SpinTek
Centrifugal Membrane Filtration

Membrane Filtration using the SpinTek II High Shear Rotary Filter

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Introduction

Recent environmental laws governing wastewater quality have driven industry to search for alternate means of pollution control. A wide variety of systems such as biodigesters, centrifuges, evaporators, and settlers can be installed that separate contaminants with varying degrees of success and cost effectiveness. Membrane filtration is fast becoming a viable alternative due in part to the development of numerous types of membrane materials. Membrane materials have been formulated to be acid and caustic resistant, high temperature resistant, chlorine and oxidizing agent resistant, and solvent resistant. Membranes have also been surface enhanced to produce a charge or affinity for certain types of molecules. Membrane surfaces can be modified to be hydrophilic or oleophobic to disallow easy passage to non polar organic substances such as oil and grease. These and other advancements have helped membrane technology gain industrial acceptance.

Membrane systems also offer many advantages over other waste treatment systems. Membrane systems eliminate the need for chemical pretreatment, and also guarantee permeate quality due to a specific particle rejection based on membrane pore size. This guarantees that even in the event of an upset (i.e. a sudden change in influent solute concentration), the effluent quality would not be affected. Membrane systems also allow the concentration of the contaminants in the waste stream to reduce waste product volume.

Membranes are classified according to the size of their pores or by their molecular weight cutoff. Microfiltration membranes are used to remove contaminants in the 0.025 - 2µ range. Although micron-sized particles can be removed by use of non-membrane or depth materials, such as those found in fibrous media, only a membrane or screen filter, having a precisely defined pore size, can ensure qualitative retention. Ultrafiltration (UF) membranes are used to separate high molecular weight solutes from liquids. The pore sizes are usually given in Nominal Molecular Weight Cutoffs (NMWC) rather than micron rejections. UF membranes have pore sizes that range from I ,000,000 NMWC down to 10,000 NMWC. Low molecular weight species (for example, salts, sugars, and most surfactants) are able to permeate through the membrane. Suspended solids, colloids, and macromolecules are rejected and concentrated. Nanofiltration (NF) membranes, with a range of pore sizes from 10,000 NMWC, down to 200 NMWC, offer the unique capability of selective separation of low molecular weight compounds at low to medium pressures. Organic components such as proteins and sugars are retained as well as a certain percentage of dissolved sodium chloride, while low molecular weight dissolved solids are passed through as permeate. Reverse Osmosis is a high pressure membrane process which rejects dissolved salts, but allows pure water to pass through. RO membranes are designed to process those streams with very low levels of suspended solids. Many industrial wastewater applications require only a UF or NF system, unless high amounts of BOD or dissolved solids must be removed prior to discharge. In this case, an RO system would be required either alone, or in the case of high suspended solids streams, in series with a UF system.

Traditional membrane systems fundamentally consist of dead-end type systems and cross-flow systems. Dead-end flow is the manner in which 100% of the feed stream flow is through the filter media (see *figure I).*

