EVOLUTION IN SEPARATION
TECHNICAL DEVELOPMENT BY MUTATION AND SELECTION

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ABSTRACT

The separation of particles from liquids represents a cross-sectional technology, which touches nearly every industrial process, our personal life and the environment. It is obvious, that very different separation principles and a huge variety of highly specialized apparatuses are needed to solve all separation problems in such different areas of application. Looking to the history of apparatus development one can observe several interesting analogies to evolutionary processes in biology. Motivation for development of new separation technology normally is a preferably urgent need to solve a separation problem and the pressure to be successful on the market. To be successful a new concept must offer advantages in comparison to competing solutions. In contrast to nature the creative "genius" of the engineer in combination with advanced knowledge make new developments more targeted and faster. Some evolutionary aspects of separation technology will be discussed on the example of filters and centrifuges. According to actual trends latest developments are demonstrated and some future prospects are pointed out.

1. Introduction

The separation of particles from liquids represents a cross-sectional technology, which touches nearly every industrial process, our personal life and the environment. Solid liquid separation can be focussed on very different tasks like thickening, demoisturing, purification, washing, fractionation, sorting, extraction and others. Separation processes have to be mastered in extreme ranges concerning particle size, distribution and shape, specific solids and liquids weight, suspension concentration and chemical composition, suspension and liquid rheology, flow rates, process and technical boundary conditions and last but not least demands on the separation results. It is obvious, that very different separation principles and a huge variety of highly specialized apparatuses are needed to solve all of these separation problems as optimal as possible. Looking to the history of apparatus development one can observe several interesting analogies to evolutionary processes in biology. According to the requirements of the environment more and more improved and specialized species came up and disappeared again, when they had been not successful enough in comparison to competitors or the conditions for life had been changed. The natural principle of development by mutation and selection shows similarities to technical processes and especially here to separation technology. Motivation and driving force for new developments in separation technology normally is a real and preferably urgent need to solve an actual separation problem and the pressure to be successful on the market. If, in most cases on the basis of a profound knowledge of the physical and technical background of separation processes, a bright and innovative idea appears, an improved or new solution has the chance to be realized and to capture a certain market segment. However some basic preconditions like technical and economical feasibility must be fulfilled to establish a new concept. To be successful the new concept must have specific advantages in comparison to competing solutions, otherwise it will disappear again. In contrast to nature the creative “genius” of the engineer in combination with the advanced knowledge from systematic basic research work make new developments more targeted and faster. Today improved measurement techniques and powerful numerical simulation methods are helping in addition. In recent times interdisciplinary collaboration becomes increasing importance, because separation tasks become more complex. Nevertheless systematic methods to support creative processes like thinking in analogies, brainstorming, morphologic boxes and others are indispensable for successful new developments. Especially the finding of new solutions by thinking in analogies, which means to stimulate phantasy by transferring pictures into an completely other context, will be demonstrated on some examples. Some evolutionary aspects of separation technology will be discussed on the example of filters and centrifuges. According to actual trends like energy efficiency or process intensification latest developments are demonstrated and some future prospects and are pointed out.

2. Transfer of pictures from nature to separation technology

At first the method of thinking in analogies should be illustrated on some examples. Similar to biology a genealogical tree of separation technology can be formed like to be seen in fig.1.

