EUROPEAN ROADMAP OF PROCESS INTENSIFICATION

- TECHNOLOGY REPORT -

<u>TECHNOLOGY:</u>
Centrifugal extractorss

<u>TECHNOLOGY CODE</u>: 3.1.2

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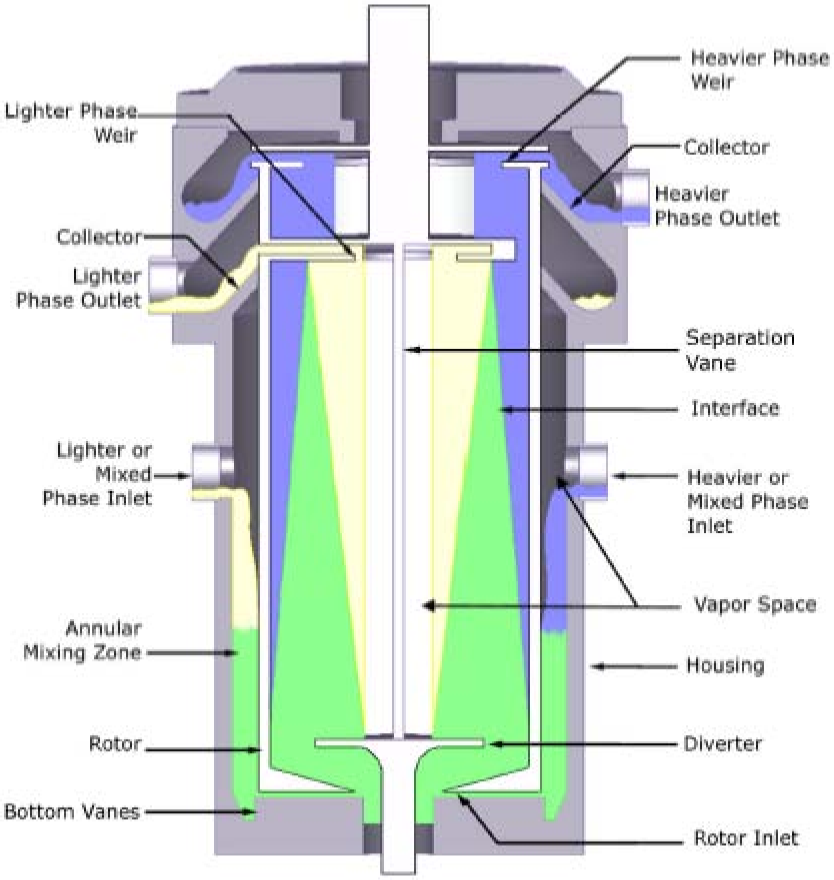
1. Technology

1.1 Description of technology / working principle

Contactor Design and Operation

The annular centrifugal contactor can be operated as both a separator and a contactor, which make it a valuable tool in numerous processes. Its unique design provides mixing and separation in a single, compact unit. Figure 1 gives a cutaway view of the centrifuge housing and rotor with the significant design features including the liquid flow path.

Figure 1 – Monostage Centrifugal Contactor Details



Two immiscible liquids of different densities are fed to the separate inlets and are rapidly mixed in the annular space between the spinning rotor and stationary housing. Please note that the areas above the liquid levels in the contactor housing and at the centre of the rotor are vapour space.

Incoming mixed phases are directed toward the centre of the rotor bottom by radial vanes in the housing base. As the liquids enter the central opening at the base of the rotor, they are accelerated toward the inner diameter wall. The self-pumping rotor is divided into four vertical chambers and is dynamically balanced by the pumped liquids. The mixed phases are rapidly accelerated to rotor speed once trapped in a quadrant and separation occurs at elevated g force as the liquids are displaced upward by continued pumping.

The separating zone extends from the diverter disk to the lighter phase weir. It provides a residence time for the liquid-liquid interface to form and sharpen. The interface should be positioned half way between the lighter phase weir and the heavier phase underflow at the top of the separating zone by selecting the proper size heavy phase weir ring. Optimum performance is thus achieved despite changes in flow rate or liquid ratios because the interface position can shift a significant distance without loss of separation quality.

Because the interface is free to adjust in position, it is important to keep the liquid discharges unrestricted in terms of liquid flow, vapour flow, and pressure. Equilibration of pressure between the centrifuge housing, discharge pipes, and receiver tanks ensures trouble-free operation over a wide range of process conditions.

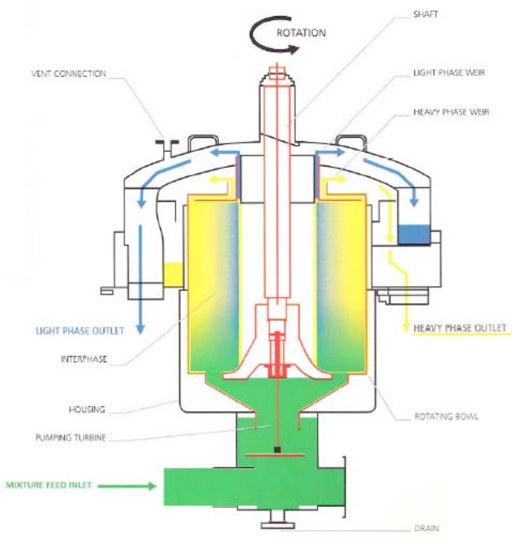
Performance parameters that can be adjusted and optimized for various two-phase processes include: heavy phase weirs, rotor speed, input phase ratio, input flow rate and thus separation residence time, and mixing mode. Input phase ratios of 0.1 to 10 are readily processed with both good mixing and separation performance at all but the lowest feed rates.