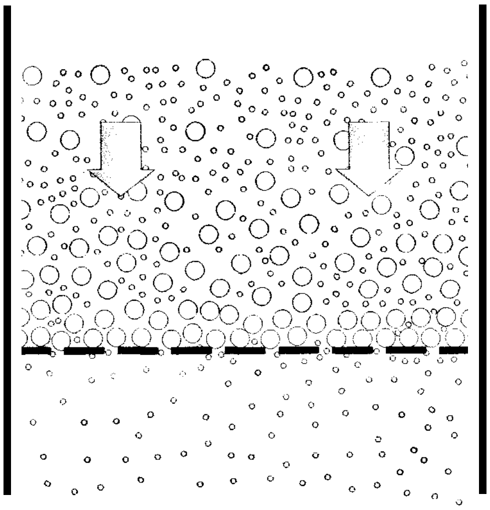

Figure 1 - Dead-end Filtration

Particulates rejected by the membrane surface build up and create a layer of particles referred to as a cake. This cake initially improves the effectiveness of the membrane and when operated under controlled conditions, could be considered a "secondary membrane". However, when operating in a dead-end configuration, the thickness of the layer quickly gets to the point where filtrate flow is completely obstructed. Cross flow systems allow only a portion of the feed stream to pass through the membrane (see *figure* 2). The remaining feed flow is recirculated at a much greater rate to create a stream of fluid flow parallel to the membrane. The quickly flowing stream creates a fluid shear near the membrane surface, which aids in minimizing the thickness of the particulate layer. The efficiency of this fluid shear, or "sweeping action" increases with the velocity of the fluid. Unlike dead-end systems, cross-flow systems can be operated continuously with a steady throughput.

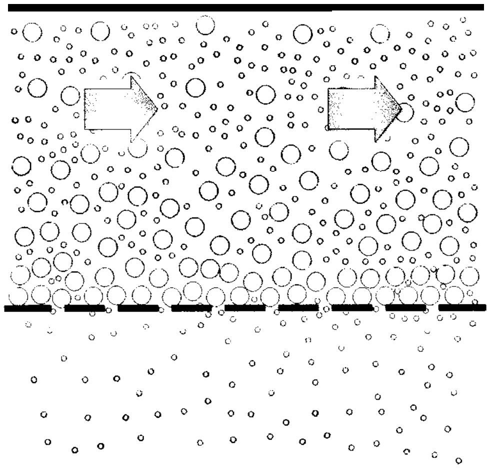

Figure 2 - Cross flow Filtration

Cross Flow Filtration

Cross flow filtration is widely practiced today. The ability to operate at a continuous filtration rate, or flux is possible in many applications. In order to acheive this, a cross flow system must recirculate the process fluid through the membrane modules to permit the "sweeping action" to take place. This requires the use of recirculation pumps, which continuously feed the material to the membrane housing over and over at a much greater rate than the actual flow of permeate effluent being drawn off. Figure 3 shows a typical flow sheet for a cross flow system. In this example, the feed pump fills a holding tank with process fluid.

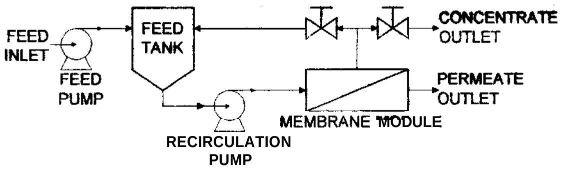

Figure 3 - Typical Flow Sheet

The recirculation pump provides a means of acheiving cross flow as well as the driving force for permeation. A valve located on the tank return line is used to adjust the backpressure, thus controlling the driving force pressure on the membrane surface. Another valve allows the precise control of concentrate to be drawn off, allowing control over the solute concentration in the recirculating fluid.

If the recirculation rate is sufficient to maintain an efficient boundary layer at the membrane surface, a steady state of permeate flow is acheived.

Affecting Performance

Cross flow systems rely on the recirculation flow to maintain the boundary layer at the membrane. Since the pressure losses through the system due to friction increase with an increase in flow, the driving force pressure becomes dependent on the cross flow velocity, This severely limits the maximum cross flow velocity that can be acheived. Typically, cross flow velocities above 5 meters/second are impractical or impossible to reach with conventional equipment.

Concentration Polarization

Concentration polarization is a boundary layer phenomenon in which solutes retained by the membrane accumulate at the membrane surface. During the membrane separation process, solvent and solutes are transported to the membrane surface. As the solvent and permeable solutes pass through the membrane, the concentration of the retained solutes increases until a critical concentration is reached and steady state is established. At this point, the convective transport rate of these solutes to the membrane surface equals the diffusion transport rate of these solutes out of the boundary layer. In cross flow filtration, assume that fluid flowing across the membrane is in turbulent flow and that the concentration of the solute within the bulk flow region is uniform at C_b (see figure 4).

