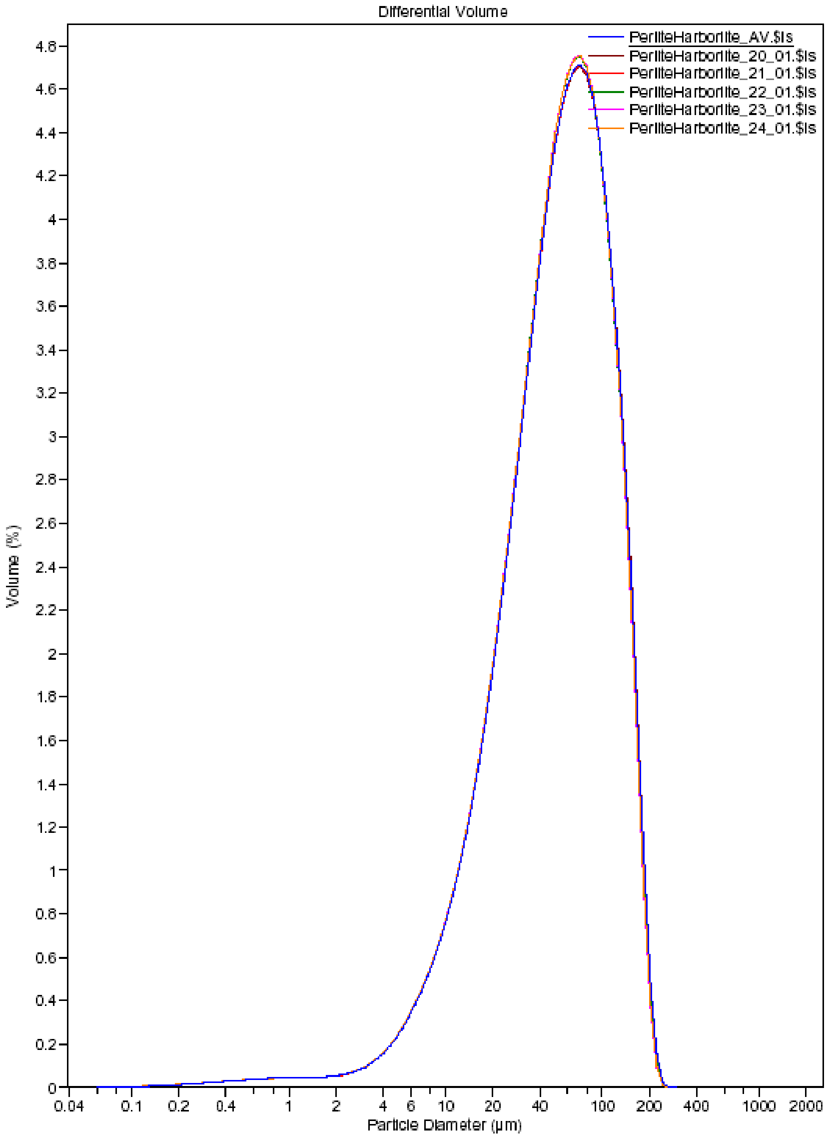
			Precoat tank volume					Bodyfeed				
D-series	Single-flange, Duplex		Precoat tank volume					Feed solution, cake accumulation		Bodyfeed		
Model	Filtration area	Volume	<5 m^3	<10m^3	<20m^3	<30m^3	>30m^3	Flow to the filter (m^3/h)	DS ($l/m^2/h$)	Needed amount of Bodyfeed V (KAP 10), $l/m^2/h$	Bodyfeed l/h	Filter aid DS ($l/m^2/h$)
D8	40	4,45		1				80	0,39	0,94	37,65	0,39
D10	50	4,96		1				100	0,39	0,94	47,06	0,39
D12	60	5,47		1				120	0,39	0,94	56,47	0,39
D14	70	5,98		1				140	0,39	0,94	65,88	0,39
D16	80	6,49		1				160	0,39	0,94	75,29	0,39
D18	90	7			1			180	0,39	0,94	84,71	0,39
	Single-flange, Singlex											
Model	Filtration area	Volume										
D8	29	4,45		1				58	0,39	0,94	27,29	0,39
D10	36	4,96		1				72	0,39	0,94	33,88	0,39
D12	43	5,47		1				86	0,39	0,94	40,47	0,39
D14	50	5,98		1				100	0,39	0,94	47,06	0,39
D16	58	6,49		1				116	0,39	0,94	54,59	0,39
D18	65	7			1			130	0,39	0,94	61,18	0,39
	Double-flange, Duplex											
Model	Filtration area	Volume										
D8	40	4,54		1				80	0,39	0,94	37,65	0,39
D10	50	5,05		1				100	0,39	0,94	47,06	0,39
D12	60	5,56		1				120	0,39	0,94	56,47	0,39
D14	70	6,07		1				140	0,39	0,94	65,88	0,39
D16	80	6,58		1				160	0,39	0,94	75,29	0,39
D18	90	7,09			1			180	0,39	0,94	84,71	0,39
D20	100	7,63			1			200	0,39	0,94	94,12	0,39
D22	110	8,13			1			220	0,39	0,94	103,53	0,39
D24	120	8,64			1			240	0,39	0,94	112,94	0,39
D26	130	9,15			1			260	0,39	0,94	122,35	0,39
D28	140	9,66			1			280	0,39	0,94	131,76	0,39
D30	150	10,17			1			300	0,39	0,94	141,18	0,39
D32	160	10,68			1			320	0,39	0,94	150,59	0,39
D34	170	11,19			1			340	0,39	0,94	160,00	0,39
D36	180	11,7			1			360	0,39	0,94	169,41	0,39
	Double-flange, Singlex											
Model	Filtration area	Volume										
D8	29	4,54		1				58	0,39	0,94	27,29	0,39
D10	36	5,05		1				72	0,39	0,94	33,88	0,39
D12	43	5,56		1				86	0,39	0,94	40,47	0,39
D14	50	6,07		1				100	0,39	0,94	47,06	0,39
D16	58	6,58		1				116	0,39	0,94	54,59	0,39
D18	65	7,09			1			130	0,39	0,94	61,18	0,39
D20	72	7,63			1			144	0,39	0,94	67,76	0,39
D22	79	8,13			1			158	0,39	0,94	74,35	0,39
D24	86	8,64			1			172	0,39	0,94	80,94	0,39
D26	94	9,15			1			188	0,39	0,94	88,47	0,39
D28	101	9,66			1			202	0,39	0,94	95,06	0,39
D30	108	10,17			1			216	0,39	0,94	101,65	0,39
D32	115	10,68			1			230	0,39	0,94	108,24	0,39
D34	122	11,19			1			244	0,39	0,94	114,82	0,39
D36	130	11,7			1			260	0,39	0,94	122,35	0,39