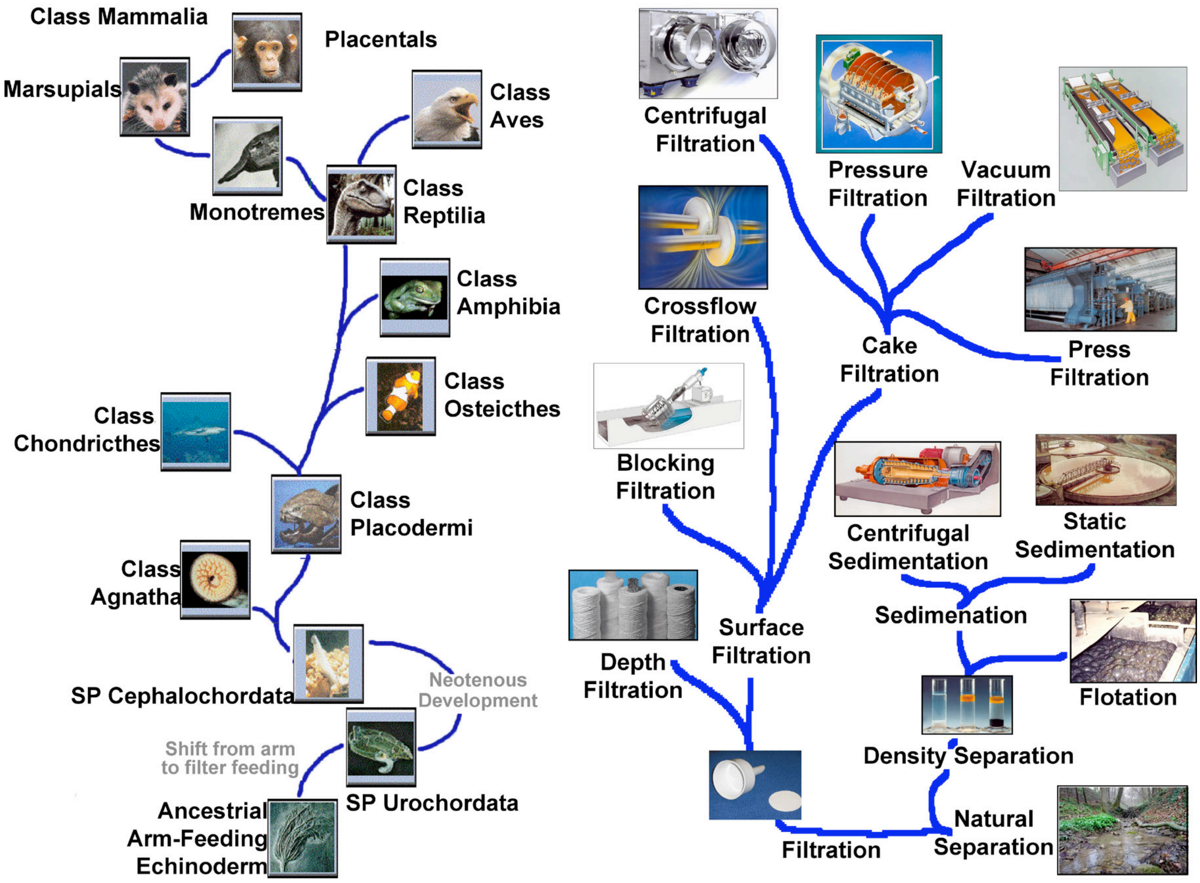

Fig.1: Genealogical trees of animals and separation technology

Starting from a natural beck, where depth, cake and crossflow filtration as well as sedimentation of particles take place simultaneously very sophisticated filtration and sedimentation technologies have been developed during history (Anlauf, 2003). In a similar way one can follow the evolution of animals from the ancestrial arm-feeding echinoderms to highly developed species like aves, reptilia and mammalia.

An other example for analogies between nature and technology may be the assimilation of species to a special environment. As can be seen in fig.2 brown and polar bears are specificly assimilated to the environment, where they live.

Fig.2: Assimilation in nature and technology to the environmental conditions

Similar to that for example peeler centrifuges have to be adjusted to the conditions under which they have to work. A peeler centrifuge for chemicals or minerals must not fulfill principles of hygienic design like in the case of separating pharmaceuticals. In the first case a rotation siphon can be installed, which is very effective to regenerate the remaining heel on the filter medium and to increase the filtration pressure by an additional vacuum. This is not allowed in the case of pharmaceutical applications because the inaccessible filtrate collecting chamber of the siphon bowl behind the filter medium can not be cleaned to the necessary extend and the heel must be removed after each batch completely by pneumatic means to avoid cross contamination of the product batches.

Pictures, which can be directly translated from nature into modern separation technology are illustrated on two examples in fig.3.

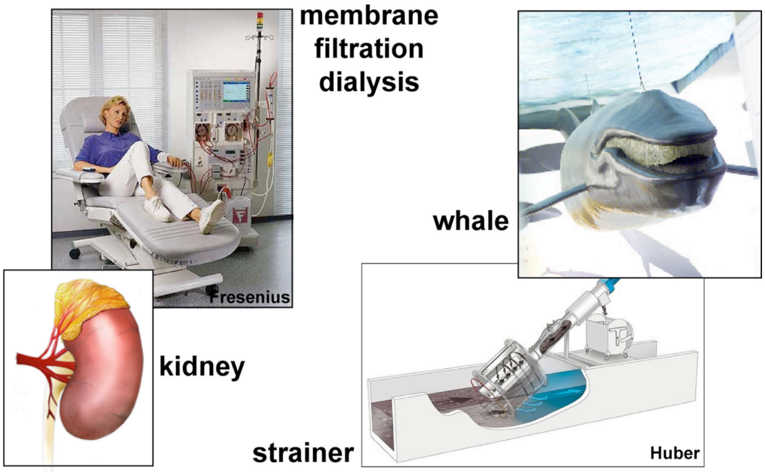

Fig.3: Learning from nature

Artificial kidneys for haemodialysis can be realized by crossflow membrane filtration and strainers for preseparation of oversize is an analogon to the baleen of a whale to filter krill from sea water.

A forth example of analogies between nature and separation technology may be the necessity of a system change (see fig.4), when approaching specific limitations.

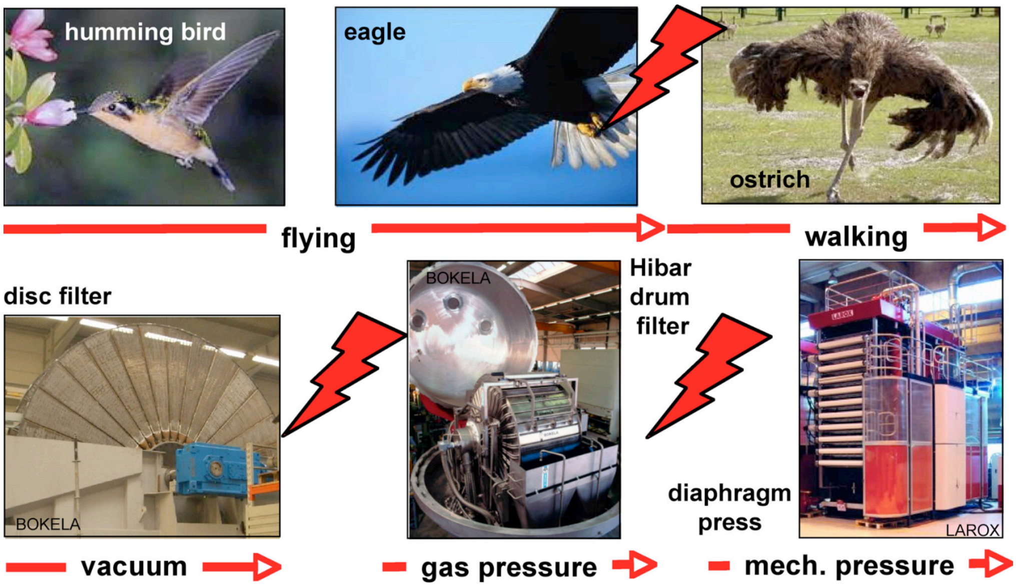

Fig.4: Change of system, when reaching limitations

The locomotion of birds depends on their size and weight. Normally birds are flying, but if they become larger and larger a critical point will be reached, when they are not able to fly anymore but have to walk like an ostrich.