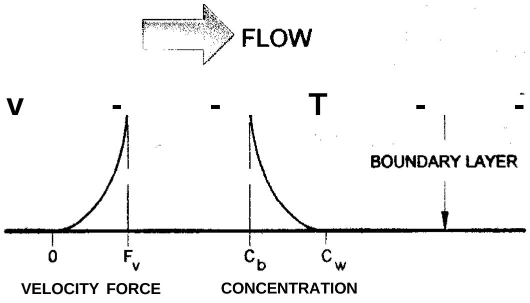

Figure 4 - Velocity and Concentration Gradients

Further assume that there exists a very thin laminar boundary layer adjacent to the membrane surface. Under the influence of a transmembrane pressure gradient, water and solute will be forced to flow across this boundary layer in order to pass through the membrane. If the membrane, however, completely retains the solute, the solute concentration adjacent to the membrane will have to increase as a natural consequence of the removal of solvent. This results in the development of a concentration gradient across the boundary layer with the maximum solute concentration located adjacent to the membrane surface. This concentration gradient is referred to as concentration polarization, or gel layer formation.

The concentration polarization boundary layer usually produces two adverse effects: a reduction of flux and a change in particle selectivity. The boundary layer resistance to permeation can become much larger to that of the membrane, and thus significantly reduce flux. As the concentration of retained solutes increases at the membrane surface, the pressure required for permeation of the solvent and permeable solutes through this layer increases. As a result, membrane system separation capability is adversely affected.

Fouling

Whereas concentration polarization might be described as a dynamic fouling, other types of membrane fouling can affect membrane performance, and in some cases, permanently. This kind of fouling may be composed of materials adsorbed directly on the membrane, or may accumulate on the surface, where it is difficult to control. In general, fouling is a boundary layer or sub-boundary layer phenomenon, caused or aggravated by concentration polarization, in which solutes deposit on the membrane surface and reduce membrane flux and selectivity. The mechanisms of deposition include chemical reaction, precipitation, electrical attraction, and other interactions. Whereas concentration polarization is a fluid dynamics phenomenon, fouling is a chemical phenomenon between solutes and the membrane. Foulants include organic salts, macromolecules, colloids, and microorganisms. Proper selection of membrane material is the only defense against fouling.

Cleaning

Although it is effective at reducing fouling, cross flow alone is often insufficient to eliminate fouling. If fouling at some level occurs, practically the only way to reverse its effect is to perform a cleaning on the membrane. Cleaning of membranes typically is ***in situ*** at an elevated temperature, using either acids, caustics, oxidizing agents, enzymatic detergents, or a combination of these. This is done to chemically remove the fouiants within the structure of the membrane. In many cases, near complete regeneration of performance can be acheived. However, each cleaning causes a certain amount of wear and tear on the membrane. A high cleaning frequency can severly limit membrane life.

Since concentration polarization has an effect on fouling, a system that limited concentration polarization would tend to limit cleaning frequency, and thus prolong membrane life.

Types of Systems

There are several types of cross flow systems in use today, the most widely accepted being spiral wound, hollow fiber, tubular, and plate and frame systems.

Spiral Wound Systems

In the spiral wound system, alternate layers of membrane sheets. permeate carrier and feed spacer material are rolled into a spiral configuration (see ***figure 5).***

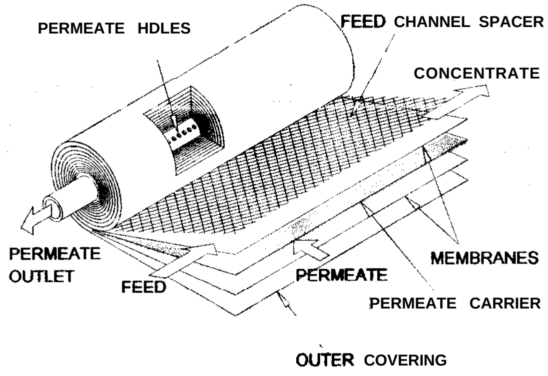

Figure 5 - *Spiral Wound Membrane Module*

The permeate carrier material provides support for the membrane as well as allowing open communication with the permeate tube in the center of the module. The tube has many holes all along its length. Modules may be constructed of one or more individual wrappings or "leaves". Since the permeate stream must flow through the entire length of the permeate carrier before exiting at the center tube, the length of each leaf could be so great as to inhibit the flow of permeate. A larger number of leaves mean a shorter length for each leaf, and less permeate side pressure drop.