Evaluation of total feed rates of less than 10% of the hydraulic limit is advisable in extraction processes to ensure adequate mixing for high stage efficiency. For direct separations, in either high or low mix mode, there is no turn down limit for the feed.

When more than one contactor is used in series the pumping turbine in each contactor is sufficient to transfer material between the stages without additional pumping.

Figure 2 below shows a monostage contactor set up for phase separation purposes with a single mixed phase :-

Figure 2



BXP liquid/liquid separator

The key benefits for centrifugal contactors are:-

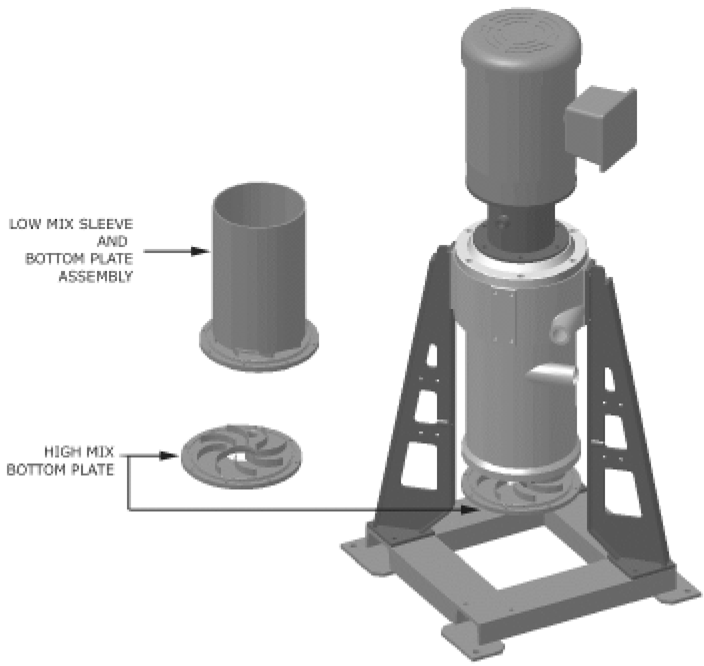
Intensified mixing for good mass transfer.
High centrifugal force (over 1000g) gives rapid phase separation.
Short residence time where degradation of product or solvent can occur e.g. degradation of antibiotic in extracting solvent or radiation induced degradation of extraction solvent in spent fuel reprocessing.
High degree of throughput turn-up/down.
Can handle wide range of phase flow ratios without adjustment.

Additional Features

Low Mixing Sleeve
In processes requiring only two-phase separation or when shear sensitive liquids are being processed, excess mixing in the annulus should be avoided. Therefore, a low mixing sleeve, a cylinder slightly larger in diameter than the rotor, has been developed. It is attached to a modified bottom plate of the centrifuge housing and is easily exchanged for the high mix version.

A view of these two mixing options and their location in the ACC is provided in Figure 3. The low mix sleeve encases the rotor preventing the feed liquids from being mixed by the spinning rotor's outer surface.

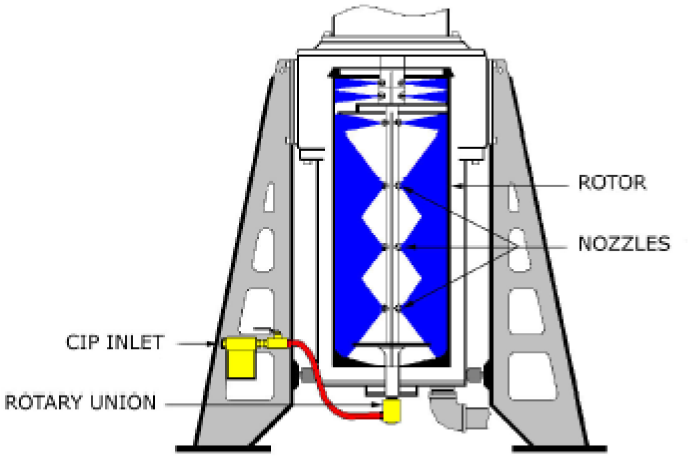
Figure 3 – High and Low Mixing Intensity Options



Feed is diverted to the new annulus formed between the outside of the low mix sleeve and the inside diameter of the lower housing. Radial vanes direct the feed liquids to the centre of the rotor bottom and into the rotor entrance aperture. A lip seal is installed into the base of the low mix sleeve to prevent liquids from bypassing the rotor entrance and entering the high shear area between it and the spinning rotor. Limited mixing still occurs as the liquids enter and are pumped by the rotor, useful in certain washing applications.