If particles of decreasing size have to be separated a vacuum disc filter may be well suited to separate relatively coarse particles of about 10µm diameter and more. If the particles become smaller the flow resistance of the filter cake and its capillary pressure are increasing and due to the physically limited vacuum the pressure difference meets at a certain point of critical low throughput and critical high cake moisture. Now a system change is necessary and gas overpressure filtration instead of the limited vacuum filtration leads to satisfying results. If the particle size still decreases to about 1µm and below the filter cake structure changes from stiff, brittle and incompressible to week, pasty and compressible. Desaturation leads in such cases normally to shrinkage crack formation in the cake and the compressor is in danger to break down. Again a system change has to be realized and a press filter like a diaphragm press may solve the separation problem successfully.

3. Evolution of separation principles

3.1 Decanter centrifuges

First decanter centrifuges have been patented in 1902 (Stahl, 2004). The first decanter centrifuges exhibited according to the exemplarly in fig.5 documented „Jahn centrifuge“ (1907) fully conical shape. The decanter changed during the course of time and on the basis of proceeding sedimentation theory to the more slender cylindrical/conical shape of the solid bowl like to be seen in fig.5 on the example of a modern standard type of counter-current decanters. Solids are transported by a screw to the right side whereby the liquid leaves the machine over a weir on the left side. During an evolutionary process the constructive principle of decanter centrifuges has been diversified to meet very different separation tasks from which a little assortment is depicted in fig.5. For very hard to separarte small and light particles, which are forming a week and slippery sediment a special co-current flow concept has been developed, which is known as „Sedicanter“. Co-current flow of solids and liquid reduces the danger of redispersing particles and the transport of the sludge underneath a baffle plate and supported by hydrostatic pressure guarantees its discharge.

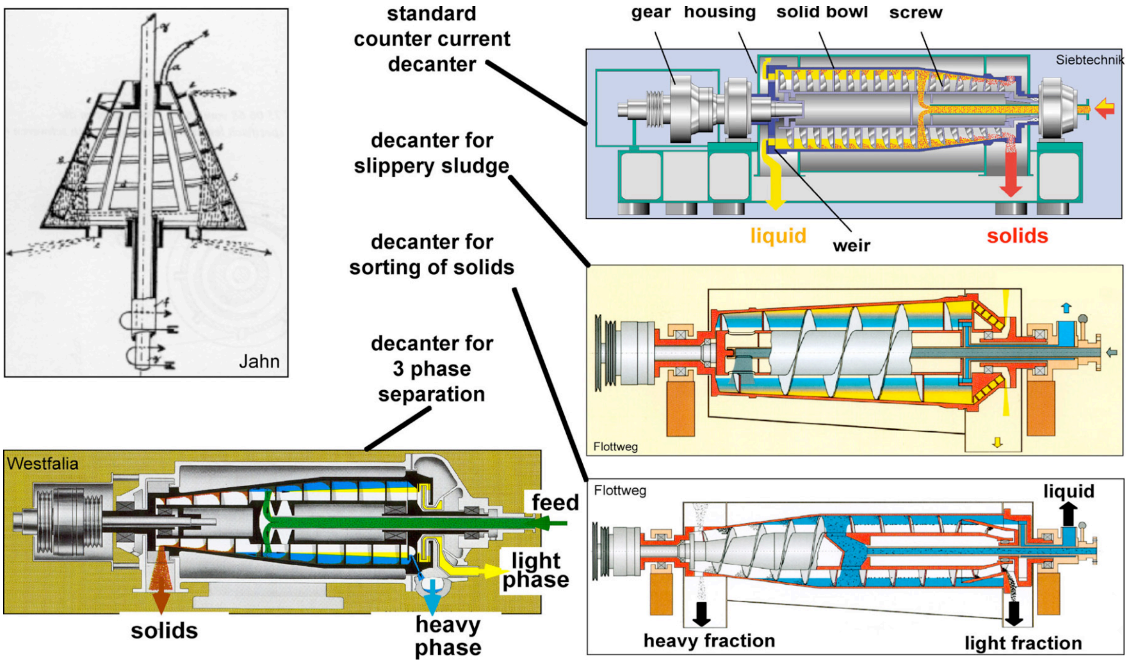

Fig.5: Decanter centrifuges

In an other typ of decanter light and heavy particles, which settle down or float in the liquid can be sorted by a special configuration of the transport screw, which transports sediment and flotate in opposite directions. An other constructive variant allows to separate particles and two immiscible liquids, like oil and water. Several further constructions for special separation tasks, like particle classification, extraction, particle washing amongst others are existing. This demonstrates a powerful basic principle, which is used successfully in many variations for very different separation problems. Maximum of centrifugal number (Froude number) for decanters is about 8.000. Attemps in the past to raise these numbers to more than 10.000 failed due to dynamic machine problems, which refers to fig.4 and the necessity to change the system, when approaching limits. In the case on hand a disc stack separator may be a well suited alternative for centrifugal numbers up to about 15.000 (Kopf, 2008).