Precoat

E-series	Duplex															
Model	Filtration area	Volume	DS (kg)	DS (m^3)	Water (kg)	Water (m^3)	Water + DS (m^3)	Mixer KAP	KAP 10 -> precoat tank. Tot V	Min. Mixer Volume	Needed precoat (V)	Extra water (m^3)	KAP (precoat tank)	Pipeline (DN)	Flow (m/s)
E10	100	13,49	84	0,60	840,0	0,84	1,44	10,00	1,44	2,94	18,1	16,7	0,5	150	3,14
E12	120	14,76	101	0,72	1008,0	1,01	1,73	10,00	1,73	3,23	19,7	18,0	0,5	200	2,12
E14	140	16,04	118	0,84	1176,0	1,18	2,02	10,00	2,02	3,52	21,3	19,3	0,6	200	2,48
E16	160	17,31	134	0,96	1344,0	1,34	2,30	10,00	2,30	3,80	22,9	20,6	0,6	200	2,83
E18	180	18,58	151	1,08	1512,0	1,51	2,59	10,00	2,59	4,09	24,5	21,9	0,6	200	3,18
E20	200	19,83	168	1,20	1680,0	1,68	2,88	10,00	2,88	4,38	26,0	23,2	0,7	250	2,26
E22	220	21,10	185	1,32	1848,0	1,85	3,17	10,00	3,17	4,67	27,6	24,5	0,7	250	2,49
E24	240	22,38	202	1,44	2016,0	2,02	3,46	10,00	3,46	4,96	29,2	25,8	0,7	250	2,72
E26	260	23,65	218	1,56	2184,0	2,18	3,74	10,00	3,74	5,24	30,8	27,1	0,7	250	2,94
E28	280	24,93	235	1,68	2352,0	2,35	4,03	10,00	4,03	5,53	32,4	28,4	0,8	250	3,17
E30	300	26,20	252	1,80	2520,0	2,52	4,32	10,00	4,32	5,82	34,0	29,7	0,8	250	3,40
E32	320	27,48	269	1,92	2688,0	2,69	4,61	10,00	4,61	6,11	35,6	31,0	0,8	300	2,52
E34	340	28,75	286	2,04	2856,0	2,86	4,90	10,00	4,90	6,40	37,2	32,3	0,8	300	2,67
E36	360	30,03	302	2,16	3024,0	3,02	5,18	10,00	5,18	6,68	38,8	33,6	0,8	300	2,83
	Singlex														
Model	Filtration area	Volume													
E10	72,5	13,49	61	0,44	609,0	0,61	1,04	10,00	1,04	2,54	18,1	17,1	0,3	125	3,28
E12	87	14,76	73	0,52	730,8	0,73	1,25	10,00	1,25	2,75	19,7	18,4	0,4	150	2,74
E14	101,5	16,04	85	0,61	852,6	0,85	1,46	10,00	1,46	2,96	21,3	19,8	0,4	150	3,19
E16	116	17,31	97	0,70	974,4	0,97	1,67	10,00	1,67	3,17	22,9	21,2	0,4	200	2,05
E18	130,5	18,58	110	0,78	1096,2	1,10	1,88	10,00	1,88	3,38	24,5	22,6	0,5	200	2,31
E20	145	19,83	122	0,87	1218,0	1,22	2,09	10,00	2,09	3,59	26,0	23,9	0,5	200	2,56
E22	159,5	21,10	134	0,96	1339,8	1,34	2,30	10,00	2,30	3,80	27,6	25,3	0,5	200	2,82
E24	174	22,38	146	1,04	1461,6	1,46	2,51	10,00	2,51	4,01	29,2	26,7	0,5	200	3,08
E26	188,5	23,65	158	1,13	1583,4	1,58	2,71	10,00	2,71	4,21	30,8	28,1	0,5	200	3,33
E28	203	24,93	171	1,22	1705,2	1,71	2,92	10,00	2,92	4,42	32,4	29,5	0,5	250	2,30
E30	217,5	26,20	183	1,31	1827,0	1,83	3,13	10,00	3,13	4,63	34,0	30,9	0,6	250	2,46
E32	232	27,48	195	1,39	1948,8	1,95	3,34	10,00	3,34	4,84	35,6	32,3	0,6	250	2,63
E34	246,5	28,75	207	1,48	2070,6	2,07	3,55	10,00	3,55	5,05	37,2	33,6	0,6	250	2,79
E36	261	30,03	219	1,57	2192,4	2,19	3,76	10,00	3,76	5,26	38,8	35,0	0,6	250	2,95

			Precoat tank volume							Bodyfeed		
E-series	Duplex		Precoat tank volume					Feed solution, cake accumulation		Bodyfeed		
Model	Filtration area	Volume	<5 m^3	<10m^3	<20m^3	<30m^3	>30m^3	Flow to the filter (m^3/h)	DS (l/m^2/h)	Needed amount of Bodyfeed V (KAP 10), l/m^2/h	Bodyfeed l/h	Filter aid DS (l/m^2/h)
E10	100	13,49			1			200	0,39	0,94	94,12	0,39
E12	120	14,76			1			240	0,39	0,94	112,94	0,39
E14	140	16,04				1		280	0,39	0,94	131,76	0,39
E16	160	17,31				1		320	0,39	0,94	150,59	0,39
E18	180	18,58				1		360	0,39	0,94	169,41	0,39
E20	200	19,83				1		400	0,39	0,94	188,24	0,39
E22	220	21,10				1		440	0,39	0,94	207,06	0,39
E24	240	22,38				1		480	0,39	0,94	225,88	0,39
E26	260	23,65					1	520	0,39	0,94	244,71	0,39
E28	280	24,93					1	560	0,39	0,94	263,53	0,39
E30	300	26,20					1	600	0,39	0,94	282,35	0,39
E32	320	27,48					1	640	0,39	0,94	301,18	0,39
E34	340	28,75					1	680	0,39	0,94	320,00	0,39
E36	360	30,03					1	720	0,39	0,94	338,82	0,39
	Singlex											
Model	Filtration area	Volume										
E10	72,5	13,49			1			145	0,39	0,94	68,24	0,39
E12	87	14,76			1			174	0,39	0,94	81,88	0,39
E14	101,5	16,04				1		203	0,39	0,94	95,53	0,39
E16	116	17,31				1		232	0,39	0,94	109,18	0,39
E18	130,5	18,58				1		261	0,39	0,94	122,82	0,39
E20	145	19,83				1		290	0,39	0,94	136,47	0,39
E22	159,5	21,10				1		319	0,39	0,94	150,12	0,39
E24	174	22,38				1		348	0,39	0,94	163,76	0,39
E26	188,5	23,65					1	377	0,39	0,94	177,41	0,39
E28	203	24,93					1	406	0,39	0,94	191,06	0,39
E30	217,5	26,20					1	435	0,39	0,94	204,71	0,39
E32	232	27,48					1	464	0,39	0,94	218,35	0,39
E34	246,5	28,75					1	493	0,39	0,94	232,00	0,39
E36	261	30,03					1	522	0,39	0,94	245,65	0,39