Clean-in-Place Design
The ACC, despite low rotor speeds, is an efficient collector of solids due to the relatively long separating residence time provided by this design. Solids accumulate uniformly along the inside diameter of the rotor cylinder from the diverter disk to the heavy phase weir. Over time, they will form a thick layer sufficient to interfere with flow of heavy phase through the heavy phase under- flow slots at the top of the separating zone. When this occurs, heavy phase discharge is diverted over the light phase weir and separation quality suffers. Frequent disassembly for cleaning or inspection is both impractical and inconvenient, especially in remote applications.

A clean-in-place (CIP) rotor design was implemented as shown in Figure 4. It employs a hollow rotor shaft that protrudes from below the contactor housing and extends into the upper rotor assembly.
A set of high-pressure spray nozzles is used to clean each rotor quadrant, simultaneously. Flat patterned spray heads are used in the weir areas to avoid contamination of the product discharge areas by cleaning solutions. This process is performed off-line with the rotor drained and stopped. A rotary union, attached to the bottom of the rotor shaft, provides a permanent inlet for cleaning fluids and allows CIP cycles to be fully automated.



The ability of a centrifugal contactor to carry out a given extraction and separation is determined by the following variables:-

Table 1

VARIABLE	EFFECT
Throughput	Increasing the throughput reduces the residence time in the units and at some point incomplete separation and phase entrainment in the outlet will occur. Alternatively if the feedrate is increased above the pumping capacity of the impellers, the contactors will flood, again resulting in entrainment of the phases in the outlet. The point at which this occurs is termed the hydraulic limit and is the maximum flowrate typically given in the manufacturer's literature using water as a test fluid. Reducing the throughput has little effect except for increasing the residence time in the contactor.
Phase viscosity	Higher viscosity reduces pumping capacity of unit and increases the required phase disengagement time, reducing the capacity.
Phase density difference	Low density differences will increase the required residence time for the separation to occur, reducing the throughput for a given unit.
Viscosity	Higher viscosities require longer residence times for phase disengagement and reduce pumping capability; both reduce the capacity for a given unit.
Emulsification potential	If a process is prone to emulsification, then a low shear impeller can be fitted. Increasing rotation speed can either increase the risk of emulsification or conversely cause the emulsion to separate under increased centrifugal force.
Shear sensitivity	Most models can be fitted with a low shear impeller for shear sensitive streams.
Rotation speed	Increasing the rotation speed typically increases the operating envelope. For example if the throughput is increased until phase entrainment occurs, typically increasing the rotation speed will eliminate the entrainment and give a clean separation.
Phase ratio	For a given fluid system, the heavy to light phase ratio can be changed. Testing has shown that 1:10 to 10:1 is possible but this range will

	depend on the fluids. The weir size and rotation speed can be adjusted to extend these limits if required. The limits are usually indicated by entrainment of one phase in the other.

As indicated above, the first indication that the hydraulic limit of a contactor is reached is usually the entrainment of one phase in the other at the outlet of the contactor. Increasing the rotation speed can eliminate the entrainment. For an extraction with relatively slow kinetics, the maximum throughput may be determined b the residence time required for the extraction rather than the phase separation hydraulic limit.

1.2 Types and “versions”

Vertical Monostage

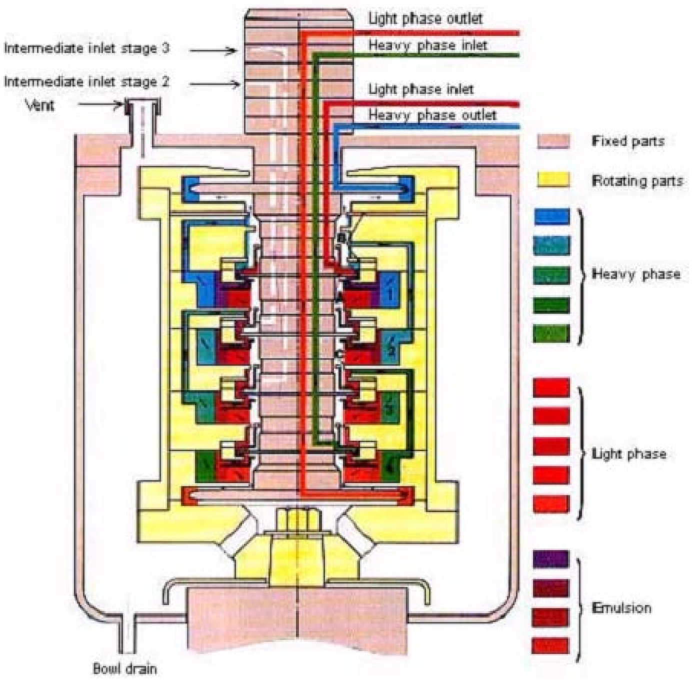
This is the most widely used version and diagrams and internal details are given in Section 1.1. They can be used for simple phase separation or for liquid-liquid extraction (LLE). When used for LLE, a number of contactors will be connected in series and operated as a battery to give multi-stage, counter current extraction. See section 2.1 for details.

Materials of construction are various grades of stainless steel, Hastelloy and PVDF.

Capacities range from 50 litres/hour to 80000 litres/hour total liquid feed.

