TRAXXYS

Innovation & Sustainability

# UPDATE OF BEST PRACTICES SEPARATION TECHNOLOGIES

| **Objective** | **Updating Best Practices Separation Technologies** | | |
|---|---|---|---|
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| Revision | 16.0**A** | Remark | Appended to this document is Addendum 2021 008 1 version 16.0**B** 15-3-22.doc, as discussed with Bart Manders on March 15th 2022 |

# CONTENT



*Disclaimer*

References have been obtained from renowned experts listed below.
Traxxys has mitigated the risk of missing out on latest developments by cross-checking different and – more importantly – international commercial as well as academic open sources from around the globe. Completeness has to be judged in the context of available time and budget.

*Acknowledgement*

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| Heleen Sombekke | Project Manager, EMI Twente |
| John Woodcock | Senior Director Project Sales Europe, Honeywell UOP |

1. <u>Objective</u>

The objective is to update Best Practices of Membrane Technology, Liquid-Solid Separation Technology, Reactive Distillation and Dividing Wall Column Technology as well as the Introductory Webpage on Separation Technology of RVO.

2. <u>Best Practices Structure</u>

The BP structure applied below has been devised with the needs and concerns of the <u>end user</u> in mind. Most likely the end user is active in the process industry and he or she is working on a process related issue. Since nowadays many professionals in the process industries have an international background Traxxys has chosen to rewrite all BP's in the English language.

The interest and curiosity of the envisaged end user for a Best Practice offered by RVO on their website therefore come from a very practical – i.e. non-academic - background. There is an issue, it needs solving and there is time pressure. By screening lists of commercial applications, the end user can find out quickly, whether an application resembles his/her field of interest. If so, diving deeper into the matter makes sense and the BP accommodates that as well.

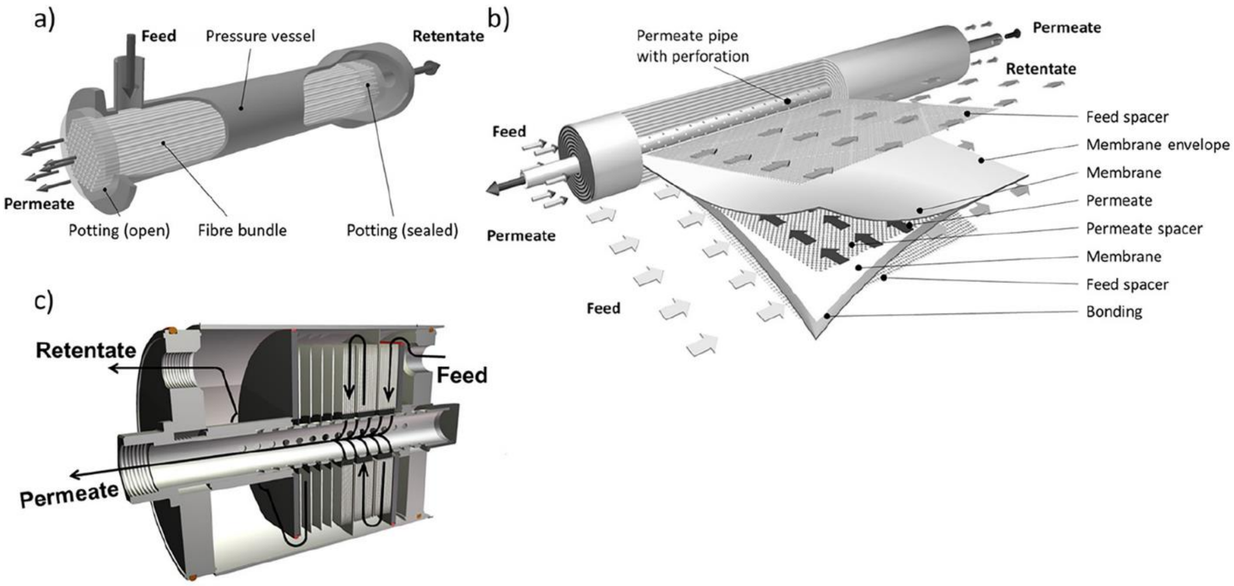
a) Can this technology solve my issue?
b) What are its specific costs and benefits?
c) What are TRL-level, operational and safety risks?
d) Examples?
e) How does it work?
f) Where can I find more information?

This translates into the following Best Practices structure:

| | | |
|---|---|---|
| 1. | Technology function | what does it do? |
| 2. | Application window | what are known applications with which I can compare my issue? |
| 3. | Operating window | what temperatures / pressures / flow regimes / concentrations? |
| 4. | Benefits and Costs | what are the profit incentives and how does compare with cost? |
| 5. | TRL and Risks | is the technology mature? Does it involve HSE- / financial risks? |
| 6. | Working principle | how does it work? |
| 7. | References | where can I find more information? |
| 8. | Suppliers | which companies sell this technology? |

3. BP Membrane technology

# Best Practice Membrane Technology

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| | |
|---|---|
| 4.1 Technology function | what does it do? |
| 4.2 Application window | what are known applications with which I can compare my issue? |
| 4.3 Operating window | what temperatures / pressures / flow regimes / concentrations? |
| 4.4 Benefits and Costs | what are the profit incentives and how does compare with cost? |
| 4.5 TRL and Risks | is the technology mature? Does it involve HSE- / financial risks? |
| 4.6 Working principle | how does it work? |
| 4.7 References | where can I find more information? |
| 4.8 Suppliers | which companies sell this technology? |

## 4.1 Technology function

The function of membrane technology is to separate liquid/solid, liquid/liquid, liquid/gas and gas/gas mixtures.

## 4.2 Application window

This subchapter is meant to give an overview of areas where membrane technology is already commercially applied as a solution. The majority of membrane technology applications is associated with water. A minority of applications is associated with non-water solvent recovery but this area is expanding rapidly. Ref. 3 provides an excellent overview of the first subdivision:

4.2.1 Water associated applications

- Process water
- Drinking water
- Process water reuse
- Irrigation water
- Ultrapure water
- Foods and beverages
- Emergency water supply
- Car wash
- Cooling towers

4.2.2 Non-water associated applications (ref.4)

- Solvent recovery in pharma
- Solvent recovery in refining

4.2.1 Water associated applications

4.2.1.1 Process water

Boiler feed water
Boiler water consumption
Boiler make-up water
Boiler blowdown
Boiler water treatment
Characteristics of boiler feed water
Scaling
Corrosion
Foaming and priming
Oxygen attack
Carbon dioxide attack

Membrane contractors
Deaeration
Ultrapure water
Galvanic-Corrosion
Caustic corrosion in boilers
Silica Scaling in Boilers
Filtration
Cooling tower water consumption
Cooling tower blowdown
Cooling tower make-up water
Cooling water data-center
Cooling water quality
Demineralized water
Demi Water

4.2.1.2 Drinking water

Condensate polishing
Flue Gas Desulfurization
FGD Wastewater Treatment
FGD Wet Scrubber Systems
FGD Equipment
Removal of sulphate in Chloralkali process
Chlorine production in chlor alkali industry
Membrane cell process for chlor alkali production
Removal of sulfate from chlor alkali brine by nano filtration
Removal of sulphate in mining
Salt recovery from sea water
Spent caustic purification