Particle size analysis APPENDIX IV (1/6)

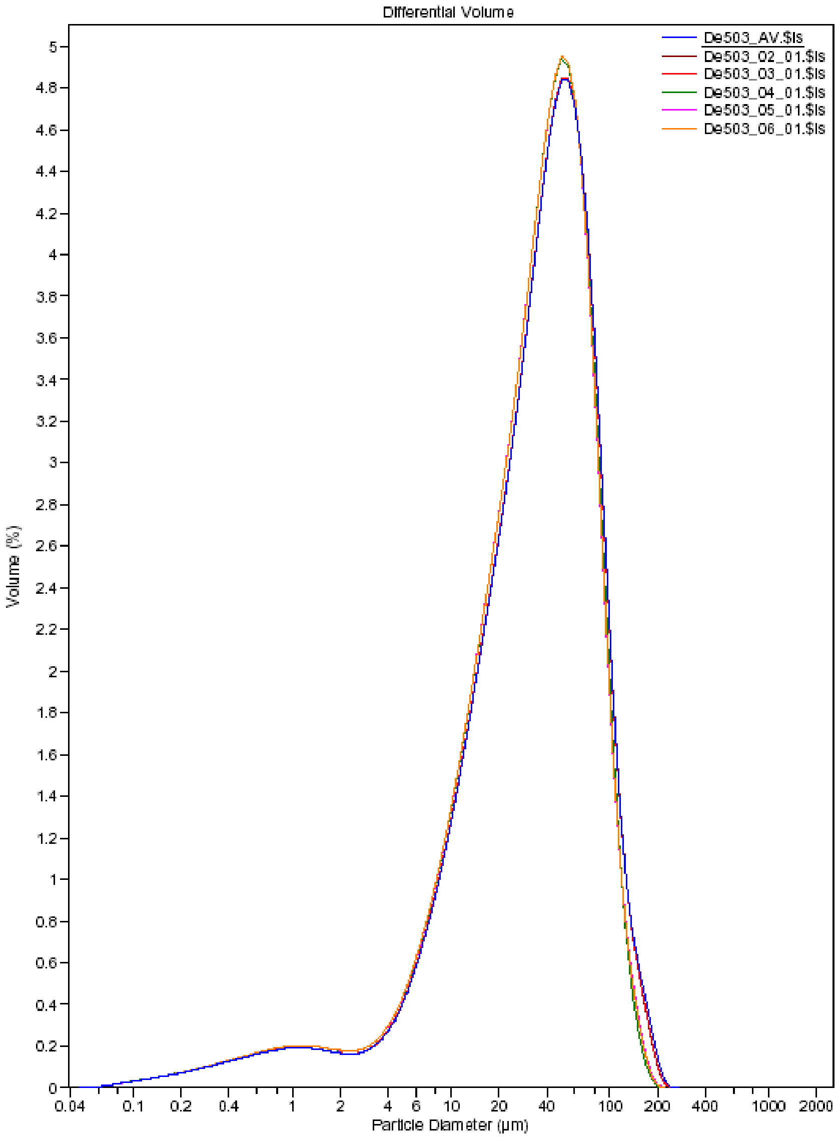


Volume Statistics (Arithmetic) PerliteHarborlite_AV.$ls

Calculations from 0.040 µm to 2000 µm

Volume:	100%		
Mean:	64.35 µm	S.D.:	44.17 µm
Median:	54.95 µm	Variance:	1951 µm^2
Mean/Median ratio:	1.171	C.V.:	68.6%
Mode:	72.94 µm	Skewness:	0.674 Right skewed
		Kurtosis:	0.282 Leptokurtic