Vertical Multistage

The diagram below shows the internal arrangement of a four stage unit from Roussellet Robatel. There are four stages fitted to the same vertical shaft and the over- and under-flow from one stage is fed directly to the adjacent stage in a counter-current operation. As the diagram shows, there is no capability of intermediate outlet streams but intermediate feeds can be made at any stage with the outlet from that stage being a combination of the two feeds. For example taking the metal extraction process example given earlier, the aqueous scrub feed will be fed into Stage 4. The aqueous outlet from this stage is then combined with the main aqueous extract feed to Stage 3.



Multistage extractions are less flexible than a series of mono-stage units but they are a more economical way of obtaining a multistage extractor where the full flexibility is not required.

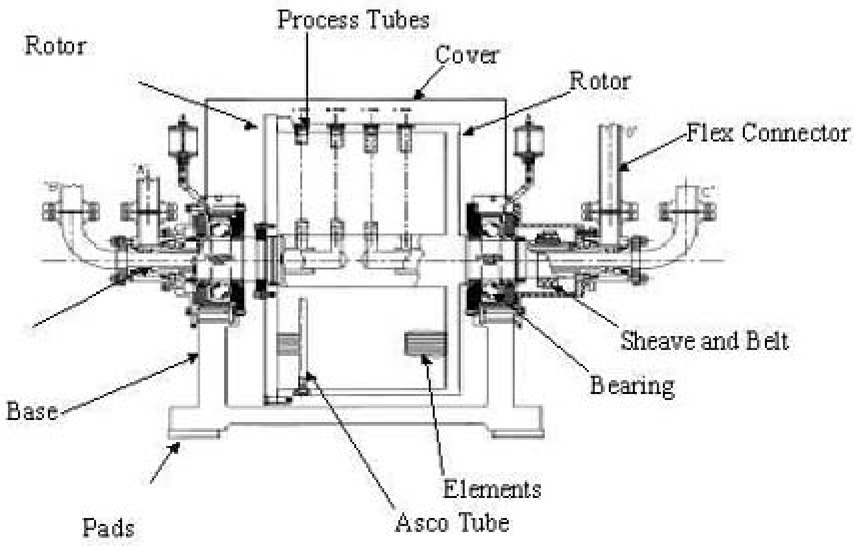
Materials of construction are stainless steel and Hastelloy. Capacities range from 30 litre/hour to 8000 litres/hour total liquid flowrate.

Horizontal Axis Podbielniak (Pod) Centrifugal Contactors

Mechanical Features

The Podbielniak contactor is a horizontally mounted centrifuge. The Pod has perforated, concentric cylindrical bands that fit into grooves on the rotor at one end and the endplate at the other. As seen in figure 3, the rigid inner shaft supports the rotor, and also provides the ports that serve as process liquid inlets and outlets. The shaft is drilled almost to the center from each side, but not through. There is a central channel and an annular channel on both the sides. This provides the four channels needed for process liquid flow.

Figure X Mechanical Features of a Podbielniak Horizontal Centrifugal Contactor



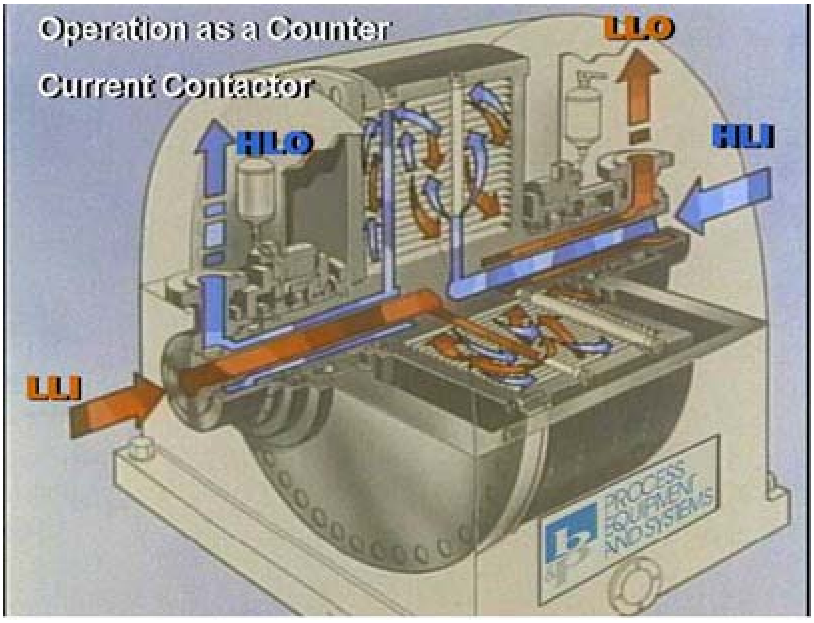
Feed tubes are provided inside the rotor for each inlet and outlet that connect to the shaft. These tubes extend to the rim and are drilled into the rotor for added stability. These tubes are cross-drilled at the appropriate radius to provide an inlet or outlet for a liquid. The mechanical design of the Pod offers the following features:

- Stability. Horizontal orientation provides increased stability and this robust configuration makes the centrifuge more tolerant to vibrations caused by process upsets. The rotor is supported by widely spaced bearings, which also increases stability.
- Hermetic. The Pod is flooded with the process liquids during operation and is equipped with mechanical seals in order to facilitate hermetic operation.
- Versatility. The elements are customized for each application, taking into consideration variables like flow rates, percentage and properties of solids in feed, viscosity of material, etc. The Pod elements can be tailored for systems with solids in order to minimize the solids buildup, reducing downtime due to cleanup. Some feed tubes can be removed from the rim, which provides access to the inside of the rotor for cleanup without disassembly. To accommodate for corrosive materials, the Pod has been manufactured out of alloys such as Hastelloy C, Monel, Inconel, Alloy 20, etc.