4.2.1.3 Irrigation water

Irrigation water quality
Bicarbonate hazard of irrigation water
Irrigation water lab analysis
Nutrients in irrigation water
Salinity hazard irrigation
SAR hazard of irrigation water
Toxic ions hazard of irrigation water
Waste Water
Anaerobic/aerobic treatment
Biological excess sludge reduction
Grey water recycling

4.2.1.4 Ultrapure water

Mixed bed Ion exchange
Water Conductivity
Boiler feed water
Demineralized process water
Laboratory grade water
Semiconductor
Hemodialysis
Hydrogen

4.2.1.5 Foods and Beverages

Meat, poultry and seafood
Fruits and vegetables
Dairy
Beverages

4.2.1.6 Emergency water supply

Emergency potabilisation units
Emergency seawater desalination units

4.2.1.8 Car wash water treatment

4.2.1.9 Cooling towers

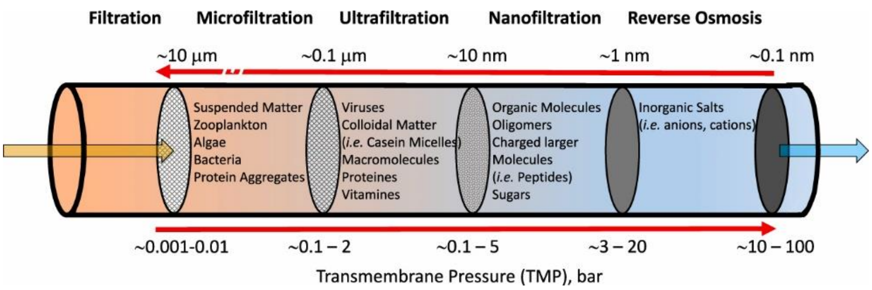
4.2.2 Non water associated applications

| Industry | Solute/solvent | Membrane | Reference |
|---|---|---|---|
| Pharma | APIs/methanol | Starmem™120, Starmem™122, Puramem™228 | Geens *et al.*[73] |
| Pharma | APIs/IPAc | Starmem™122, Starmem™240, Puramem™280 | Rundquist *et al.*[68] |
| Pharma | APIs/crystallisation mother liquor (82% methanol, 15.9% methyl isobutyl ketone, 2.1% toluene) and ethyl acetate | Starmem™122 | Rundquist *et al.*[10] |
| Pharma | APIs/methanol and DCM | GMT-oNF-2 | Szekely *et al.*[52] |
| Pharma | Peptide/MeCN and water | Inopor Nano 450 and 750 | Marchetti *et al.*[74] |
| Refining | Waxy oil stream/toluene and methyl ethyl ketone | Starmem 228 | White *et al.*[75] Gould *et al.*[76] |
| Refining | Free fatty acids/methanol | Nitto Denko, Film-Tec, Osmonics, Desalination Systems, Fluid Systems | Raman *et al.*[77] |
| Refining | Oil/*n*-hexane | PDMS/PAN | Stafie *et al.*[78] |
| Refining | Cotton oil/*n*-hexane, IPA, ethanol | Romicon, Osmonic, Paterson Candy International | Koseoglu *et al.*[79] |
| Refining | Soybean oil/*n*-hexane | Whatman (ceramic membrane) | Wu and Lee[80] |
| Refining | Free fatty acids/ soybean oil and *n*-hexane | Osmonics | Ribeiro *et al.*[4] |
| Refining | Corn oil/ethanol | Koch, FilmTec, Osmonic-Desal, Hydranautics | Kwiatkowski *et al.*[81] |
| Refining | Ethanol, isopropanol, acetone, cyclohexane, hexane | GE Osmonic, Nadir, Evonik MET and Solsep | Darvishmanesh *et al.*[82] |
| Refining | Vegetable oils/hexane | NTGS-2200 | Manjula *et al.*[83] |
| Refining | Soybean oil/hexane | PDMS/PVDF and Zeolite PDMS/PVDF | Weibin *et al.*[84] |
| Refining | Free fatty acids/soybean oil and hexane | PDMS/PVDF and CA/PVDF | Firman *et al.*[85] |
| Refining | Free fatty acids/soybean oil and hexane | Nitto Denko, Film-Tec, Osmonics, Desalination Systems, Fluid Systems | Raman *et al.*[86] |
| Refining | Heavy boilers from a hydroformylation mixture | Puramem S 380, GMT ONF 1, GMT ONF 2, GMT NC 1 | Micovic *et al.*[9] |

**Note**: references quoted above can all be found in master ref. 4 with their original number

## 4.2 Operating window

The picture below shows the pressure regimes at which the various membrane processes tend to operate (ref.11).



The temperature range for membrane processes is mainly dictated by the maximum temperature at which the membrane in question is fully stable without deterioration or performance loss.