<10%	<25%	<50%	<75%	<90%
15.09 µm	29.63 µm	54.95 µm	90.78 µm	129.1 µm

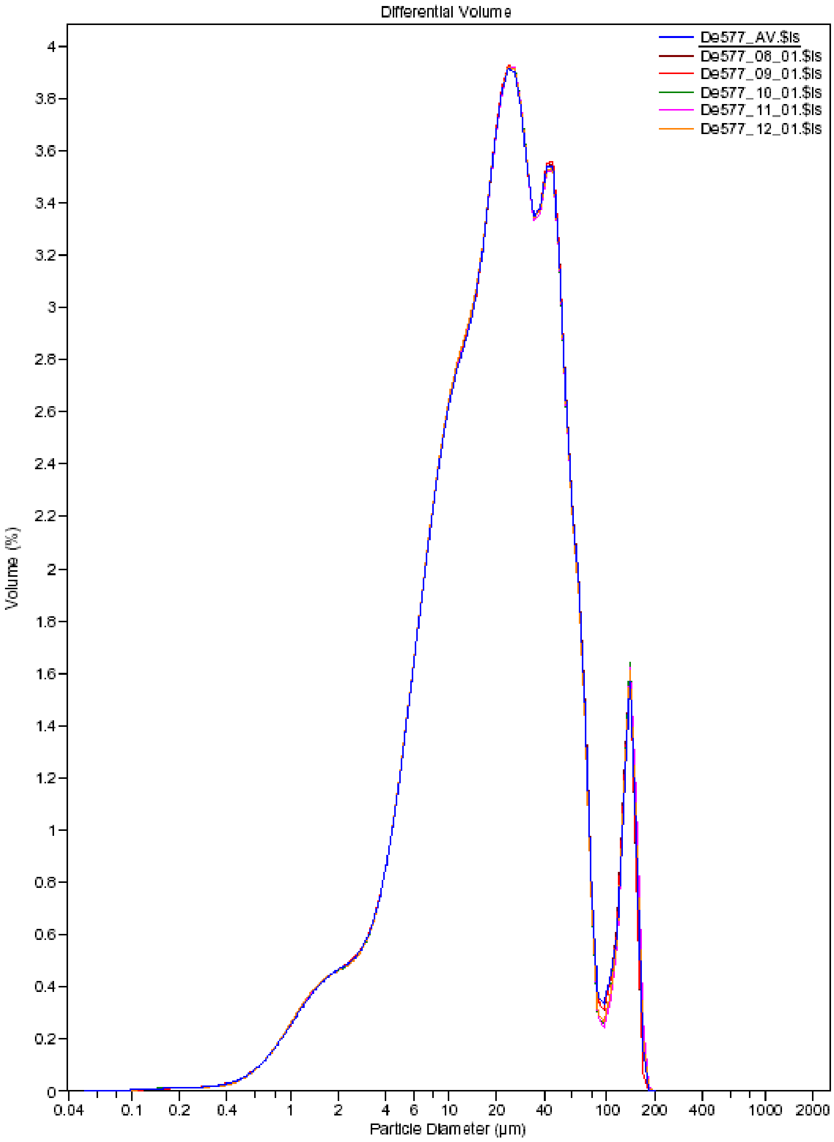


Volume Statistics (Arithmetic) De503_AV.$ls

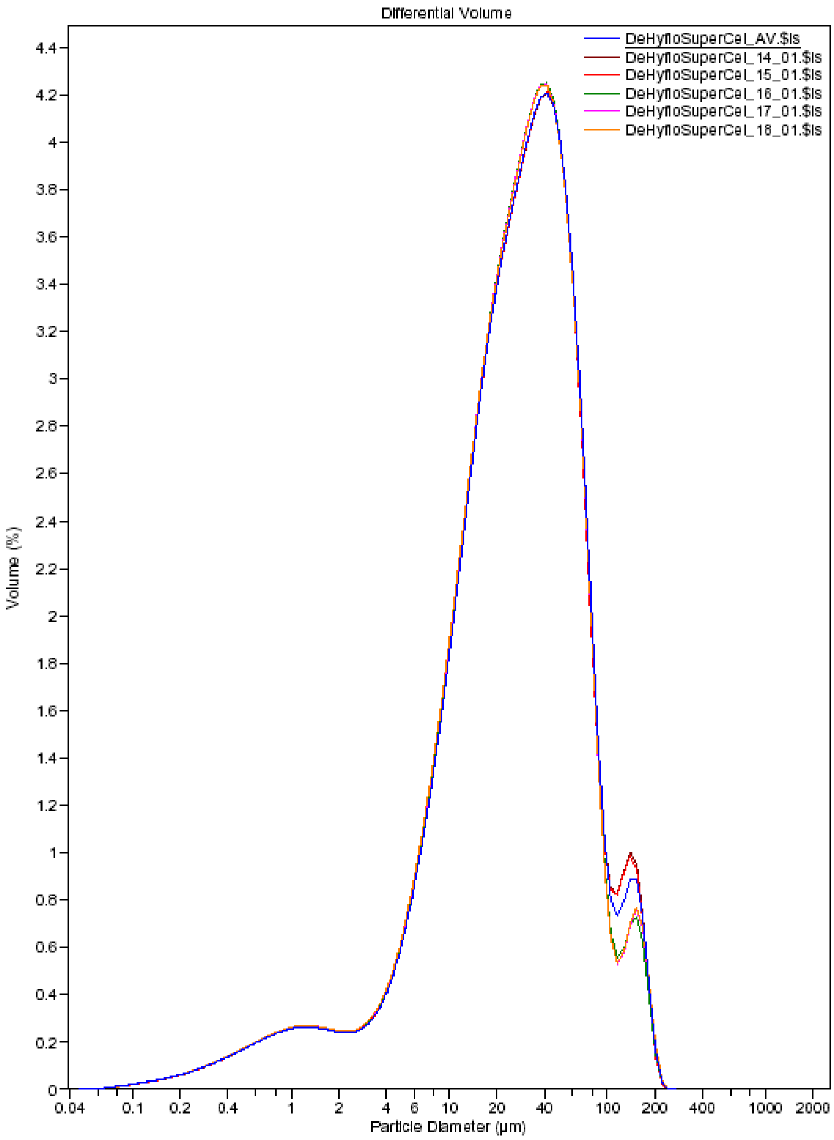
Calculations from 0.040 µm to 2000 µm

Volume: 100%
Mean: 44.64 µm
Median: 38.03 µm
Mean/Median ratio: 1.174
Mode: 50.23 µm
S.D.: 33.81 µm
Variance: 1143 µm^2
C.V.: 75.7%
Skewness: 1.257 Right skewed
Kurtosis: 2.164 Leptokurtic

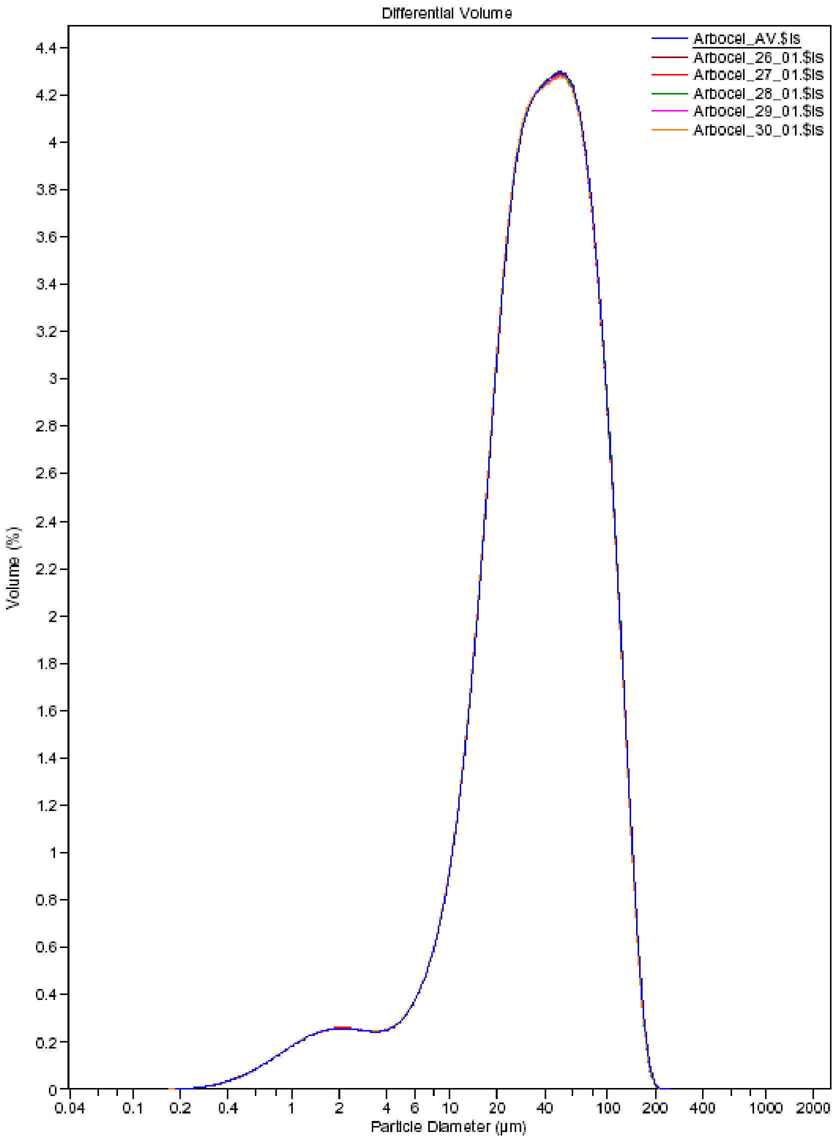
<10%	<25%	<50%	<75%	<90%
8.355 µm	19.00 µm	38.03 µm	62.44 µm	89.06 µm



```
Volume Statistics (Arithmetic)            De577_AV.$ls

Calculations from 0.040 µm to 2000 µm

Volume:               100%
Mean:                 30.10 µm            S.D.:              30.45 µm
Median:               21.03 µm            Variance:          927.0 µm²
Mean/Median ratio:    1.431               C.V.:              101%
Mode:                 23.82 µm            Skewness:     2.155 Right skewed
                                          Kurtosis:     5.187 Leptokurtic

<10%          <25%          <50%          <75%          <90%
4.662 µm      9.655 µm      21.03 µm      39.73 µm      62.80 µm
```