Looking more into detail of the Sedicanter solids discharge (see fig.5), a baffle plate, drawn in a larger scale in fig.6, is the decisive element to realize the safe sludge transport by hydrostatic pressure. Using the method of thinking in analogies to find new solutions for further problems one can ask, what can be done else with a baffle plate and try to transfer this picture into other fields of application. In fig.6 three examples for very different applications are given. Beside the discussed sludge discharge in decanter centrifuges a baffle plate can be installed in a special circular chamber of a disc stack separator, which is filled with liquid (water). The baffle plate is fixed and immerses into the liquid, whereby the chamber and liquid is rotating. The centrifugal force holds the liquid in the chamber and a „hydro-hermetic“ sealing is realized. A third function of a baffle plate is given by separating downwards settling and upwards floating sludge in a static rectangular settling basin. The clarified liquid has to dive underneath the plate through to get into the discharge channel and the floating sludge has no chance to follow.

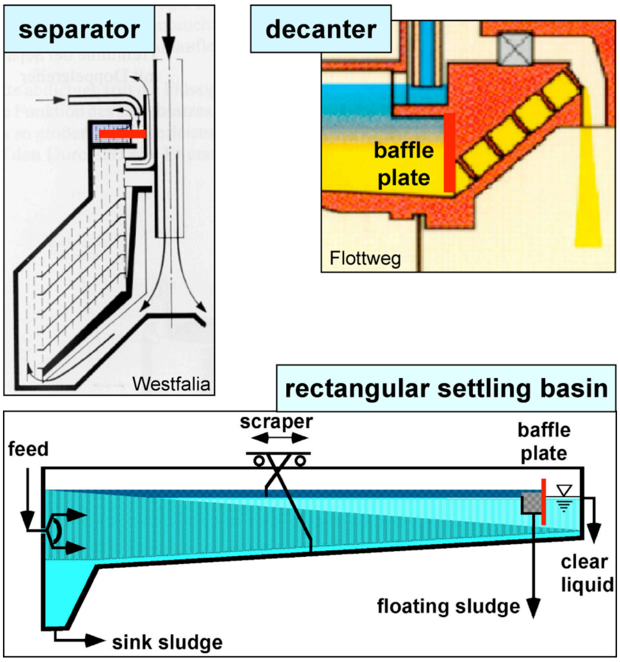

Fig.6: Different functions of a baffle plate

3.2 Continuous vacuum and pressure drum filters

First vacuum drum filters have been patented in 1872. The principle of continuously operating rotary filters has been developed evolutionary over the decades in different directions like variation, modification and intensification. The variation of the filter area arrangement promotes special filter characteristics. According to fig.7 the main types of rotary filters, which have been developed by variation of the principle are the drum, disc, belt and pan filter.

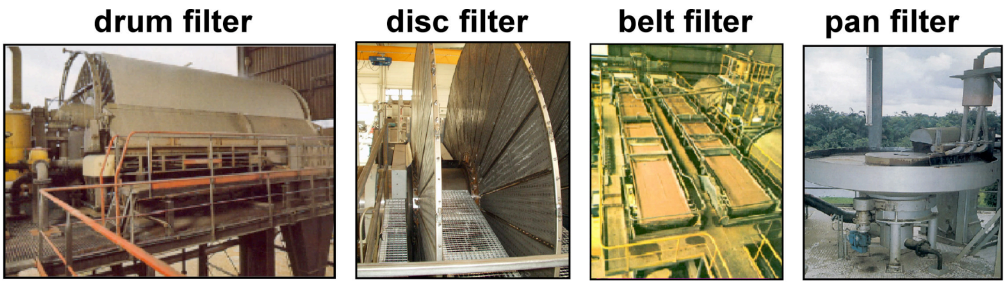

Fig.7: Variation of rotary vacuum filters

The drum filter is the most flexible one, the disc filter offers largest throughput for lowest costs, the belt filter is excellent suited for intensive cake washing and the pan filter is able to separate very coarse and fast settling particles.

As can be seen in fig.8 drum filters have been modified by different possibilities for cake discharge, which made them able to separate slurries of various properties.

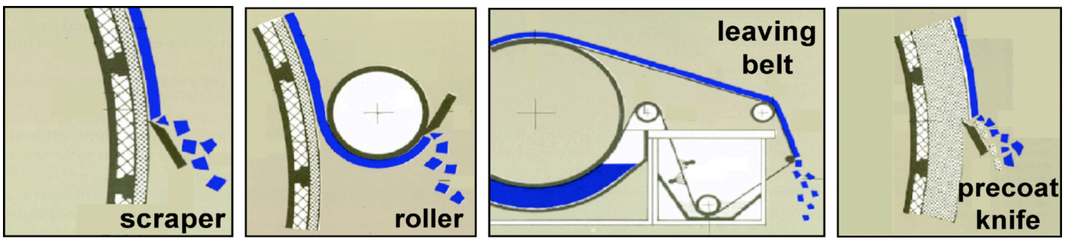

Fig.8: Modification of drum filter cake discharge systems

Scraper discharge supported by a moderate gas blow back is the standard type for good desaturated brittle filter cakes. Very thin, pasty and sticky cakes of high capillary entry pressure can be removed perfectly from the drum by a roller, which takes the cake over from the drum and from which the moist material is usually cut off by a comb shaped knife. If the slurry tends to block the filter medium very quickly, an intensive cloth washing is needed. This is realized by a drum filter with leaving filter belt. If last but not least an extremely fine grained slurry of very low concentration has to be separated, a depth filter, a cross-fow filter or a disc stack separator could be the right solution. An often better alternative is given by a drum filter with precoat, which needs a special modification of cake discharge. The blocked upper layer of the precoat has to be cut off after each filter cycle by an advancing knife (minimal cuttig depth for most modern filters today ca. 50µm).