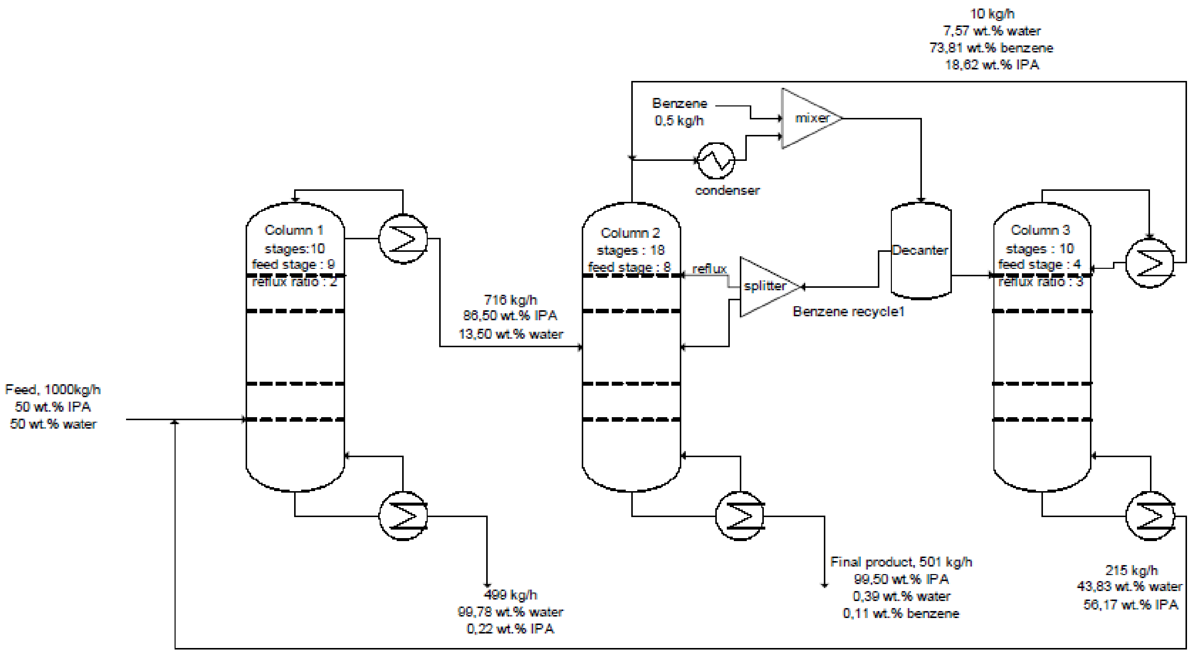
## 4.3 Benefits and Costs

### 4.3.1 Water associated applications

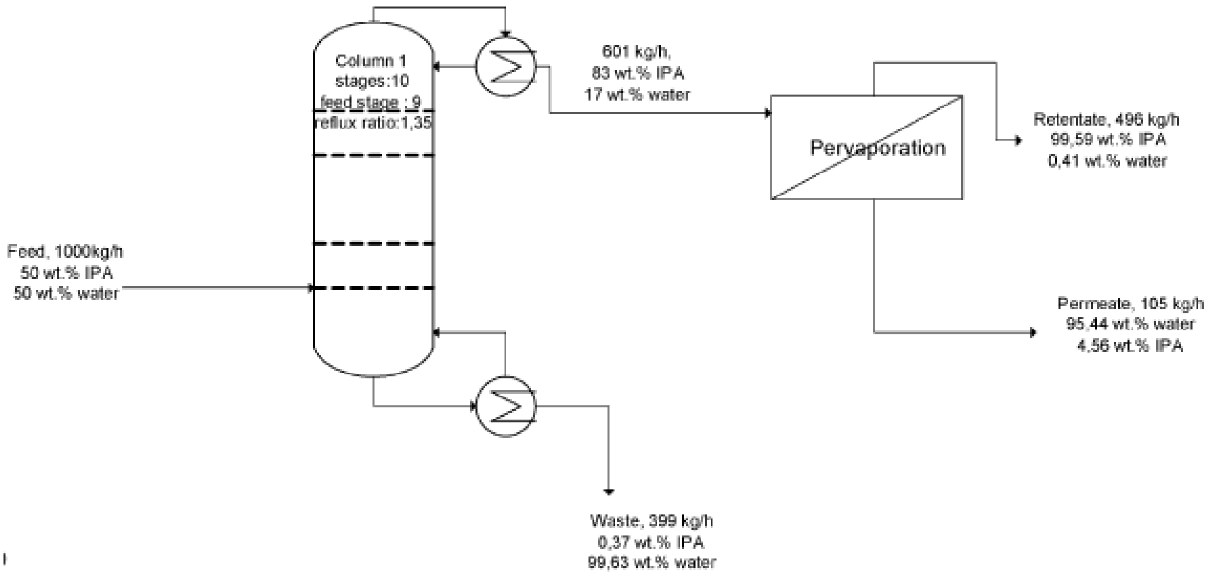
Energy saving most of the time is the primary benefit in water associated applications, especially when water evaporation can be avoided. Below you'll find two examples.

**A. Energy saving in hybrid IPA dehydration (ref.6)**

**Traditional** IPA dehydration by Extractive distillation



**Hybrid** IPA dehydration: Traditional up to azeotrope; membrane from azeotrope to pure IPA




Energy saving in hybrid IPA dehydration

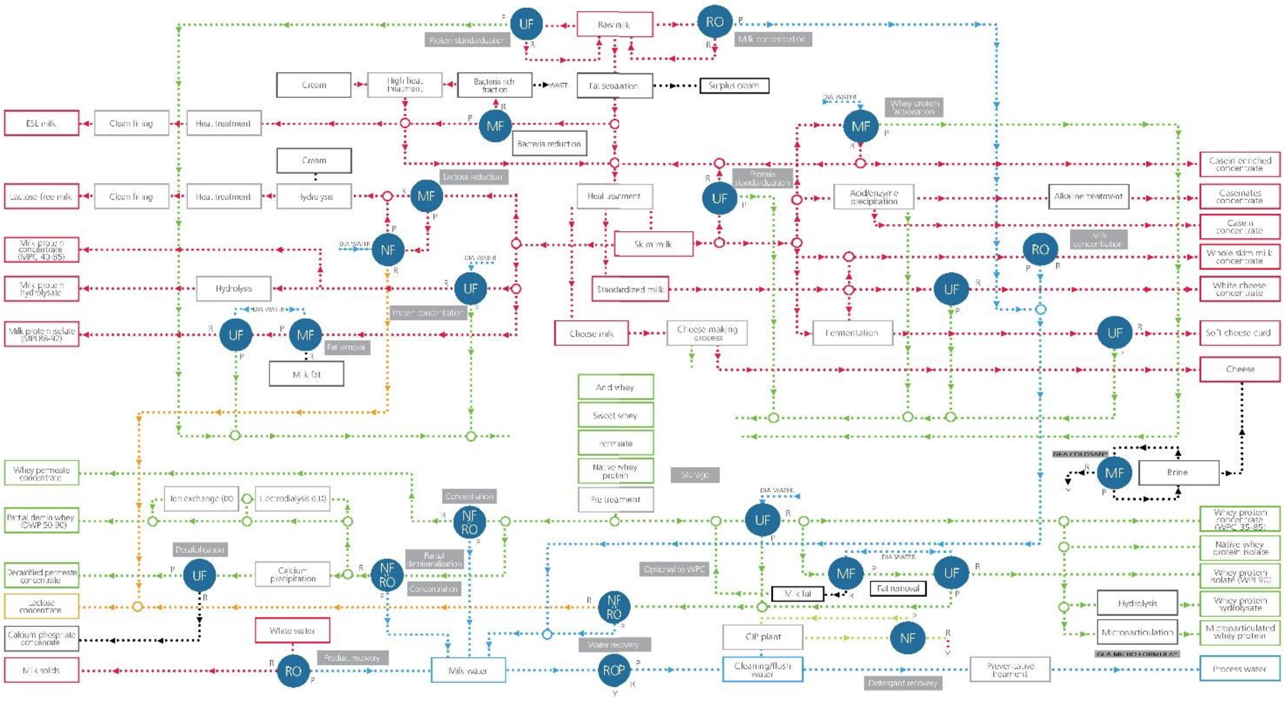
| | D–PV (polymeric) | D–PV (polymeric) | D–PV–D (polymeric) | D–PV–D (ceramic) | Azeotropic distillation |
|---|---|---|---|---|---|
| Cooling water costs (€/year) | 4098 | 4098 | 9923 | 10030 | 15507 |
| Steam costs (€/year) | 52438 | 52678 | 98548 | 100774 | 103595 |
| Permeate condensing costs (€/year) | 5055 | 4856 | 4958 | 4800 | NA |
| Total energy costs (€/year) | 61591 | 61632 | 113428 | 115605 | 119102 |
| Benzene costs (€/year) | NA | NA | NA | NA | 13230 |
| Operation costs (€/t product) | 17.25 | 17.12 | 31.61 | 32.02 | 36.65 |

NA: not applicable.

Energy use of hybrid operation using polymeric membranes is 52% of conventional IPA dehydration using an entrainer like glycerol.

**B. Energy saving in dairy industry (ref.7)**

The figure below not only shows an overview of all relevant dairy process steps; it also shows where membrane separation steps can / have been introduced. On average, introducing a membrane process in a certain step increases energy efficiency of that step by 20-30%.