The feed spacer material consists of a plastic mesh which provides a spacing between the membranes. As the feed flow is rapidly circulated through the channel formed by this spacer, the structure of the spacer causes an increase in turbulence near the membrane which helps to improve sweeping action.

Advantages

Spiral-wound modules utilize membrane material found in flat-sheet form, which allows a wide range of membrane materials and pore sizes to select from. A large amount of membrane surface area can be packed into each module, reducing overall system cost.

Disadvantages

The mesh spacer has a large area of contact with the membrane, reducing effective area. In addition, the presence of the mesh in the mainstream flow creates a tortuous path, causing increases in friction-induced pressure losses. The structure also restricts the flow of agglomerated or fibrous particles, leading to plugging of the feed channel. Also, membranes cannot be visually inspected without destruction of the module.

Hollow Fiber Systems

Hollow-fiber membranes are grouped together in tight bundles. The end of the bundle is potted to hold the tiny tubes together and form an end cap which can be sealed against. They usually are available only in the very low NMWC ranges.

Advantages

A large amount of membrane surface area can be packed into a single hollow-fiber module. Since void volume is reduced in both feed and permeate channels, hollow-fiber systems offer the highest packing density available.

Disadvantages

An inherent disadvantage owes to the hollow-fiber's very small feed channel. Process streams with any significant level of suspended solids should not be considered due to the inevitable plugging of the flow channel. This limits their use to liquid-liquid separations or certain nanofiltration processes. Due to special processing requirements, a limited selection of membrane materials is available. Another disadvantage is that membranes may not be visually inspected without destruction of the module.

Tubular Systems

In the tubular membrane system *(see figure 6)*, the membrane is formed into a long tube with one or more of these tubes fitted into a shell housing. The feed flow of the tubular system usually is on the inside of the tube where the membrane surface is. Permeate flows from inside the tube, through the membrane on the tube wall, to the outside of the tube. The flow path of the tubular system is much the same as a tube and shell heat exchanger.

Advantages

Open feed channel permits higher Reynolds numbers, enhancing turbulence. The open channel also permits circulation of higher viscosity solution than with spiral-wound, hollow-fiber, or plate & frame systems.

Disadvantages

Maximum pressure and temperature are limited due to the low strength structure created by the membrane and its backing. Also, special manufacturing processes limit material availability. Membranes cannot be visually inspected without destruction.

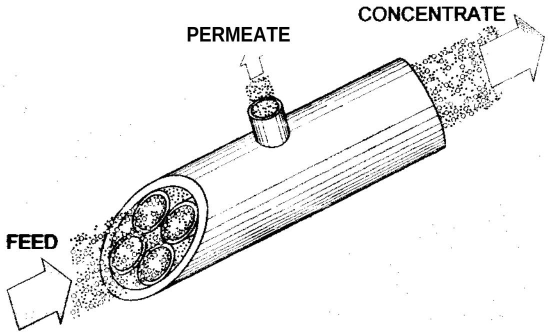

Figure 6 - Tubular Membrane Module

Plate and Frame Systems

In plate and frame systems, membrane packs are constructed of flat layers of membranes and permeate support carriers *(see Figure* 7). Many different types of configurations are available from rectangular to circular as well as elliptical. A stack of membrane packs are spaced by peripheral gaskets and flow distribution elements and clamped between pressure plates. Since each membrane pack contains its own permeate carrier, the exit path can be made very short, to minimize permeate side pressure drop. Packing density compares well to spiral-wound systems. An advantage of the plate and frame system is that the membrane stack can be disassembled to inspect the membrane surfaces, which is sometimes critical in determining how well the membrane is suited for the application. Peripheral sealing of the membrane packs is critical and varies from mechanical types to "O"-rings as well as ultrasonic welding of the pack edges.