Principles of Operation

As seen in figure X below, the heavy liquid (HLI) is introduced near the shaft, and the light liquid (LLI) is introduced near the rim of the rotor. As a result of the centrifugal force and density difference, the heavy liquid is forced out to the rim. As the heavy liquid propagates through the perforations, it displaces an equal volume of light liquid towards the shaft. The two liquids flowing counter-currently are forced to pass each other through the perforations on each band, leading to intense contact. The light liquid is collected at the shaft (LLO), and the heavy liquid is collected at the rim (HLO). This countercurrent series of dispersion and coalescence allows multi-stage extraction.

Figure X



Flow through a Pod

The internal volume of the Pod is divided into three cylindrical zones based on the radial position of the two liquid inlets. The countercurrent contact zone is the volume enclosed between the two inlet radii. In this zone, the two liquids are forced counter-currently through the perforations leading to intimate contact and maximum surface area generation for mass transfer.

Inboard of the contact zone is light liquid clarification zone, where the light liquid is settled and entrained heavy liquid is removed. Similarly, the heavy liquid clarification zone, which is outboard of the contacting zone, clarifies the heavy liquid before it exits the Pod.

Process Feasibility

The criteria for process feasibility in a Pod are that the two liquids are at least partially immiscible, have a density difference and the flow streams should not have more than 30 to 40% (v/v) solids. It is claimed that streams with density differences of less than 0.01S.G can be separated.

The Pod extractor is manufactured in the various sizes, with capacities ranging from 0.4 GPM to as high as 600 GPM for the E-48. The capacities are de-rated for systems with solids, low density difference and viscous liquids.

1.3 Potency for Process Intensification: possible benefits

Table 2: Documented and expected benefits resulting from technology application

Benefit	Magnitude	Remarks
Solvent reduction	Up to 85% reduction has been reported	This is mainly as a result of high efficiency counter-current operation when used as batteries of multiple units.
Reduction in process inventory	Residence times can be as short as a few seconds if required.	Significant savings over typical gravity settling systems.
Short residence time		Significantly reduced degradation of solvent in high radiation environment. Significantly reduced degradation of antibiotic in solvent system.
Efficient phase separation		Can handle much smaller phase density differences than for gravity settling. As low as 0.01SG difference quoted for some equipment
High flowrate turn down ratio	Below 10%v of hydraulic limit should be tested to confirm adequate mixing times.	The turn down when used for phase separation is infinite.
Flexible solvent : water flow ratios	Ranging from 10 : 1 to 1 : 10 for given test system	Tests have been carried out showing good separation can be achieved for sample solvent: water systems with flow ratios changing from 10:1 to 1:10, with changes in rotation speed and weirs required.
Increase yields / reduced product loss	Few % yield on example pharma extraction	Stage efficiencies have been reported as close to 100% and high efficiency of phase separation reduces product loss typically present in batch vessels due to imprecise phase detection and cut-off.
Cost savings	Payback of less than 2 years	Reported for replacing batch extractions with continuous operation. Savings are from extraction solution savings and yield savings as detailed above.

1.4 Stage of development

Originally developed for nuclear fuel reprocessing and have had over 30 years operating experience in challenging environment. Commercially available from a number of vendors in a range of sizes and materials of construction to meet a wide range of applications.

Centrifugal contactors are described by their rotor size; with ranges from lab-sized 12mm diameter rotors up to units with 800mm rotors.

2. Applications

2.1 Existing technology (currently used)

Simple phase separation is typically carried out using gravity settlers. The scale of this operation ranges from 1000m^3 horizontal vessels for continuous removal of water from crude oil feed streams to pharma manufacturing using batch settling in small (<10litre) reactor vessels. The rate of settling can be enhanced using coalescing plates or pads in the vessels.