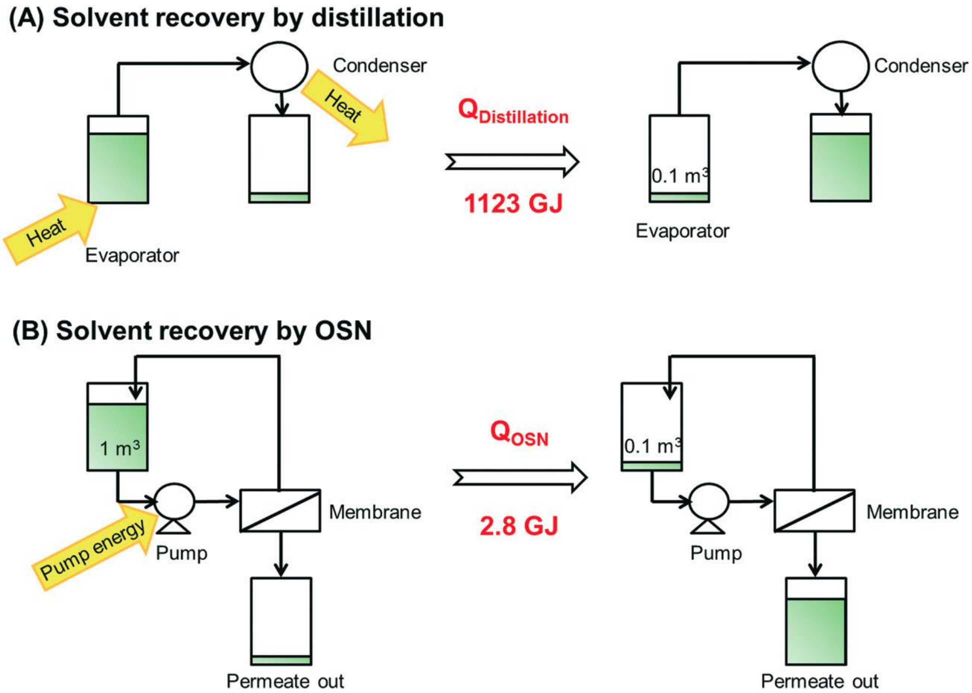

## 4.3.2 Non-water associated applications

Energy use for solvent recovery by distillation vs. solvent recovery by Organic Solvent Nanofiltration (OSN) (ref. 4, p. 4456)

| Solvent | Rank[66] | Solvent generated [$10^6$ kg per year] | $Q_{distillation}$ [kWh] | $Q_{OSN}$ [kWh] | $Q_{distillation}/Q_{OSN}$ | $CO_2$ footprint [$10^6$ kg per year] |
|---|---|---|---|---|---|---|
| Methanol | 1 | 44.8 | 150 | 0.023 | 6453 | 18 |
| Dichloromethane | 2 | 22.3 | 111 | 0.014 | 8010 | 3 |
| Toluene | 3 | 12.1 | 197 | 0.021 | 9278 | 12 |
| Acetonitrile | 4 | 7.9 | 141 | 0.023 | 6029 | 3 |
| Chloroform | 7 | 3.71 | 131 | 0.012 | 10 543 | 0.4 |
| *n*-Hexane | 8 | 2.99 | 149 | 0.028 | 5300 | 3 |
| *n*-Butyl alcohol | 9 | 2.86 | 223 | 0.023 | 9788 | 2 |
| DMF | 10 | 2.79 | 244 | 0.019 | 12 569 | 2 |
| *N*-Methyl-2-pyrrolidone | 12 | 2.02 | 303 | 0.018 | 16 930 | 1 |
| Xylene | 13 | 1.47 | 208 | 0.021 | 9748 | 1 |
| 1,1,2-Trichloroethane | 15 | 1.23 | 194 | 0.013 | 15 090 | 0.2 |
| Methyl *tert*-butyl ether | 16 | 1.2 | 126 | 0.025 | 5062 | 1 |
| Ethylene glycol | 18 | 0.82 | 337 | 0.017 | 20 285 | 0.3 |

**Note**: the carbon footprint was calculated for 70% solvent recovery after Kim e.a. (ref. 4 / 53)

An example of the potential of OSN for significant enhancement of energy efficiency is given in the example below. For recovering 451 tons of methanol by distillation the total energy consumption is 1123 GJ. The OSN set-up requires only 2.8 GJ @15 bara operating pressure which is more than 200 times less. (ref. 4, p. 4455).




## 4.4 TRL-level and Risks

All membrane processes quoted in chapter 3.2 are commercial and TRL therefore is 9.

Still there are risks in applying membrane technology which can unexpectedly interfere with your operation. You will find these risks primarily in the area of concentration polarization and membrane fouling / scaling.

### 4.4.1 Concentration polarization

This phenomenon is an easily understood yet difficult to solve example of mass transfer limitation by counter diffusion. When a membrane does a proper job, it lets one or more components pass through, blocking one or more other components at the same time. These components cannot stay at the membrane surface: they have to diffuse back to the bulk of the mixture at the retentate side of the membrane. It is this back diffusion that hampers the components in easily passing through the membrane. Especially desalting processes like reverse osmosis suffer from this back diffusion which requires *higher* trans-membrane pressures to keep fluxes at a reasonable level.

From an engineering point of view one can think of a few solutions to reduce or eliminate concentration polarization. An obvious solution is to apply crossflow alongside the membrane causing high shear stress in the immediate area of the membrane surface. This ensures a) sweeping non-permeable components off the membrane surface and b) enhancing transport of permeable components to the membrane surface. This comes at the price of higher operational cost since more pumping energy has to be applied. In liquid phase operation pressure drops and associated pump energy will be limited. In gas phase operation these parameters can become significant since volumes in the gas phase tend to be orders of magnitude higher than in liquid phase.

Another solution is the use of turbulence promotors or static mixers, which positively affect mass transfer in the immediate vicinity of the membrane surface. Needless to say these promotors only work when crossflow is applied. They do not work if the mixture flow is perpendicular to the membrane surface. In that case they may even have an unintended opposite effect.

4.4.2 Scaling and fouling

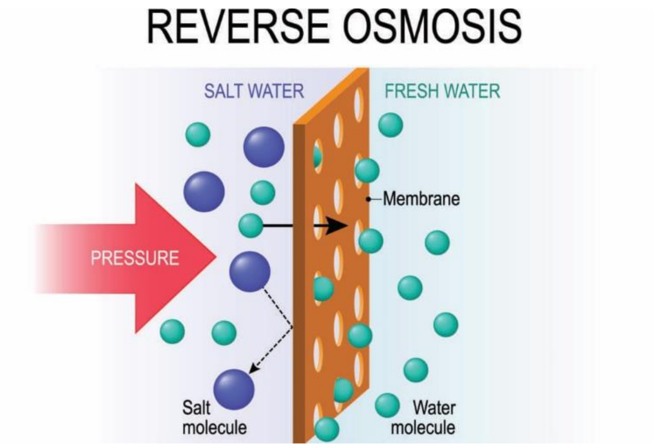
Membrane fouling occurs when components from the feed stream deposit on the membrane surface or in the pores of the membrane. This can decrease the flux through the membrane or change the separation properties of the membrane. As a result, the energy efficiency of the membrane process decreases. In membrane fouling, a distinction is made between four types of fouling, being (i) colloidal (including silica, iron and aluminum oxides), (ii) scaling (including calcium carbonate and sulfate), (iii) organic (including oil, fats, proteins) and (iv) biologically (by bacterial growth). Each type of pollution requires its own approach. See references 8 and 9 for an overview.