Volume Statistics (Arithmetic)		DeHyfloSuperCel_AV.$ls		
Calculations from 0.040 µm to 2000 µm				
Volume:	100%			
Mean:	37.43 µm	S.D.:	33.96 µm	
Median:	28.40 µm	Variance:	1153 µm^2	
Mean/Median ratio:	1.318	C.V.:	90.7%	
Mode:	41.68 µm	Skewness:	1.910 Right skewed	
		Kurtosis:	4.545 Leptokurtic	
<10%	<25%	<50%	<75%	<90%
6.249 µm	14.14 µm	28.40 µm	50.13 µm	76.37 µm



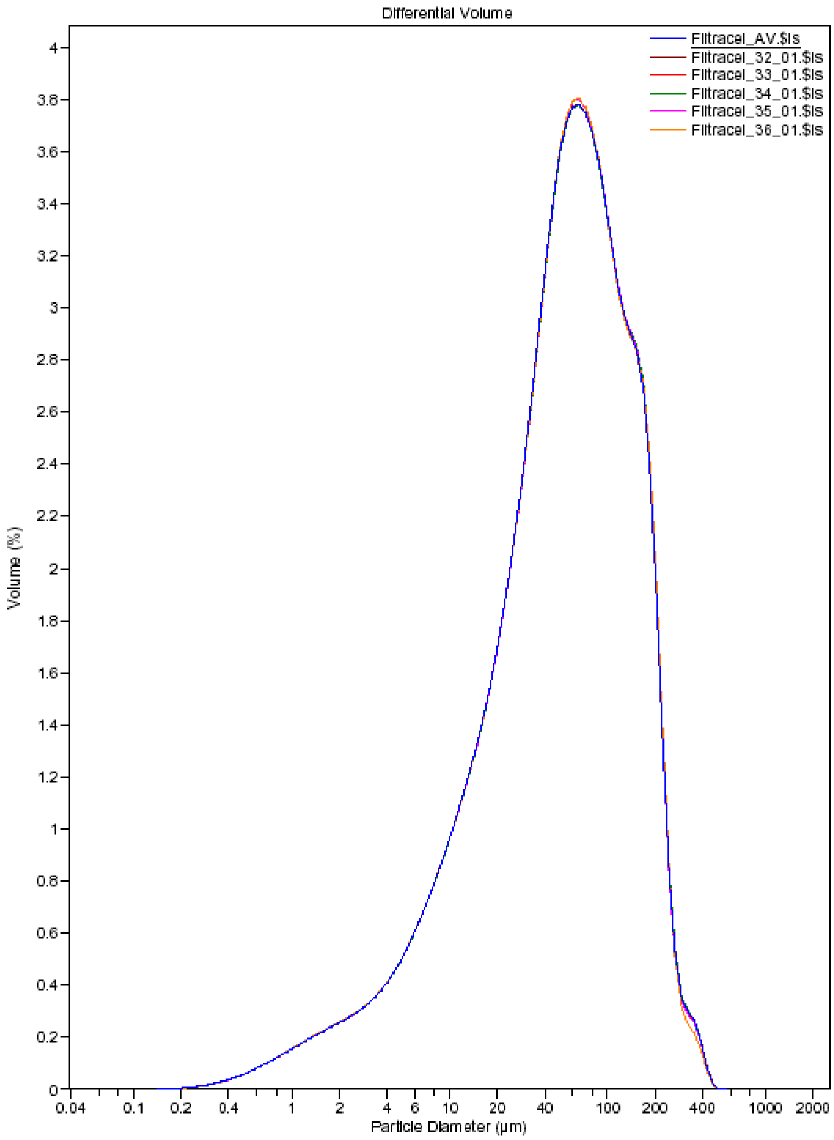
Volume Statistics (Arithmetic) Arbocel_AV.$ls

Calculations from 0.040 µm to 2000 µm

Volume:	100%		
Mean:	47.18 µm	S.D.:	34.42 µm
Median:	38.45 µm	Variance:	1185 µm²
Mean/Median ratio:	1.227	C.V.:	73.0%
Mode:	50.23 µm	Skewness:	1.037 Right skewed
		Kurtosis:	0.750 Leptokurtic