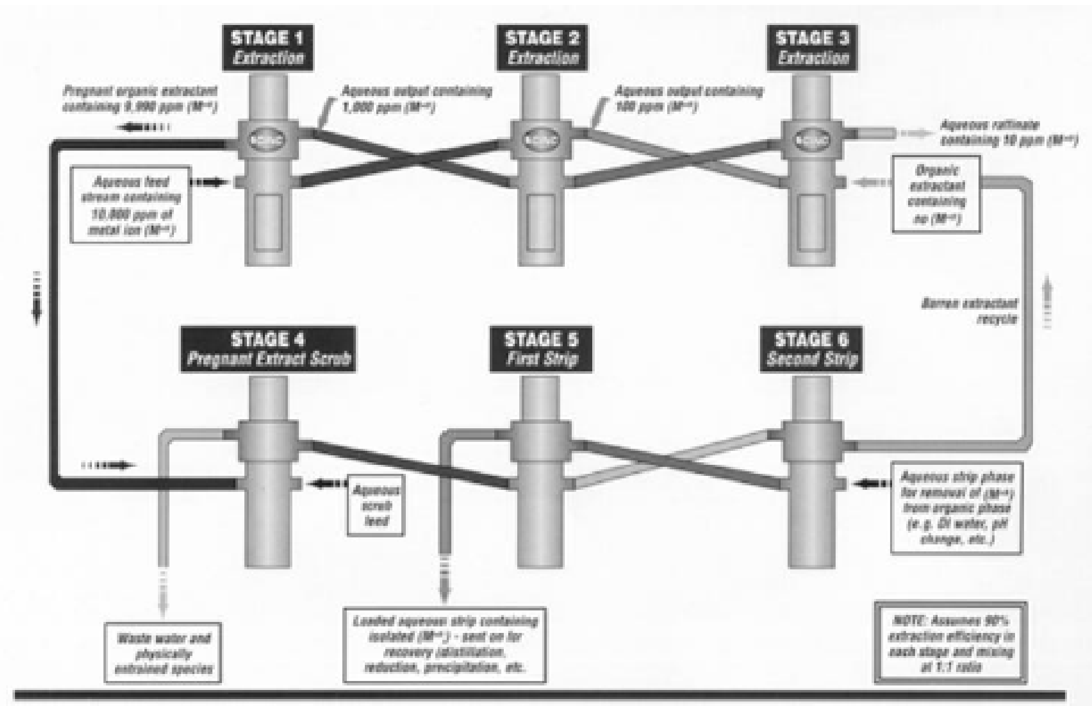
Centrifugal contactors are used where the benefits outlined in Section 1.3 offers benefits over gravity systems.

- Accelerated phase separation of multiphase streams
- Washing out impurities
- Extracting product from feed stream
- Phase transfer reaction e.g. liquid - liquid ion-exchange
- Solvent exchange – using partially miscible solvents to transfer product from one solvent to another continuously.

Given centrifugal contactors' wide operating envelope and flexibility, they are ideal R&D tools. In addition, the impact of scale up is well understood and commercially proven and available in sizes that will cover most conceivable industrial processes.

When used for liquid liquid extraction, centrifugal contactor are typically combined as a battery to provide multistage, counter current operation and also integrated washing, scrubbing and stripping stages. The diagram below shows a typical multi-stage metal purification process.

Figure 5 – Multistage Metal Extraction Process



In the above arrangement, the extraction process has three sequences:-

Extraction — The aqueous solution containing dissolved metal is contacted with an organic solvent counter-currently in three stages. The conditions are designed so that the dissolved metal (or metal complex) partitions favorably into the organic.

Scrub — The loaded organic extract is scrubbed in a single stage to remove any undesirable salts or entrained aqueous phase carried over from the extraction stages.

Strip — The loaded organic phase is contacted with an aqueous phase at conditions where the metal preferentially partitions back into the aqueous phase. The stripped organic phase is then recycled directly back to the first extraction stage.

The critical process parameters are the conditions under which the extraction and stripping are carried out. For metal purification (hydro metallurgy) for example, the aqueous feed into the extract is often strongly acidic whilst the aqueous strip feed is weakly acidic. The organic feed often contains additives that provide or enhance the extraction capacity of the solvent. For example Tri Butyl Phosphate (TBP) is a commonly used additive in nuclear fuel separation LLE and it provides the ligands for extracting the metal into the solvent.

Other additives act as liquid ion exchange agents by protonating in the strong acid extraction conditions, increasing the solubility of metal species, then de-protonating in the weakly acidic strip conditions, causing the extracted metal to partition back into the aqueous phase.

2.2 Known commercial applications

Table 2. Industrial-scale applications of the Technology (existing and under realization)