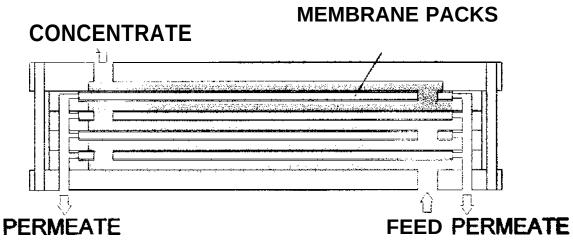

Figure 7 - Plate and Frame Membrane Housing

Since the feed flow is usually introduced into a rectangular chamber, plate and frame systems must rely on a flow distribution device that guarantees even flow across all of the membrane surfaces.

Advantages

Plate & frame systems offer high packing density, nearly that of spiral-wound systems. Virtually any flat sheet membrane may be used. Disassembly of a plate & frame housing allows non-destructive inspection of a membrane.

Disadvantages

Flow distribution is poorly acheived in most designs. This limits the effectiveness of much of the membrane area. The flow channel typically doesn't guarantee an even crossflow velocity across all membrane surfaces. In systems which do provide for more even flow distribution, devices which contact the membrane are used, reducing effective area and causing feed channel plugging.

Spintek II High Shear Rotary Filter

The SpinTek II High Shear Rotary Filter (patent pending) has rotating disks, coated with any available flat sheet membrane. The disks mount on a common rotating shaft. The entire stack of membrane disks are enclosed within a pressure vessel.

The feed fluid enters the vessel, flows between disks across the membrane surface, where permeate flows through the membrane. Concentrate exits the system at the opposite end. The fluid is recirculated as in conventional crossflow systems, but not at the same high rates.

Stationary disks oppose the rotating membrane disks and provide a means for prohibiting fluid rotation and promoting turbulent flow if desired. This increases the shear rate, or the change in surface velocity per distance from the membrane surface.

The stationary disks may have vane-like protrusions to enhance fluid flow in and out of the channel between disks. The vanes can be from .06" to .12" away from the membrane surface.(see Figure 8).

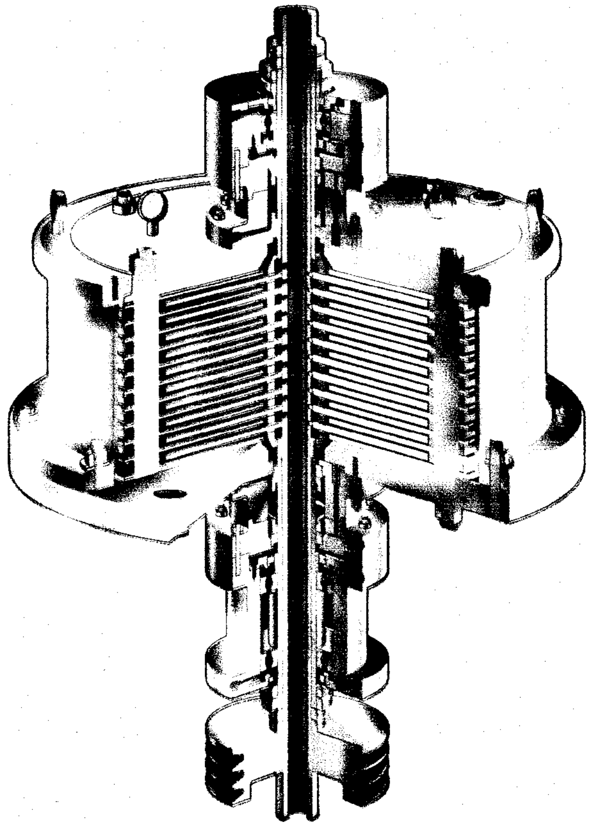

Figure 8 - SpinTek *II* High ***Shear Rotary Filter***

Comparison to Conventional Cross Flow

The high shear membrane process is basically like that of conventional membrane systems (see Figure 3), with the exception of the rate at which the process fluid is recirculated. Since the cross flow velocity is controlled by rotating the membranes, the recirculation flow rate is set based on the amount of permeate removed. This way, the dependence of pressure is decoupled from the feed flow rate, allowing more control over the driving force pressure, and independent control of cross flow velocity.