After variation and modification the intensification of the basic principle should be discussed as third route of successful evolutionary drum filter development. The vacuum drum filter is limited with regard to the maximal pressure difference by the vapour pressure of the liquid. To overcome this limitation a system change of pressure generation has to be performed (see fig.4). As can be seen in fig.9 drum filters can be installed in a pressure vessel and thus operate up to pressure differences of ca. 10bar.

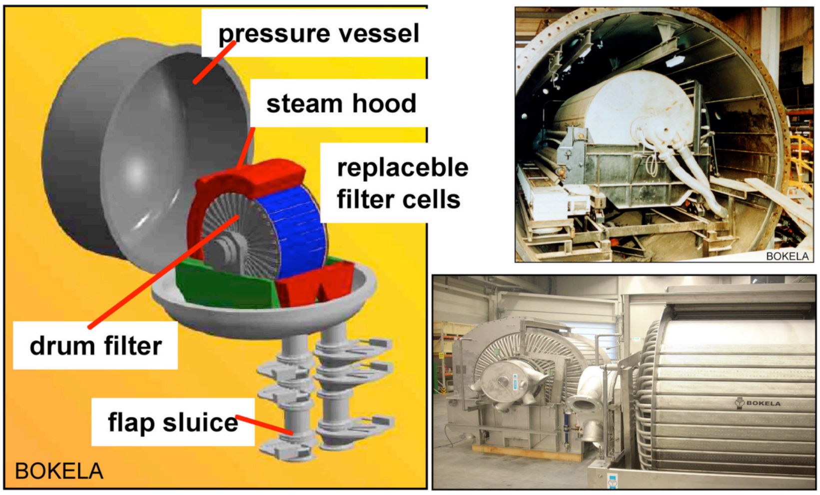

Fig.9: Pressure and steam pressure drum filter

To intensify this principle even more, a hybridisation of mechnical and thermal demoisturing can be realized (Bott, 2002). The pressurized air in the vessel can be substituted by steam of equal pressure, which then is applied in a special steam hood. The steam penetrates the cake in a piston like flow and displaces the pore liquid very effectively. Simultaneously some condensate is originating, which is a perfect wash liquid. To take maximal advantage of these phenomena, the filter construction has to be optimized. Aspects for this are in recent times the minimizing of hydraulic limitations in the filtrate piping system and the increase of the filter cell number. More filter cells enable sharp filtrate separation and thus highly efficient counter-flow washing even on drum filters.

In chapter 3.1 the method of thinking in analogies to find new solutions has been discussed on the example of baffle plates. Now this method should be applied to for vacuum drum filters. How the forces generated by the falling water in a hydropower plant like depicted in fig.10 can be used to improve vacuum drum filters?

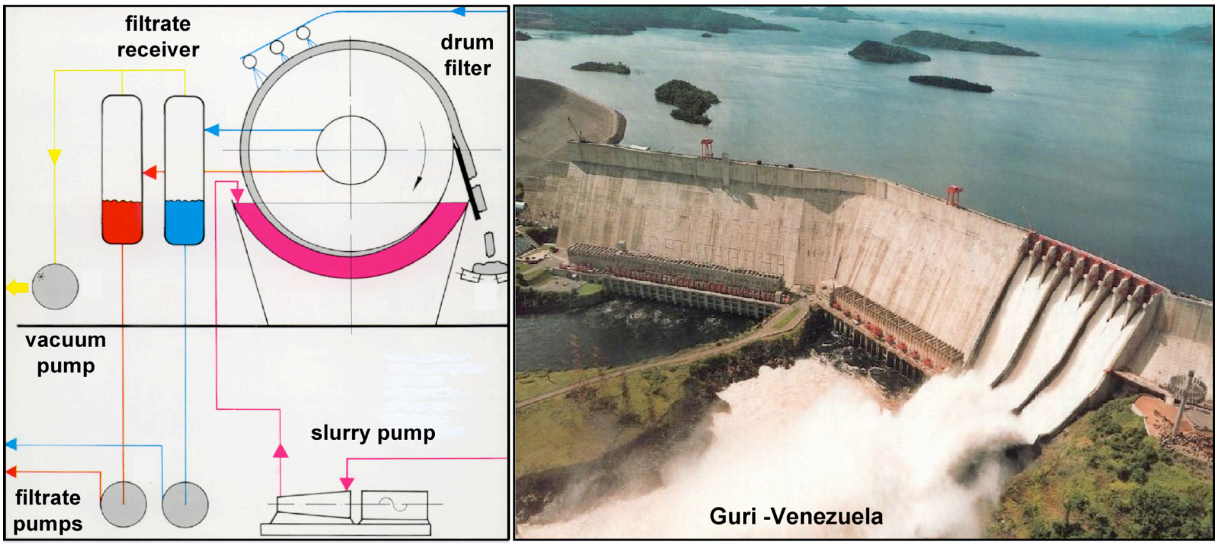

Fig.10: Vacuum drum filter installation and hydropower plant

According to fig.10 a vacuum filter plant normally needs pumps for generating the vacuum and for discharging the filtrate out of the evacuated system. As can be seen in fig.11 a hydrostatic pressure or a siphon effect originates, if the filtrate has the possibility to flow downwards through a pipe.