## 4.5 Working principle

All membrane technologies have in common that when confronted with a mixture of molecules in liquid or gaseous state they show a preference for letting pass one type of molecule and holding back other type(s). They differ however in the type of driving force that governs the separation and in the exact transport phenomena that occur in the membrane material itself. The picture below (ref.5, page 3) shows the driving force can be:

a) Hydraulic pressure
b) Electrical voltage
c) Concentration gradient
d) Relative volatility

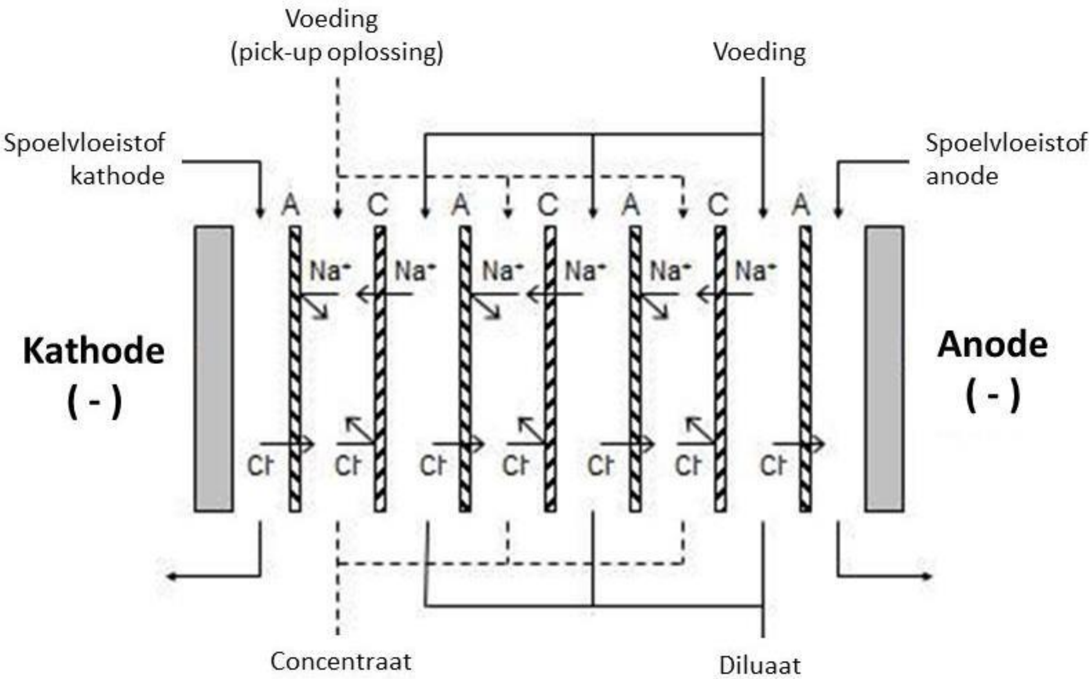
a) Hydraulic pressure



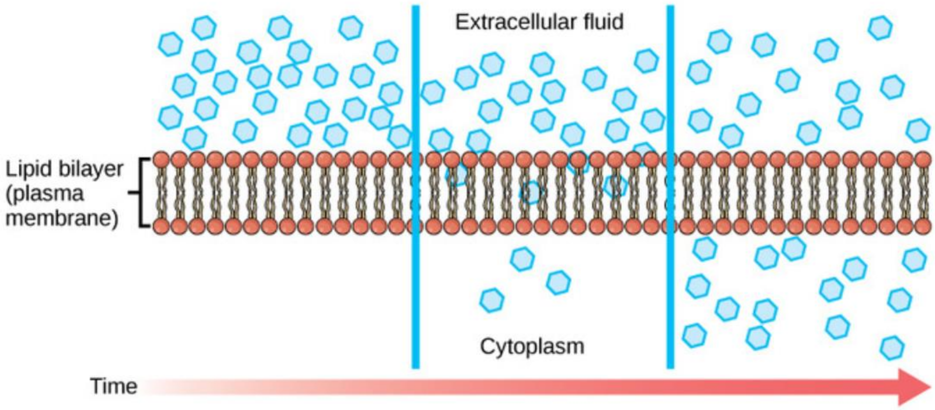

By exerting a pressure on the left side of the membrane that exceeds the osmotic pressure resulting from the salt concentration difference across the membrane, water molecules are selectively transported through the membrane from left to right.

b) Electrical voltage (ref.10)

By applying a voltage difference, ions start moving in opposite directions. Since the membranes preferentially reject one type of ion and let the other type pass, a concentrating effect is obtained.



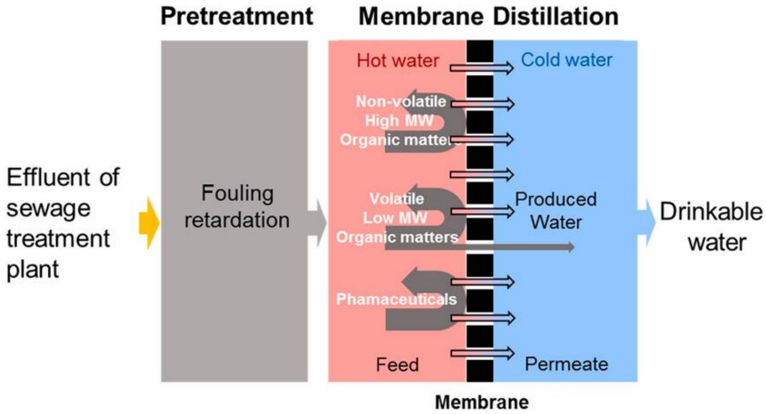
c) Concentration gradient (ref. 12)




**Passive Transport**: Diffusion is a type of passive transport. Diffusion through a permeable membrane moves a substance from an area of high concentration (extracellular fluid, in this case) down its concentration gradient (into the cytoplasm).

d) Relative volatility (ref.13)

Especially in membrane distillation processes, the relative volatility of components is a driving force. Components with low volatility are rejected; components with high volatility can pss the membrane.



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## 4.7 Suppliers

### Manufacturers of pressure vessels

LENNTECH Water Treatment Solutions Pressure Vessels

BEL Bel Pressure Vessels

CodeLine Pentair Water Codeline Pressure Vessels

Knappe Composites Knappe Pessure Vessels

PENTAIR Pentair Pressure Vessels

phoenix Phoenix Pressure Vessels

PROTEC arisawa Protec Bekaert Pressure Vessels

Wave Cyber Membranes / Vessels

PWG Membrane Housings

Closed Circuit Reverse Osmosis:

Desalitech MAXIMUM RECOVERY GUARANTEED Reflex

Suppliers of membrane spare parts

Membrane adapters

i-lec for Filmtec membranes

Parts for RO systems

Additional information

Competitive Membrane Comparison Guide

Competitive Membrane Comparison Guide NEW

Reverse Osmonics Chemicals

RO cleaning Chemicals

Antiscalant Chemicals (Avista-Vitec)

Antiscalant Chemicals (ROPUR)

GE-Water-Antiscalants

Scaling and Antiscalant

Membrane brands

LENNTECH Water Treatment Solutions Lenntech Membranes

DOW FILMTEC MEMBRANES Filmtec Membranes

HYDRANAUTICS Nitto Group Company Hydranautics Membranes

TORAY Toray Membranes

suez SUEZ Membranes

KOCH INDUSTRIES INC. Koch Membrane Systems (Fluid Systems™)