Affecting Performance

Not only is cross flow velocity directly controlled, its magnitude is significantly greater. A conventional membrane system may have a cross flow velocity of 8 ft/sec. The SpinTek II high shear membrane typically operates at 55 ft/sec. This has a dramatic influence on concentration polarization, enhancing performance, and allowing selectivity to be determined by the membrane instead of by the layer that forms on top of the membrane.

Experimental

Comparison testing was performed on several applications. In each test, a conventional tubular ultrafiltration membrane module was compared to the SpinTek ST-IIL laboratory test unit. Both units used polyvinylidiene fluoride (PVDF) membranes with 100.000 dalton nominal molecular weight cutoffs. In each test, temperature and pressure was held constant. Cross flow velocity in the tubular unit was about 12 ft/sec in each test. The SpinTek ST-IIL used had an 8" diameter membrane disk rotating at 1750 rpm. In all cases the surface speed at the periphery of the active membrane area was about 55 ft/sec.

Latex Concentration Test

Objective

The Styrene Butadiene (SBD) Latex wastewater is the result of the internal rinsing of tanker trucks and rail cars used to transport the latex emulsions. A filtration process was adopted to separate the latex solids from the rinse water, enabling the latex solids to be reblended into fresh latex, and produce a clean permeate which can be reused in the tank rinsing process. A test was conducted to evaluate the effects of concentration on flux.

Results

The SpinTek unit outperformed the tubular unit at all concentrations by a significant margin (see *Figure 9).* Even at over 40% concentration, the flux was still around 30 gfd. The tubular unit could not sustain significant flux above 30% concentration.

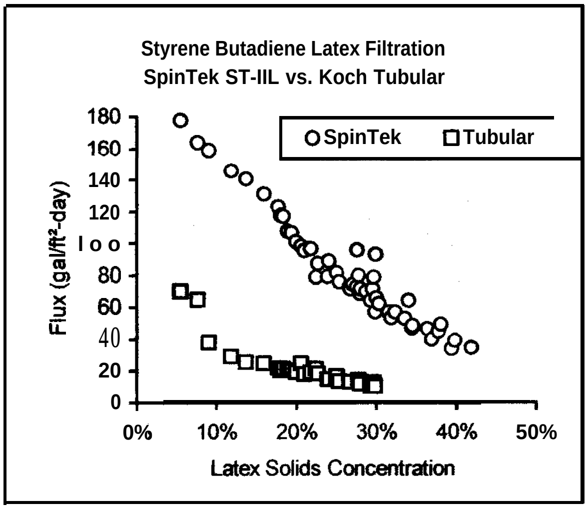

Figure 9 - Latex comparison

Kaolin Clay Concentration Test

Objective

Kaolin Clay is mined, washed, refined and dewatered to be used in the paper industry. In the refining process, the clay is classified into various particle sizes each having a different effect in the paper which is produced. The filtration process was used as a first stage dewatering of the clay fines. A test was conducted to evaluate the effects of concentration on flux.

Results

As can be seen from the graph below, the SpinTek unit performed about 400% better than the tubular system throughout the concentration run.