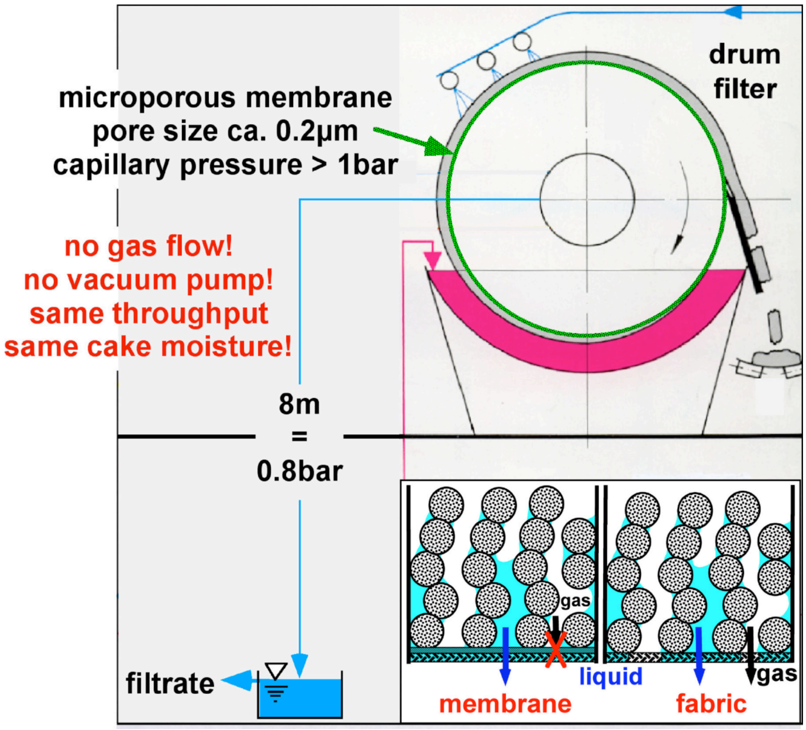

Fig.11: Vacuum drum filter installation without vacuum and filtrate pumps

If the vacuum pump generates a pressure difference of 0.8bar, which means that the liquid column must exhibit a height of 8m, the filtrate can leave the pipe without any filtrate pump. This is already state of the art and known as „barometric leg“. In this configuration the vacuum pump is still necessary.

A vision for the future would be to work in the ideal case without any vacuum or filtrate pump by covering the filter drum by a hydrophilic microporous membrane with a capillary entry pressure of more than 0.8bar (pore sizes < 1µm). In that case no gas is able to flow through the membrane during vacuum filtration (Anlauf, 2006). The filtration pressure is now generated by the barometric leg and can be maintained, because no gas flow interrupts the liquid column due to the semipermeable behaviour of the membrane. Here the principle of a waterproof clothing (analogy!) is inverted!

Evolution by mutation of the basic principle includes in every case the aspect of selection and a new process has only a chance on the market, if it exhibits some advantagues in comparison to the state of the art. In fig.12 the process flow-sheet of a polyterephtalic acid (PTA) production for 600kt per year is shown.

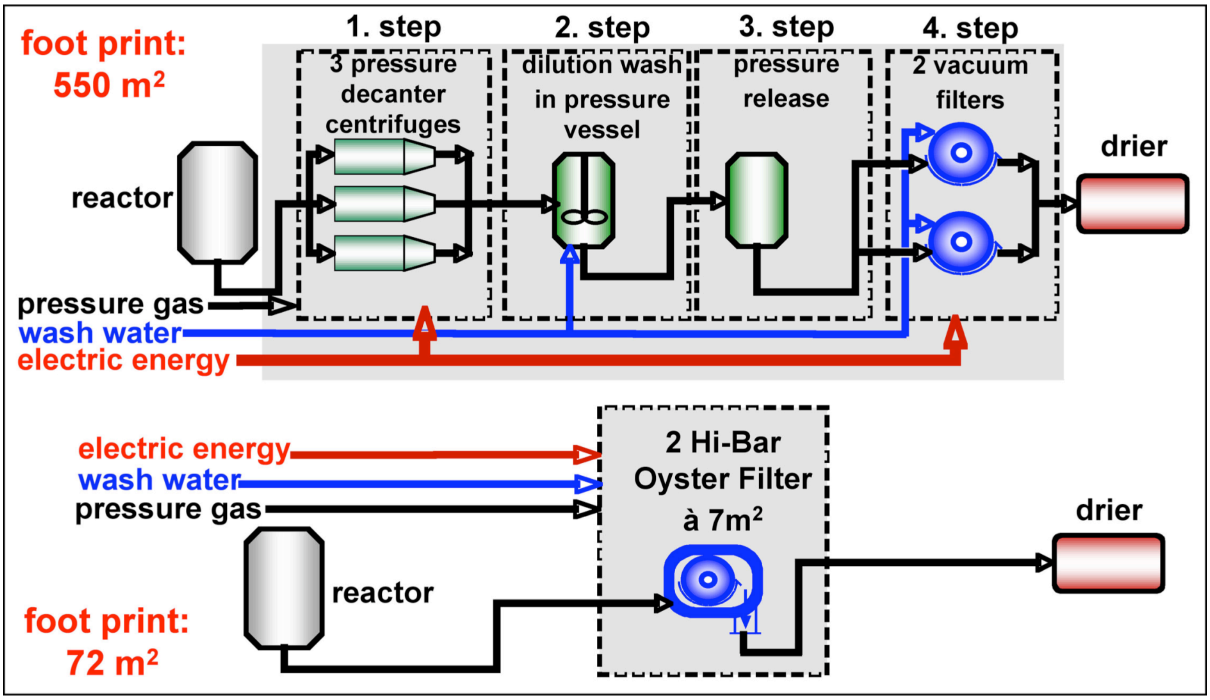

Fig.12: Alternative process chains for PTA production (600kt/a)

In the conventional process 4 process steps are necessary between reactor and thermal drier to separate and purify the solid particles. This complex process can be simplified and improved by replacing the 4-step arrangement by 1 single step using only 2 high efficient pressure drum filters.