Sector	Company - Process/ Product name/type	Short characteristic of application	Production capacity/Plant size	Year of application	Reported effects
Nuclear	Purex/Urex – recovery of isotopes from spent fuel reprocessing.	Metal complexes extracted into liquid-liquid extraction of radioisotopes from fuel reprocessing liquor	Small scale due to fissile criticality limitations.	At least 30 years	Significant reduction in inventory and residence time – key drivers for the nuclear applications
	DoE – Savannah River	Salt recovery – extraction of short half life caesium from processing residue			Significant reduction in High Level waste.
Pharma	Multiple	Enhancing liquid-liquid extraction or phase separation in existing batch plant. Pharma companies appear to be using single stage contactors as first choice equipment for small scale development and manufacturing plants.	Few tonnes/year to few '000 tonnes/year	Current	Up to 85% reduction in wash liquid. Yield increase through cleaner phase separation Capacity increase through debottlenecking extraction stage.
Pharma	Multiple	Large scale extraction of antibiotics from fermentation broth. GSK use Robatel units to extract antibiotics in bulk purification	>10 years Podbielniak used in 1946 for first large scale penicillin production		Reference X High efficiency and short residence time minimize degradation of penicillin under extraction conditions.
Pharma	Multiple	Solvent exchange	Small scale lab units to 300mm rotor units		Continuous solvent exchange in liquid phase
Hydro-metallurgy	Multiple	Liquid-liquid extraction of metals from acidic liquor	Precious metal recovery and purification		Reduced inventory, more concentrated product stream than from alternative processes such as ion exchange.
Food	Purification of food components such as citric and lactic acid	Citric acid uses liquid ion exchange			
	Lecithin recovery from soya oil	Oil mixed with 2-3% water/steam which extracts the lecithin.			90% recovery
Chemical industry	Polymer washing				
	Acetic acid purification				
	Washing of phenols from waste streams				
	Liquid Ion exchange				
	Waste dye extraction	Waste dye in aqueous stream is concentration be extraction into organic. This is subsequently stripped and the organic is recycled	Sulphonic acid dye		97% efficient removal of waste dye. 700 fold concentration of dye and minimization of aqueous effluent
Biodiesel manufacture		Accelerated phase separation of diesel from aqueous phases – glycerine separation and wash water separation			Must compete at large scale with low cost gravity settling tanks or corrugated plate settlers
Oil and gas		Drain water de-oiling Cleaning diesel fuel oil Bilge water/oil separation Oil spill clean up Oil separation from aqueous wastes	See reference X for further details Up to 600mm rotor unit	Last 10 years	Onboard treatment of oil/water wastes rather than shipping to shore. Far more compact that gravity based systems.
Shipping		Bilge water/oil separation. Ship borne space is at a premium hence additional cost and efficiency is offset by greatly reduced space requirement.		Last 10 years	Far more compact and more efficient separation than for gravity based systems

2.3 Known demonstration projects

The technology is well proven and research and development is focusing on new applications of the technology rather than on developing the technology.

2.4 Potential applications discussed in literature

There are many potential applications that are developments of existing applications where the benefits of intensified mixing and phase separation are of use.

One interesting new use for which they have been tested in ref X is their use in non-equilibrium extraction, where the fast residence time is used to exploit the extraction kinetics rather than just the extraction equilibria. This is analogous to using continuous reactor residence time to promote fast desired reactions and inhibit slower undesired reactions.

3. What are the development and application issues?

3.1 Technology development issues

Table 4. Technology development issues

Issue	Description	How and by whom should be addressed?
Nitrogen purging	When flammable liquids are used at any scale larger than lab scale, the contactors should be nitrogen inerted. Vendors can provide details of the required flowrates and pressures of inerting gas (normally nitrogen) and some can provide the inerting system and controls as part of the overall contactor package. The nitrogen purging will typically form part of the requirements for the ATEX certification of the equipment.	Decision on whether ATEX rated equipment is required should be made during early design stage as it impacts significantly on the design and cost of the equipment. Due to the ATEX certification process, non-ATEX equipment cannot be readily retrofitted to become ATEX approved.
Control and interlocks	The contactors should be fitted with speed control to allow the rotation speed to be varied. Vendors have a typical control and interlock scheme that provides sufficient control and protection.	
Discharge against backpressure	The centrifugal contactors operate at atmospheric pressure and cannot discharge against backpressure without disturbing the balance and causing entrainment in the discharge. The light and heavy phase outlet (from a single contactor or a battery) must discharge into a buffer vessel with minimal backpressure.	This issue can easily be designed for with a collection vessel downstream of the centrifugal contactor. This vessel also acts as a “slug catcher” to remove any entrained slugs of the opposite phase that get carried over due to disturbances in the operation of the contactors.
Liquid feed	Liquid feed should be as pulse free as possible	This is addressed through the selection of the feed pumps.
Venting	The contactor should be fitted with a vent port to prevent pressure build up due to flow disturbances of off-gassing during the extraction process. Multiple units in a battery should be fitted with a balance line between the contactors to allow pressure equalization hence minimize flow disturbances.	The use of pressure transfer to feed the contactors must take into account the solubility of the pressurizing gas in the feed stream and the degree of off-gassing in the contactor.
Temperature control	The centrifugal contactors typically operate at ambient temperature. It is possible to fit a heating/cooling jacket onto the bowl and trace heat/cool the interconnecting pipework.	The decision on whether a contactor should be fitted with temperature control system should be made as early as possible.
Shaft seals	A range of designs are available – decision should be based on the required seal integrity to prevent emissions. Flammable and/or toxic materials should be fitted with higher integrity seals. If the equipment is installed in an electrically classified (ATEX) area, the seal type will determine the required classification of the equipment. E.g. a double gas purged seal may the required to isolate the ATEX Zone 0 inside the contactor from an external Zone II area. Use of a single seal will cause the environment immediately outside the seal to be classified as a Zone I.	Most vendors supply ATEX certified units so this is an application issue rather that something that needs to be addressed. Seal type and resulting area electrical classification must be considered before ordering equipment