CSM CMS Membranes

Inge Membranes

Parker Membranes

Ropur Membranes

TriSep Membranes

Axeon Membranes

Millipore Membranes

LewaBrane Membranes

Pentair RO Membranes

Microdyn Nadir

OLTREMARE

LG RO Elements

Mann + Hummel

Membranium

Porex Membranes

Synder Filtration Synder Membranes

Akkim Akkim Membranes

SIEMENS Siemens Membrane

4. BP Reactive distillation

# BEST PRACTICE REACTIVE DISTILLATION

®Katapak SP – Sulzer Chemtech

® Sulzer Chemtech – distillation tower with different kind of internals

| | |
|---|---|
| 5.1 Technology function | what does it do? |
| 5.2 Application window | what are known applications with which I can compare my issue? |
| 5.3 Operating window | what temperatures / pressures / flow regimes / concentrations? |
| 5.4 Benefits and Costs | what are the profit incentives and how does compare with cost? |
| 5.5 TRL and Risks | is the technology mature? Does it involve HSE- / financial risks? |
| 5.6 Working principle | how does it work? |
| 5.7 References | where can I find more information? |
| 5.8 Suppliers | which companies sell this technology? |

## 5.1 Technology function

The function of reactive distillation (RD) is twofold: first to convert feedstocks into product(s) and second to separate product(s) from feedstocks and from each other.

## 5.2 Application window

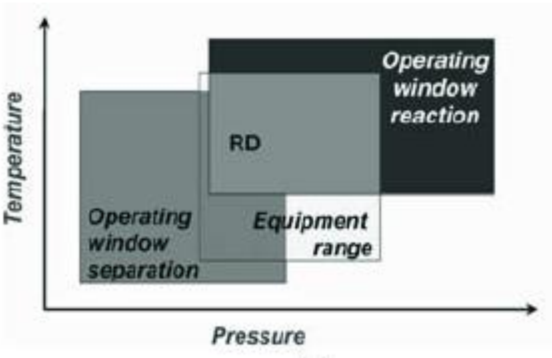
Industrial applications are listed below (ref. 1,16).

| Reaction type | Catalyst / internals |
|---|---|
| ***Alkylation*** | |
| Alkyl benzene from ethylene/propylene and benzene | Zeolite β, molecular sieves |
| Motor fuel alkylate production | Sulphuric Acid |
| ***Amination*** | |
| Amines from ammonia and alcohols | H2 and hydrogenation catalyst |
| ***Carbonylation*** | |
| Acetic acid from CO and methanol / dimethyl ether | Homogeneous |
| ***Condensation*** | |
| Diacetone alcohol from acetone | Heterogeneous |
| Bisphenol-A from phenol and acetone | N/A |
| Trioxane from formaldehyde | Strong Acid catalyst, zeolite ZSM-5 |
| ***Esterification*** | |
| Methyl acetate from methanol and acetic acid | H2SO4, Dowex 50, Amberlyst-15 N/A |
| Ethyl acetate from ethanol and acetic acid | Katapak-S |
| 2-methyl propyl acetate from 2-methyl propanol and acid | Cation exchange resin |
| Butyl acetate from butanol and acetic acid | H2SO4, Amberlyst-15, Metal oxides |
| Fatty acid methyl esters from fatty acids and methanol | H2SO4, Amberlyst-15, Metal oxides |
| Fatty acid alkyl esters from fatty acids and alkyl alcohols | Ion exchange resin bags |
| Cyclohexyl carboxylate from cyclohexene and acids | |
| ***Etherification*** | |
| MTBE from isobutene and methanol | Amberlyst-15 |
| MTBE from isobutene and methanol | Undisclosed catalytic internals |
| ETBE from isobutene and ethanol | Amberlyst-15 / pellets, structured |

| | |
|---|---|
| TAME from isoamylene and methanol | Ion exchange resin |
| TAME from isoamylene and methanol | CD IsoTAME catalyst, internals |
| DIPE from isopropanol and propylene | ZSM 12, Amberlyst-36, zeolite |
| TAEE from C5 feeds and ethanol | Ion exchange catalyst |
| ***Hydration / Dehydration*** | |
| Mono ethylene glycol from ethylene oxide and water | Homogeneous |
| ***Hydrogenation / Dehydrogenation*** | |
| Cyclohexane from benzene | Alumina supported Ni catalyst |
| MIBK from benzene | Cation exchange resin with Pd/Ni |
| Butenes from butadiene | CDModules® |
| Propene from MA/PD | CD*Hydro* |
| ***Hydrolysis*** | |
| Acetic acid and methanol from methyl acetate and water | Ion exchange resin bags |
| Acrylamide from acrylonitrile | Cation exchanger, copper oxide |
| Isobutene from MTBE | CD*IB* catalyst |
| ***Isomerization*** | |
| Iso-paraffins from n-paraffins | Chlorinated alumina and H2 |
| Isoamylenes from normal pentenes | Zeolite calatyst |
| ***Nitration*** | |
| 4-Nitrochlorobenzene from chlorobenzene and nitric acid | Azeotropic removal of water |
| ***Transesterification*** | |
| Ethyl acetate from ethanol and butyl acetate | Homogeneous |
| Diethyl carbonate from ethanol and dimethyl carbonate | Heterogeneous |
| Vinyl acetate from vinyl stearate and acetic acid | N/A |
| ***Unclassified reactions*** | |
| Monosilane from trichlorsilane | Heterogeneous |
| Methanol from syngas | Cu/Zn/Al2O3 and inert solvent |
| DEA from monoethanolamine and ethylene oxide | N/A |
| Polyesterification | Autocatalytic |

## 5.3 Operating window

The operating window of RD is dictated both by the occurring reaction between feedstocks and by the required separation of products. Ideally, one product is the lightest and the other product is the heaviest, with the reactants being the intermediate boiling components (ref.3). Moreover, as both operations occur simultaneously in the same unit, there must be a proper match between the temperatures and pressures required for reaction and separation (ref.4,5). A low temperature yielding high relative volatilities may lead to low reaction rates requiring large amounts of catalyst or liquid holdups to achieve the required conversion. In contrast, a high temperature may promote side reactions or move the equilibrium to the feedstock side making it difficult to drive the reaction to completion.




If there is no significant overlap of the operating envelopes of reaction and separation the combination of reaction and distillation is not possible. An obvious example of the latter is the combination of a high pressure reaction and a vacuum distillation.

## 5.4 Benefits and Costs

The first benefit of RD is capex reduction. Instead of designing and erecting separate reactors and distillation columns, RD requires only one integrated column. This saves investment in separate reactors, erection structures, piping, heat exchangers and possibly pumps.

The second benefit of RD is in opex reduction. Thermodynamically, the repeated short-length sequence of reaction immediately followed by separation has a higher efficiency than the gross approach of reacting / separating / reacting / etc. in different vessels interconnected with piping.

## 5.5 TRL and Risks

All quoted examples in chapter 2 are TRL 9.