Table.1 compares the two process variants under different aspects.

	foot print m^2	energy demand kWh per t PTA (el.)	wash water demand m^3 wash water/t PTA	rel. invest cost
conventional 4-step	550	13.5	1.75	100
new 1-step	72	1.2	0.9	30-40

Tab.1: Comparison of conventional and improved PTA production process

This example demonstrates impressively, how the better is the enemy of the good.

3.3 Discontinuous filter presses

As a third example of evolutionary apparatus development filter presses should be discussed. The first patent for a filter press was granted 1834. Fig.13 shows a historic filter press from 1900 with filter plates made of wood.

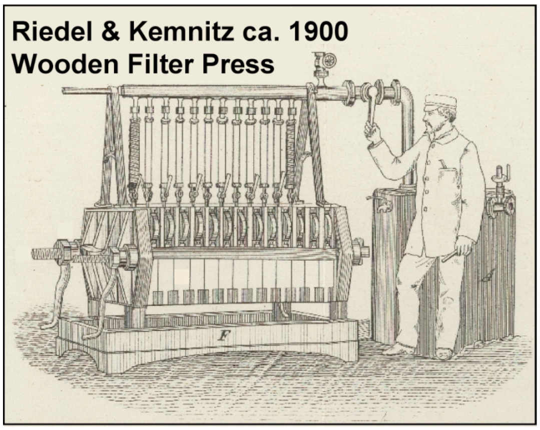

Fig.13: Historic filter press

According to fig.14 filter presses have been improved over time from the frame and chamber to the diaphragm presses.

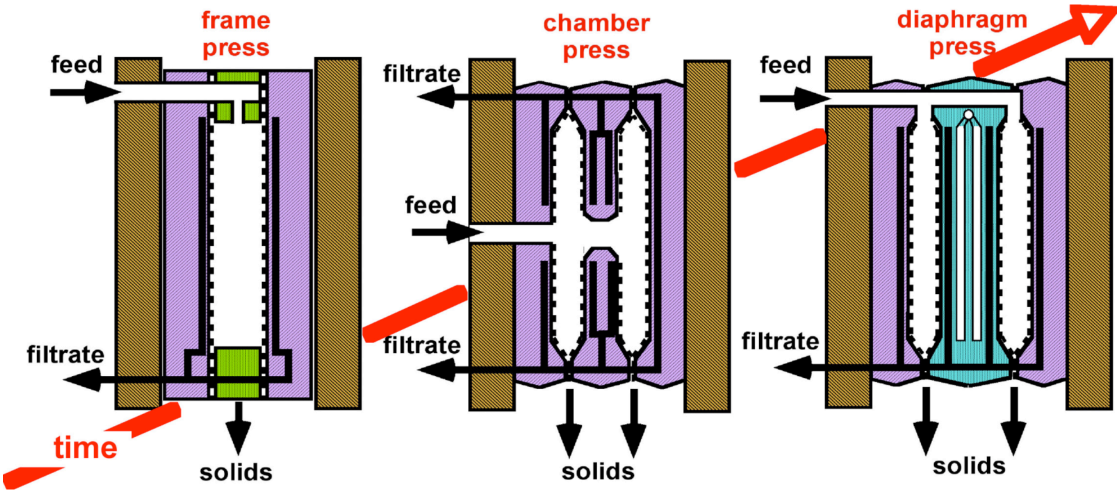

Fig.14: Principle of frame, chamber and diaphragm filter press

The frame press exhibits a simple construction but one deficiency consists in a complicated cake discharge. The cake sticks in the frame and has to be broken out for discharge. More advantageous is the construction of the more modern chamber filter press. The filter plates are forming the chamber by themselves and when the press is opened, the cake should fall out of the chamber by support of gravity. Deficiency of this concept is on one hand, that the cake compression especially in large presses - up to filter plates of 2.5mx2.5m - is fairly inhomogeneous. This results in ineffective cake washing and relatively high cake moisture content. On the other hand relatively thick filter cakes are needed to get a sufficient cake mass for gravity discharge. This requires very long filtration times of often many hours. In frame and chamber filter presses no chance is given to get dry cake in the case of an interrupted slurry feed during the cake formation phase. A part of the chamber will remain still filled with slurry in that case. Progress under several aspects brought the development of the diaphragm press. Now the filter cake can be squeezed very homogeneously by a two-dimensional flexible rubber diaphragm. This leads to better washing and dewatering results in comparison to the chamber press and guarantees the discharge of solid cake under all circumstances. The problem of not guaranteed complete cake discharge and the necessity of thick filter cakes still remains. To overcome these problems the fully automated diaphragm press with vertically arranged filter plates has been developed as can be seen schematically in fig.15.