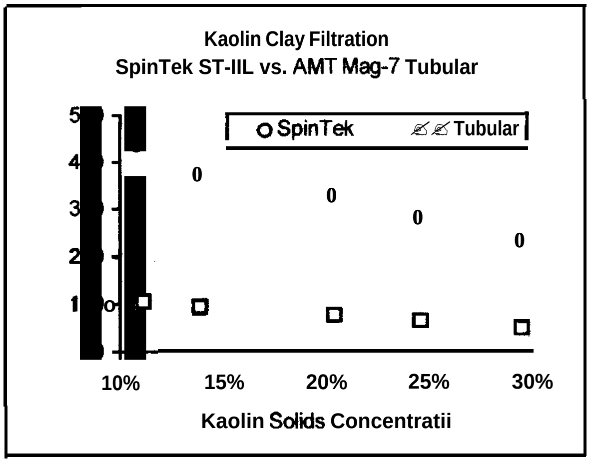

Figure 10 - Kaolin clay comparison

Pigment Concentration Test

Objective

In the processes used to produce organic pigments, many unwanted side products are produced and must be separated from the pigment product. The side products contain various salts which must be washed from the pigment slurry. Once washed free of salts, the pigment slurry must be concentrated and dried. Currently, two processes are being utilized for this washing and concentrating. The first, and most common process are filter presses. Filter presses wash the salts from the pigment slurry while creating a cake. This process is highly inefficient and can use upwards of 13 lbs. of wash water per pound of pigment. The second, and much more efficient process, membrane filtration is becoming the more preferred method of washing and concentrating. A process of diafiltration is used to wash the pigment more efficiently, using much less water. The last stage in the membrane process concentrates the slurry to be sent to the drier. A test was conducted to evaluate the effects of concentration on flux.

Results

Both the SpinTek unit and the tubular unit showed very high fluxes initially, but the tubular unit was affected significantly by the change in concentration. The SpinTek unit was still well above 400 gfd at over

15% solids, while the tubular unit was well below 200 gfd at 12%.

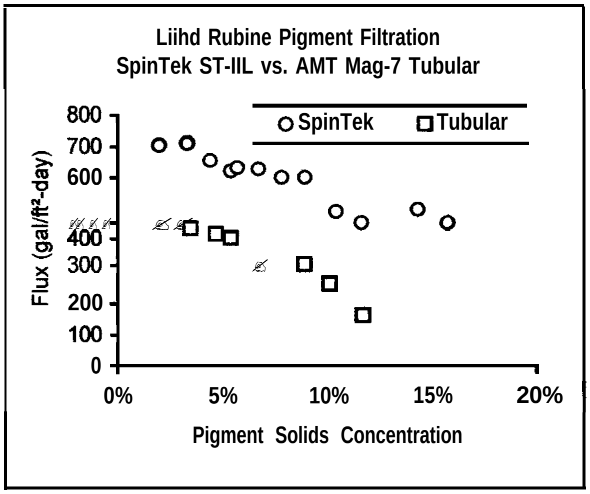

Figure 11 - Pigment comparison

Conclusion

Membrane separation has gained acceptance in many industries due to the use of new membrane materials and cross flow module designs. What limits the effectiveness of conventional cross flow systems is the dependence of cross flow velocity on the recirculation flow rate. This in turn causes a dependence of pressure on the recirculation rate as well, due to friction losses. These limitations keep the practical limit of cross flow velocity down to levels which limit performance and increase cleaning frequency.

Conventional Cross Flow Drawbacks

- Spiral wound modules cannot handle viscous slurries because of the spacers used in the feed channel
- Tubular modules require very high recirculation flow rates to acheive needed cross flow velocity
- Plate and frame designs depend on flow distribution devices which come into contact with the membrane
- Hollow fiber designs are not recommended for solutions with suspended solids
- Reduced selectivity may cause rejection of solids desired in the permeate

SpinTek High Shear Rotary Filter Advantages

The SpinTek High Shear Rotary Filter has the following advantages over conventional cross flow systems:

- Cross flow velocity, flow rate, and pressure are independent variables
- Cross flow velocity is at least 4 times greater
- Significantly higher performance
- Higher concentration levels
- Selectivity is defined by the membrane, not by the boundary layer

The performance advantages of the SpinTek unit can have further effects on membrane replacement costs. SpinTek units would have less membrane to replace, as well as require fewer cleanings, which are known to reduce membrane life.

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