The main risk associated with reactive distillation comprises the operational controllability of steady state and dynamic behavior of the column. Underlying causes are a) the high degree of non-linearity of reaction-distillation systems in general; b) the limited amount of in-process information like local temperatures and local concentrations of feedstocks and products in column, overhead condenser and reboiler; c) the limited amount of independent process variables available to the operator for steering column performance in the desired direction. Ref. 7-13 give you more background info.

Of these underlying causes, a proper understanding of occurrence and impact of non-linearity is the most important factor. This precedes the design phase of the column. Non-linearity is inherent to the chemical reaction occurring. Local reaction rates are affected by local temperature, local pressure, local feedstock concentrations and catalyst activity. Of these, temperature dependency is always non-linear and concentration dependency can be, depending on the order of the reaction involved.

In this context, imperfect reactant mixing, surface wetting, and/or spatial catalyst activity variations will certainly cause spatial differences in reaction rate. In the case of endothermic reactions, higher rates will cause temperatures to drop which has a mitigating effect on local column temperature swings. In the case of exothermic reactions higher rates will cause temperatures to increase. This in turn will lead to even higher reaction rates. At the same time, higher temperatures promote evaporation of the most volatile component, leading to lower concentrations in the liquid phase of that specific component which can be mitigating.

This brief analysis merely serves to illustrate the need for a thorough understanding of the static and dynamic behavior of combined reaction-distillation steps before entering the design phase of an RD column. It also shows the need for local process information – especially information about local temperatures and local component concentrations. With the advent of cost effective sensors over the past decade, new windows of opportunity have opened up (ref.14,15).

Finally, looking at conventional independent column control parameters, the operator can only steer or affect reboiler duty, reflux ratio, column pressure, feed temperature and feed composition. These parameters will more or less instantaneously affect top, bottom and feed entry areas of the column, but they cannot instantaneously control e.g. temperature excursions somewhere in the intermediate areas of the column. For these intermediate areas to stay inside their operating envelope it is mandatory the reaction-distillation combination is intrinsically stable.

## 5.6 Working principle

Although hardware designs of reactive distillation columns may look significantly different from one vendor to the next, the working principle invariably is the same.
Somewhere in the column there is catalyst. In most instances the catalyst is heterogeneous. In some instances, homogeneous catalysis is applied in the liquid phase. When feedstocks come in contact with the catalyst, reaction to products takes place. Separation of these products from feedstocks subsequently follows in the immediate vicinity of the reaction area.

Basically there are two classes of hardware designs. They differ in the way the catalyst area and the separation area are located relative to one another. Structured packing with a catalytic surface is one extreme. A set of conventional catalyst loaded distillation trays is the other extreme.

Looking more closely to these hardware layouts one can state that structured packing enables reaction-separation on a micro-scale, whereas catalyst loaded distillation trays enable reaction-separation on a macro-scale. This suggests structured packing will be more effective than conventional catalyst loaded trays for a given equivalent column height, provided the liquid residence time on the catalyst surface of the structured packing is not limiting.

The final choice between these two hardware layouts depends on *technical* factors like:

- ability to coat the structured packing with catalyst
- required residence time of the reaction mixture in contact with the catalyst surface
- achievable liquid hold-up of conventional trays
- required radial and axial heat transfer for temperature control
- allowable pressure drop over the column
- etc.

and on *economical* factors like:

- purchase cost of equipment of structured packing versus conventional trays
- availability of hardware in the required diameters / heights
- maintenance of packing / tray replacement
- replacement of catalyst
- etc.

## 5.7 References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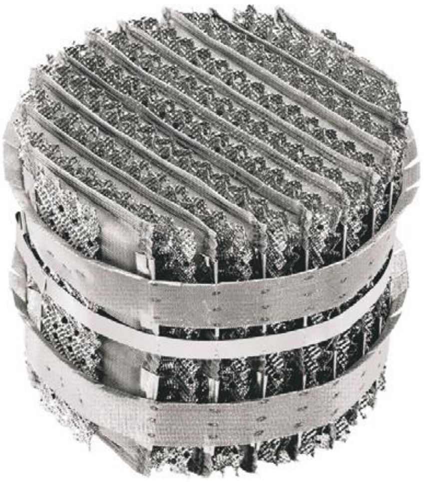
15. https://www.honeywell.com/us/en/industries/products#sensing-and-iot
16. Lummus - CDTech RD portfolio: https://www.yumpu.com/en/document/view/52709669/mtbe-steam-sheet-cdtech
17. Oral communication mr. F. Nulle, CEO of Sulzer NL – H.N. Akse of Traxxys on February 7th 2022.

## 5.8 Suppliers

1. Sulzer Chemtech
   Katapak
   https://www.sulzer.com/en/products/separation-technology/structured-packings
   Sulzer offers all sorts of column internals. When asked (ref.17) the company stated on the record they can deliver complete RD columns including internals. They do not see it as a separate type of product next to conventional distillation columns with structured packing.

2. Lummus (has acquired the CDTech RD portfolio previously owned by CB&I)
   https://www.yumpu.com/en/document/view/52709669/mtbe-steam-sheet-cdtech

3. Koch-Glitsch
   Katamax reactive distillation structured packing:
   https://koch-glitsch.com/search-results?searchtext=reactive+distillation&searchmode=exactphrase



Koch Glitsch – Katamax

Sulzer – Katapak

Images of Lummus hardware internals are absent in the public domain. However, from CDTech's original portfolio all RD-technologies and Process flow diagrams are available in the public domain (ref.16). The most straightforward designs are shown down below.

Looking more closely at the Katapak and Katamax internals we see large differences.

The Katapak design is clearly inspired by Sulzer's broad range of structured internals for distillation columns (like Mellapak, Mellapak plus, Mellapak CC, BX, BX plus, CY, CY plus, Mellacarbon, Mellagrid, etc.). This ensures optimal wetting of the surface; low gas phase pressure drop and proper mass transfer between liquid and gas phase. It also means liquid holdup on the surface is low compared to conventional distillation trays, leading to relatively low liquid residence times at the catalyst surface compared to trays.

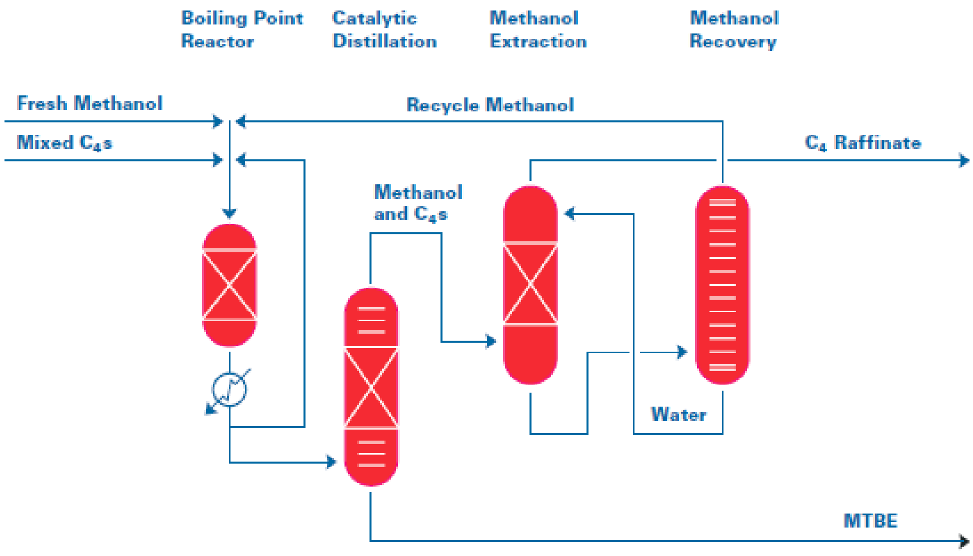
The Katamax design has the appearance of a conventional distillation tray which has been filled with open gauze envelopes containing catalyst. Depending on the percentage of cross sectional void area of the tray bottom, one can expect to be able to create significant residence time of the liquid phase in close contact with the catalyst.