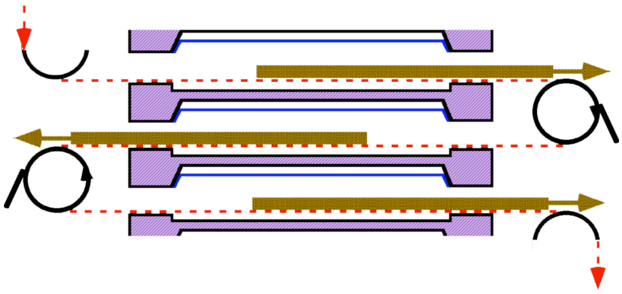

Fig.15: Fully automatic vertical diaphragm press

For cake discharge the press opens, the endless filter belt is moving one chamber length and the filter cake is transported out of the chambers. When the filter cloth is turning around the roller the stiff filter cake is detaching. An additional scraper is mounted for absolut safety of discharge. Homogeneous cake squeezing, ideal distribution of wash liquid, possibility of realatively thin filter cakes and quaranteed cake discharge are characteristics of this configuration.

An other branch in the evolutionary development of filter presses is like depicted in fig.16 the hybridisation of mechanical and thermal demoisturing in form of the so called „hot filter press“ (Anlauf, 2009).

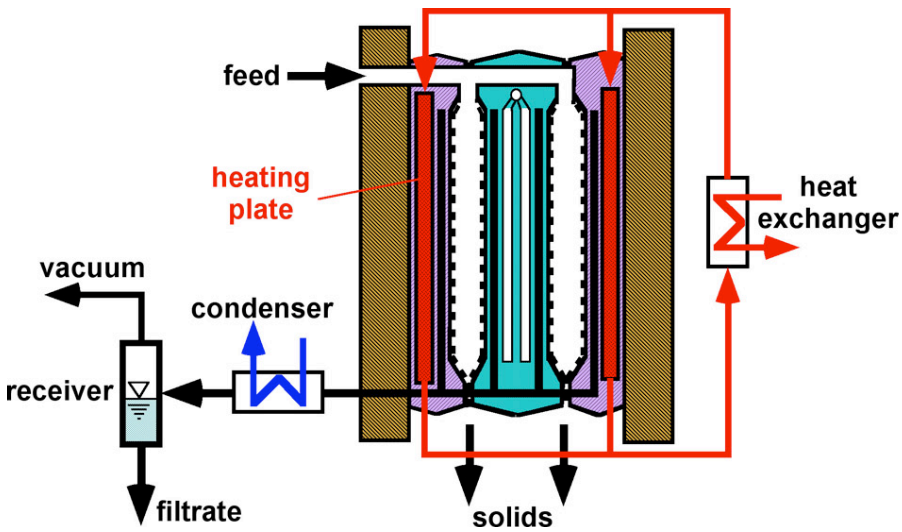

Fig.16: Hot filter press

This is similar to the steam pressure filtration with rotary filters, which has been discussed previously in chapter 3.2. After the cake formation and squeezing hot liquid can be pumped through special heating plates and warm up the filter cake. Simultaneously applied vacuum at the filtrate outlet leads to evaporation of the liquid and thus thermal drying of the cake.

Looking to visions, how extremely difficult to filter slurries could be separated more efficiently than in discontinuous operating filter presses a further system change back to rotary pressure filters might be a promising idea. In contrast to the previously discussed rotary pressure filtration now the rotary filtration process has to be modified as schematically demonstrated in fig.17. Due to extremely high filter cake resistance only very thin filter cakes of less than 1mm even for high filtration pressure will be expected. Very high capillary entry pressure of the cake will lead to fully saturated pasty cakes. Challenges for such a process will be to find a well suited membrane filter medium (see fig.11) and a well suited cake discharge method. Meanwhile some filter media producers can provide promising new products, which could be useful for such a new process and for cake detachment a special roller discharge system could be successful.

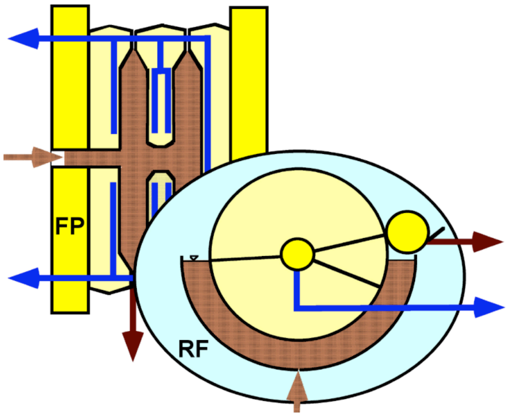

Fig.17: Continuous thin layer pressure filtration

Theoretical calculations for a rotary pressure filter on the basis of experimental data let expect an increase of spec. solids throughput by a factor of 20-40 in comparison to a conventional filter press and comparable conditions (Anlauf, 2010).

4. Conclusions

It could be demonstrated on several examples, that technical progress in the field of separation technology can be compared under many aspects with evolutionary development in nature. Mutation and selection are mechanisms, which can be found not only in biology but also in a technological context. Driving forces for new developments are real needs to get rid of not or still not sufficient solved problems. The process of development can be accelerated beside sound knowledge and modern tools for calculation and numerical simulation especially by creativity and phantasy. The method of thinking in analogies, which means the transfer of pictures into a different context, is a powerful method to find new solutions. New solutions are still needed in the field of separation technology. This results from new applications and a still increasing demand on the separation results with respect to purity, solids moisture, selectivity, sensitivity, energy saving and others.

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