<10%	<25%	<50%	<75%	<90%
10.88 µm	21.27 µm	38.45 µm	66.49 µm	97.42 µm

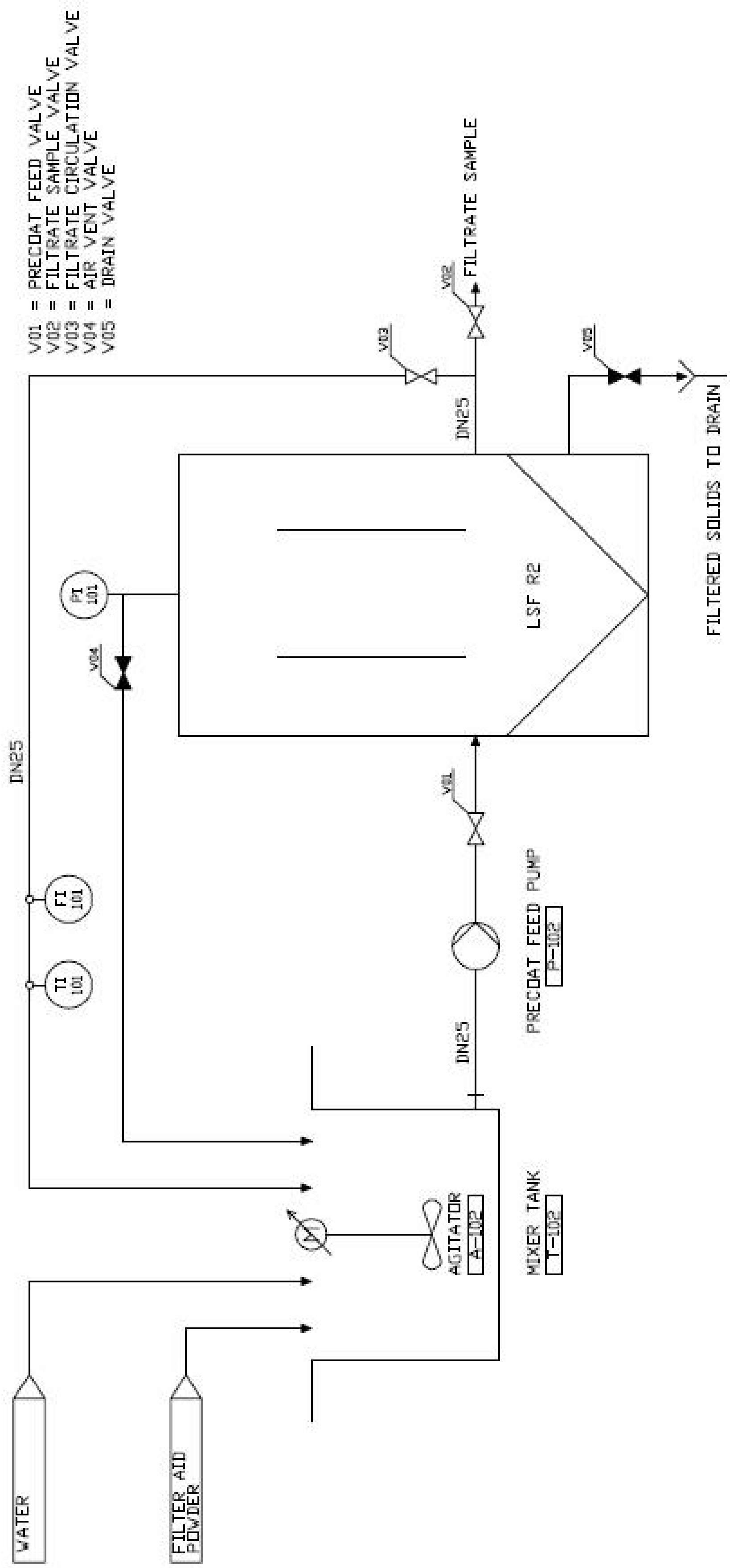
Particle size analysis APPENDIX IV (6/6)



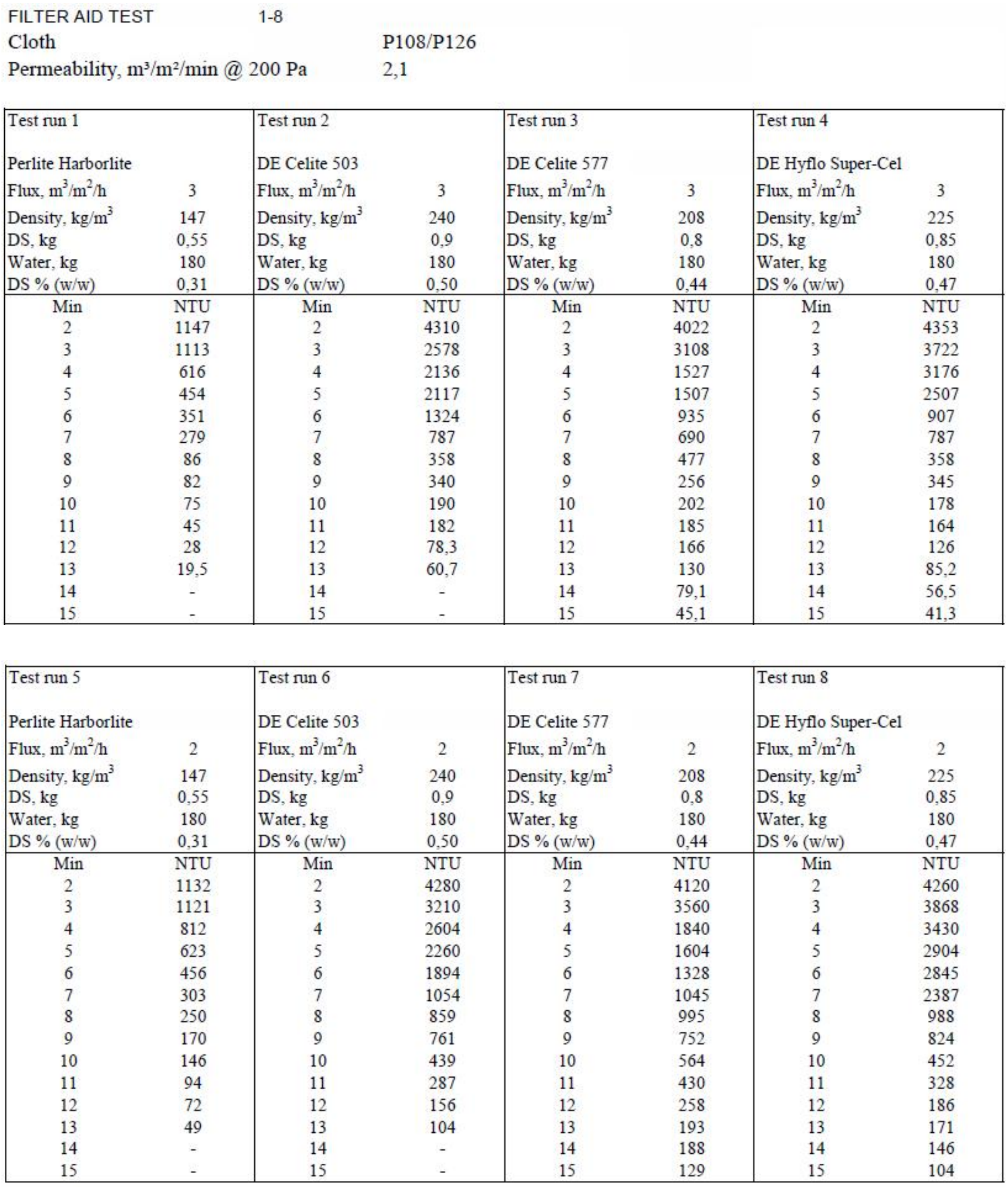
Volume Statistics (Arithmetic)		Filtracel_AV.$ls	
Calculations from 0.040 μm to 2000 μm			
Volume:	100%		
Mean:	73.62 μm	S.D.:	65.91 μm
Median:	54.98 μm	Variance:	4345 μm^2
Mean/Median ratio:	1.339	C.V.:	89.5%
Mode:	66.45 μm	Skewness:	1.544 Right skewed
		Kurtosis:	3.121 Leptokurtic