3.2 Challenges in developing processes based on the technology

Table 5. Challenges in developing processes based on the technology

Challenge	Description	How and by whom should the challenge be addressed?
Solids handling	Currently vertical axis extractors cannot operate with solids in the infeed or if solids are generated during the extraction process causing solids to precipitate out of the process.	The design can be developed to handle small quantities of solids. There is significant experience of continuous removal of solids in rotating equipment e.g. continuous centrifuges and this knowledge should be leveraged to increase the capability of centrifugal contactors.
Corrosion resistance	Units are available in PVDF and Hastelloy. PVDF has poor compatibility to many solvents and hastelloy is not completely compatible with strong hydrochloric acid (especially if fluoride is present). Potential alternatives are PFA (near universal chemical compatibility – can be reinforced to give better mechanical strength if required) or PEEK – very good mechanical strength and rigidity and very good material compatibility. The main issue with polymers is their propensity to swell in contact with solvents which creates significant issues with high speed rotating equipment. Tantalum would be ruled out on cost and difficulty of fabrication, and PTFE does not have the necessary mechanical strength.	This needs a customer to approach a vendor with a need and possibly partner the development of an existing design to accommodate a different material of construction.
Economic	Centrifugal contactors are high speed, rotating equipment and as such, are significantly more expensive than static equipment using gravity to separate two phases. The use of centrifugal contactors is accepted where significant benefits offset their cost, hence reducing the cost will expand the potential market beyond the current applications.	Vendors are currently focused on high value markets e.g. pharma, nuclear, fine chemicals. Reducing the manufacturing cost will open the market to sell more and the economies of scale imply that this will further reduce the manufacturing cost.

4. Where can information be found?

4.1 Key publications

The publications given in Table 6 are a summary of papers relating to the experimentation into the enhanced mass transfers that can be achieved in centrifugal contactors

Table 6. Key publications on the technology

Publication	Publication type (research paper/review/book/ report)	Remarks
Design Attributes and Scale Up Testing of Annular Centrifugal Contractors Chemical Engineering Division of the AIChE Spring National Meeting D. H. Meikrantz J. D. Law T. A. Todd April 2005 Can be downloaded from www.osti.gov/bridge website by searching on centrifugal contactor.	Paper	Extremely good description of contactors, operating parameters and effects of scale up.
www.osti.gov/bridge - search on centrifugal contactors	Research papers	Contains approximately 1000 papers on nuclear applications for centrifugal contactors.
Various US Department of Energy websites: search on centrifugal contactors		
Idaho National Lab	www.inl.gov	
Argonne National Lab	www.anl.gov	
Los Alamos National Lab	www.lanl.gov	
Savannah River National Lab	www.srnl.doe.gov	
Rousselet Robatel www.rousselet-robatel.com	Website, vendor literature	Give background literature, capacities and flowrates for various models and configurations.
CINC	Website, vendor literature	

4.2 Relevant patents and patent holders

Table 7. Relevant patents

Patent	Patent holder	Remarks, including names/types of products targeted by the patent

4.3 Institutes/companies working on the technology

Table 8. Institutes and companies working on the technology

Institute/Company	Country	Remarks
Various US DoE Nuclear sites	US	Nuclear processing
Multiple pharma companies	UK and US	
Phoenix Chemicals	UK	Integrated with their continuous reactors
Rousselet Robatel	France, UK, US, Germany	
CINC	US, UK	
Westfalia		
Baker Perkins		
Alfa Laval		
MEAB Metallextraktion	Sweden	

5. Stakeholders

5.1 Suppliers and developers

Table 9. Supplier and developers

Institute/Company	Country	Remarks
Roussellet – Robatel	France, UK, Germany, US	
CINC / CIT	US, UK	
Baker Perkins	US, Worldwide	Market the Podbielniak centrifugal contactor.
MEAB Metallextraktion	Sweden	Main focus is small scale units for nuclear research applications

5.2 End users

Pharma and fine chemical companies have shown that retrofitting to existing batch plants give significant improvements and rapid payback. It is likely that many more pharma and fine chemical companies could benefit.

Gravity systems will always generally be the first choice for organic/water systems unless there is a clear technical or economic benefit through using centrifugal force to enhance the mixing and/or separation. The pharma and nuclear examples have such clear benefits and similar benefits must be demonstrated to new potential users if they are to adopt this technology.

For example the separation of biodiesel from water and glycerine would be greatly enhanced by using centrifugal separation due to the high viscosities and small density differences. However the use of centrifugal force will have to show an economic benefit over the simple gravity settling in a tank or a plate coalescer, particularly as both technologies have the added advantage over vertical axis centrifugal contactors of being very robust to fouling and solids in the feed stream.

The benefits of compact size for a given separation duty and efficient operation can be further realized in offshore applications, where space is at a premium. One example where centrifugal contactors have been used is for on-board treatment of oily bilge water, where stricter environmental requirements can be met without significant cost or space penalties.

6. Expert's brief final judgment on the technology

(maximum 5 sentences)

Centrifugal contactors have a long history of use in industries where their intensified mixing and separation, and short residence and small hold-up give significant benefits over other liquid-liquid extraction equipment. They appear to be the LLE equipment of choice for pharmaceutical operations, both as additions to existing batch plants and for new continuous processes.

Single stage, vertical axis contactors are available in lab scale sizes hence allowing continuous processes to be developed with small volumes of material. They can handle a very wide operating range (flowrates, phase flow ratios, density differences, viscosities etc.) hence making them ideal R&D tools for continuous processing. In addition, the approach to scaling up is well understood and models are commercially proven and available in sizes that will cover most conceivable industrial processes.

REFERENCES

Pod data from www.chemonline.com