<10%	<25%	<50%	<75%	<90%
8.752 μm	24.66 μm	54.98 μm	104.2 μm	166.7 μm

Test procedure P&ID **APPENDIX V**



Test procedure result table APPENDIX VI (1/3)

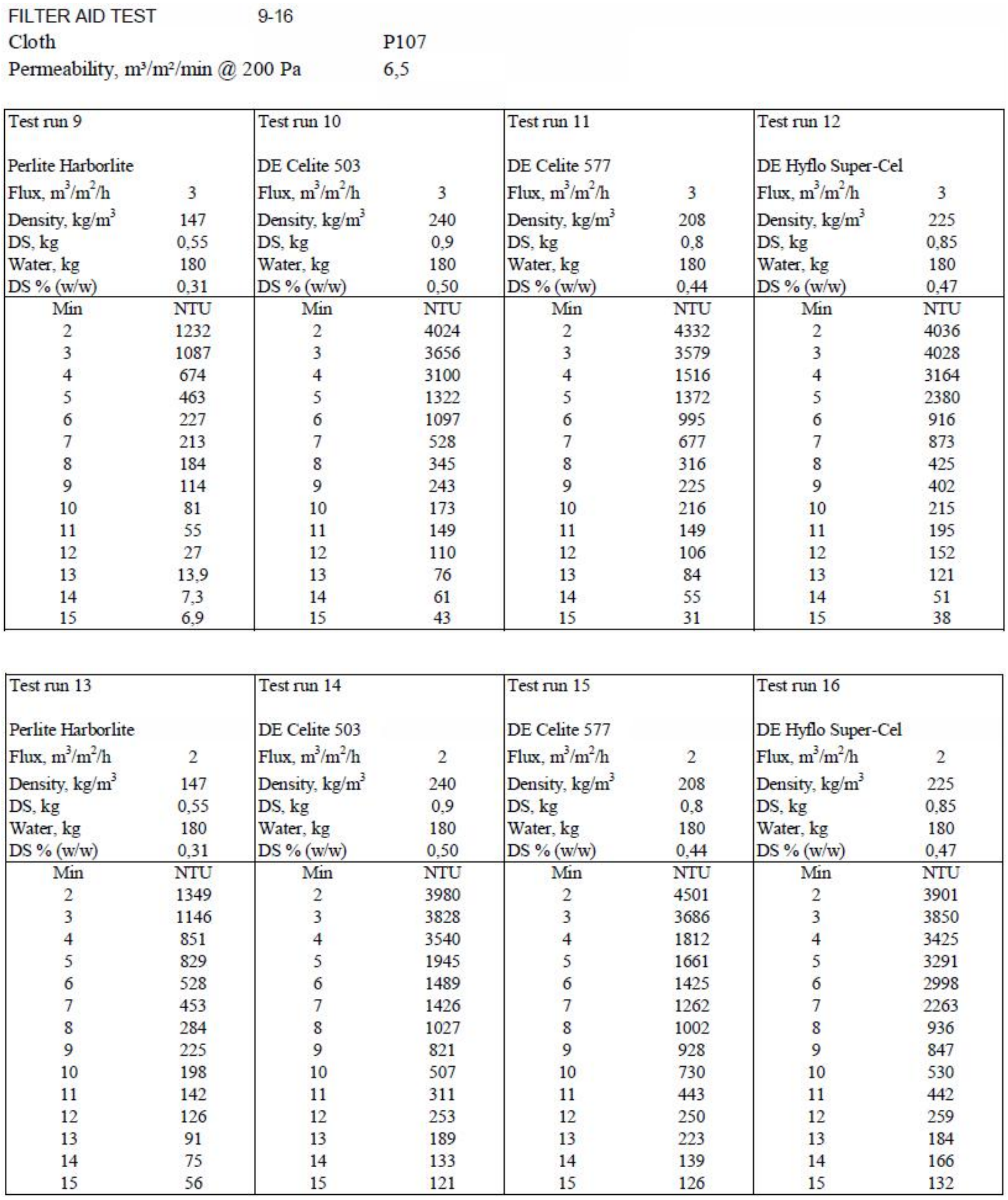


FILTER AID TEST 1-8
Cloth P108/P126
Permeability, m³/m²/min @ 200 Pa 2,1

Test run 1		Test run 2		Test run 3		Test run 4	
Perlite Harborlite		DE Celite 503		DE Celite 577		DE Hyflo Super-Cel	
Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3
Density, kg/m^3	147	Density, kg/m^3	240	Density, kg/m^3	208	Density, kg/m^3	225
DS, kg	0,55	DS, kg	0,9	DS, kg	0,8	DS, kg	0,85
Water, kg	180	Water, kg	180	Water, kg	180	Water, kg	180
DS % (w/w)	0,31	DS % (w/w)	0,50	DS % (w/w)	0,44	DS % (w/w)	0,47
Min	NTU	Min	NTU	Min	NTU	Min	NTU
2	1147	2	4310	2	4022	2	4353
3	1113	3	2578	3	3108	3	3722
4	616	4	2136	4	1527	4	3176
5	454	5	2117	5	1507	5	2507
6	351	6	1324	6	935	6	907
7	279	7	787	7	690	7	787
8	86	8	358	8	477	8	358
9	82	9	340	9	256	9	345
10	75	10	190	10	202	10	178
11	45	11	182	11	185	11	164
12	28	12	78,3	12	166	12	126
13	19,5	13	60,7	13	130	13	85,2
14	-	14	-	14	79,1	14	56,5
15	-	15	-	15	45,1	15	41,3

Test run 5		Test run 6		Test run 7		Test run 8	
Perlite Harborlite		DE Celite 503		DE Celite 577		DE Hyflo Super-Cel	
Flux, $m^3/m^2/h$	2	Flux, $m^3/m^2/h$	2	Flux, $m^3/m^2/h$	2	Flux, $m^3/m^2/h$	2
Density, kg/m^3	147	Density, kg/m^3	240	Density, kg/m^3	208	Density, kg/m^3	225
DS, kg	0,55	DS, kg	0,9	DS, kg	0,8	DS, kg	0,85
Water, kg	180	Water, kg	180	Water, kg	180	Water, kg	180
DS % (w/w)	0,31	DS % (w/w)	0,50	DS % (w/w)	0,44	DS % (w/w)	0,47
Min	NTU	Min	NTU	Min	NTU	Min	NTU
2	1132	2	4280	2	4120	2	4260
3	1121	3	3210	3	3560	3	3868
4	812	4	2604	4	1840	4	3430
5	623	5	2260	5	1604	5	2904
6	456	6	1894	6	1328	6	2845
7	303	7	1054	7	1045	7	2387
8	250	8	859	8	995	8	988
9	170	9	761	9	752	9	824
10	146	10	439	10	564	10	452
11	94	11	287	11	430	11	328
12	72	12	156	12	258	12	186
13	49	13	104	13	193	13	171
14	-	14	-	14	188	14	146
15	-	15	-	15	129	15	104

Test procedure result table



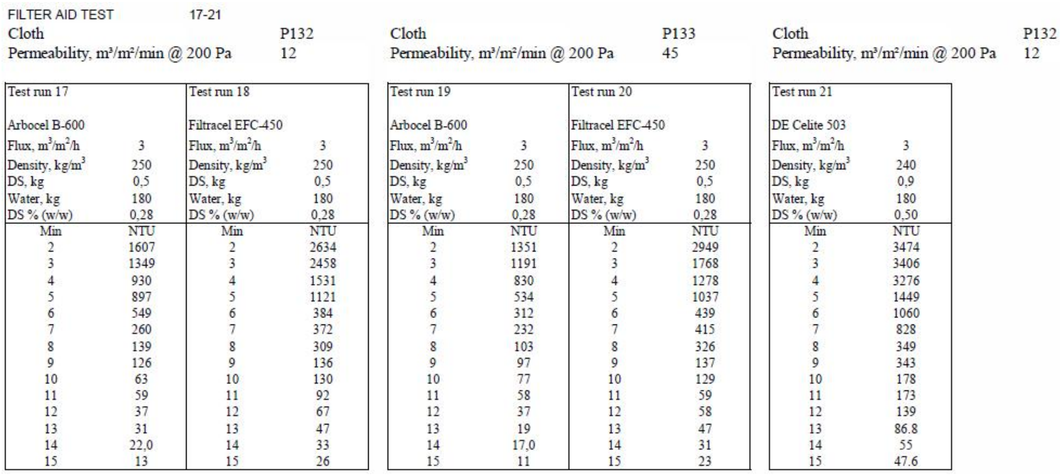
FILTER AID TEST	9-16	
Cloth		P107
Permeability, m³/m²/min @ 200 Pa		6,5

Test run 9		Test run 10		Test run 11		Test run 12	
Perlite Harborlite		DE Celite 503		DE Celite 577		DE Hyflo Super-Cel	
Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3
Density, kg/m^3	147	Density, kg/m^3	240	Density, kg/m^3	208	Density, kg/m^3	225
DS, kg	0,55	DS, kg	0,9	DS, kg	0,8	DS, kg	0,85
Water, kg	180	Water, kg	180	Water, kg	180	Water, kg	180
DS % (w/w)	0,31	DS % (w/w)	0,50	DS % (w/w)	0,44	DS % (w/w)	0,47
Min	NTU	Min	NTU	Min	NTU	Min	NTU
2	1232	2	4024	2	4332	2	4036
3	1087	3	3656	3	3579	3	4028
4	674	4	3100	4	1516	4	3164
5	463	5	1322	5	1372	5	2380
6	227	6	1097	6	995	6	916
7	213	7	528	7	677	7	873
8	184	8	345	8	316	8	425
9	114	9	243	9	225	9	402
10	81	10	173	10	216	10	215
11	55	11	149	11	149	11	195
12	27	12	110	12	106	12	152
13	13,9	13	76	13	84	13	121
14	7,3	14	61	14	55	14	51
15	6,9	15	43	15	31	15	38

Test run 13		Test run 14		Test run 15		Test run 16	
Perlite Harborlite		DE Celite 503		DE Celite 577		DE Hyflo Super-Cel	
Flux, $m^3/m^2/h$	2	Flux, $m^3/m^2/h$	2	Flux, $m^3/m^2/h$	2	Flux, $m^3/m^2/h$	2
Density, kg/m^3	147	Density, kg/m^3	240	Density, kg/m^3	208	Density, kg/m^3	225
DS, kg	0,55	DS, kg	0,9	DS, kg	0,8	DS, kg	0,85
Water, kg	180	Water, kg	180	Water, kg	180	Water, kg	180
DS % (w/w)	0,31	DS % (w/w)	0,50	DS % (w/w)	0,44	DS % (w/w)	0,47
Min	NTU	Min	NTU	Min	NTU	Min	NTU
2	1349	2	3980	2	4501	2	3901
3	1146	3	3828	3	3686	3	3850
4	851	4	3540	4	1812	4	3425
5	829	5	1945	5	1661	5	3291
6	528	6	1489	6	1425	6	2998
7	453	7	1426	7	1262	7	2263
8	284	8	1027	8	1002	8	936
9	225	9	821	9	928	9	847
10	198	10	507	10	730	10	530
11	142	11	311	11	443	11	442
12	126	12	253	12	250	12	259
13	91	13	189	13	223	13	184
14	75	14	133	14	139	14	166
15	56	15	121	15	126	15	132

Test procedure result table

APPENDIX VI (3/3)



FILTER AID TEST 17-21

Cloth	P132	Cloth	P133
Permeability, m³/m²/min @ 200 Pa	12	Permeability, m³/m²/min @ 200 Pa	45

Cloth	P132
Permeability, m³/m²/min @ 200 Pa	12

Test run 17		Test run 18		Test run 19		Test run 20		Test run 21	
Arbocel B-600		Filtracel EFC-450		Arbocel B-600		Filtracel EFC-450		DE Celite 503	
Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3	Flux, $m^3/m^2/h$	3
Density, kg/m^3	250	Density, kg/m^3	250	Density, kg/m^3	250	Density, kg/m^3	250	Density, kg/m^3	240
DS, kg	0,5	DS, kg	0,5	DS, kg	0,5	DS, kg	0,5	DS, kg	0,9
Water, kg	180	Water, kg	180	Water, kg	180	Water, kg	180	Water, kg	180
DS % (w/w)	0,28	DS % (w/w)	0,28	DS % (w/w)	0,28	DS % (w/w)	0,28	DS % (w/w)	0,50
Min	NTU	Min	NTU	Min	NTU	Min	NTU	Min	NTU
2	1607	2	2634	2	1351	2	2949	2	3474
3	1349	3	2458	3	1191	3	1768	3	3406
4	930	4	1531	4	830	4	1278	4	3276
5	897	5	1121	5	534	5	1037	5	1449
6	549	6	384	6	312	6	439	6	1060
7	260	7	372	7	232	7	415	7	828
8	139	8	309	8	103	8	326	8	349
9	126	9	136	9	97	9	137	9	343
10	63	10	130	10	77	10	129	10	178
11	59	11	92	11	58	11	59	11	173
12	37	12	67	12	37	12	58	12	139
13	31	13	47	13	19	13	47	13	86.8
14	22,0	14	33	14	17,0	14	31	14	55
15	13	15	26	15	11	15	23	15	47.6