A *cautious* conclusion can be, one type would be the preferred choice for fast reactions (low residence time suffices) while the other type would be the preferred type for slow reactions (higher residence times required).

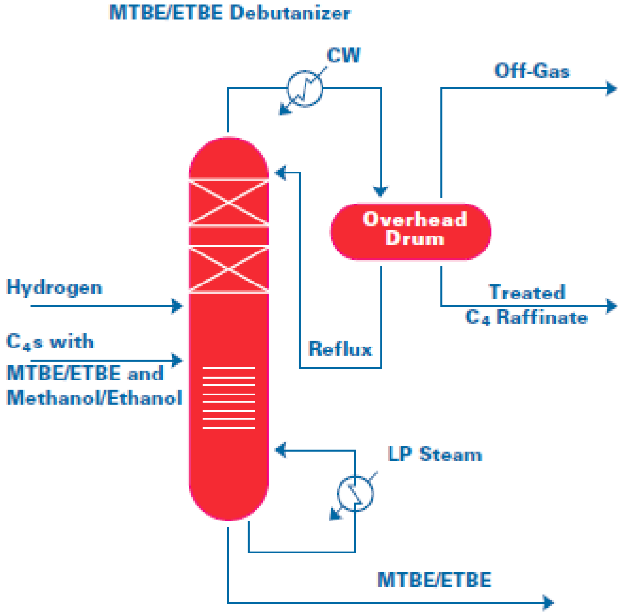
This is the Lummus / CDTech RD technology portfolio.

- MTBE From Steam Cracker and Dehydro C4 Feeds
- Selective Hydrogenation of MTBE/ETBE C4 Raffinates
- Isobutylene from MTBE Decomposition
- Advanced Sulfuric Acid Catalyzed Alkylation
- Process for the Production of Motor Fuel Alkylate
- Selective Hydrogenation of MAPD
- Selective Hydrogenation of Refinery C4 Feeds
- Increased TAME From Refinery and Steam Cracker C5 Feeds
- Isoamylenes Production from Normal Pentenes
- TAEE from Refinery C5 Feeds

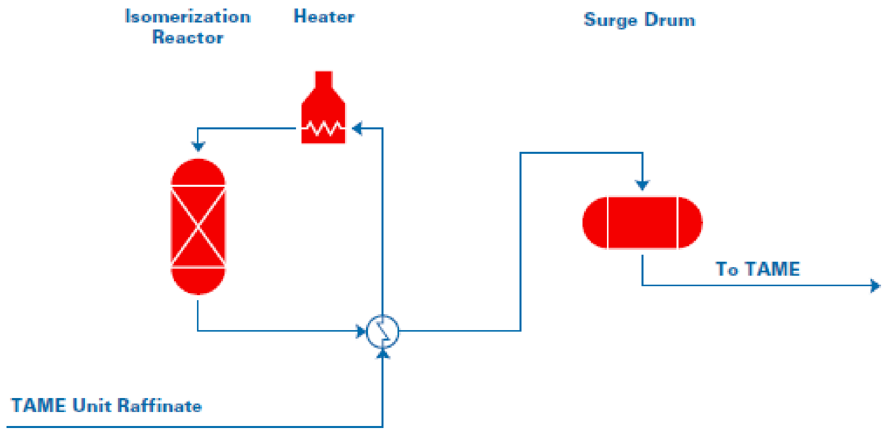
## CD*Mtbe* Process Flow Diagram




## CD*Hydro* Process Flow Diagram



ISOMPLUS Process Flow Diagram



5. BP Liquid / solid separation

# Best Practice Liquid / Solid Separation

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| | |
|---|---|
| 6.1 Technology function | what does it do? |
| 6.2 Application window | what are known applications with which I can compare my issue? |
| 6.3 Operating window | what temperatures / pressures / flow regimes / concentrations? |
| 6.4 Benefits and Costs | what are the profit incentives and how does compare with cost? |
| 6.5 TRL and Risks | is the technology mature? Does it involve HSE- / financial risks? |
| 6.6 Working principle | how does it work? |
| 6.7 References | where can I find more information? |
| 6.8 Suppliers | which companies sell this technology? |

## 6.1 Technology function

Liquid - solids separation is a mechanical separation method in which a liquid - solid mixture is separated into a solid (with as little adhering liquid as possible) and a liquid (with as little solid as possible).

This BP relates to processes in which a lot of solids are present in the liquid. The size of the solid particles is in the order of 10 to 500 µm. For filtration of particles < 1 µm, reference is made to the Best Practice Membrane Technology.

## 6.2 Application window

*General rules*

To evaporate 1 kg of water in a dryer at least 3000 kJ is needed. Any liquid that can be removed mechanically does not need to be evaporated into the dryer.

Vacuum filters are often used as liquid - solids separator, because they are simple devices on which the filter cake can be washed properly if desired. A disadvantage of these filters is the high final moisture content.

There are several methods for further dehumidifying a filter cake (gas blow-through, centrifugation, roll presses) each with advantages and disadvantages. The choice is usually determined by the existing systems and/or the requirements for the solid or liquid.

The driving force when dehumidifying by blowing gas through is a difference in gas pressure over the filter cake, whereby the interstitial liquid can only be emptied when the gas pressure is higher than the capillary pressure. This method is mainly used for open porous structures.

Particles of 100 µm and larger, which do not deform too much and do not fall apart, can be dehumidified well in a continuously filtering centrifuge with a short residence time.

For smaller particles (approx. 20 µm), a discontinuous centrifuge should be used for proper dehumidification (centrifugal force of approximately 2000*g; residence time of a few minutes).

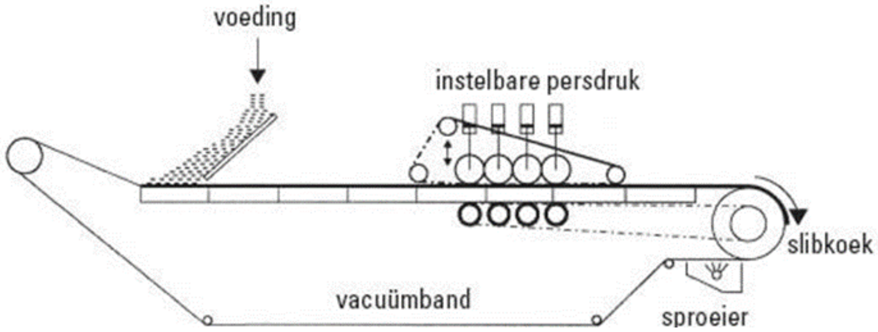
Gas blow-through and centrifuges are mainly used when a cake is compactly stacked with dimensionally stable, non-porous particles.

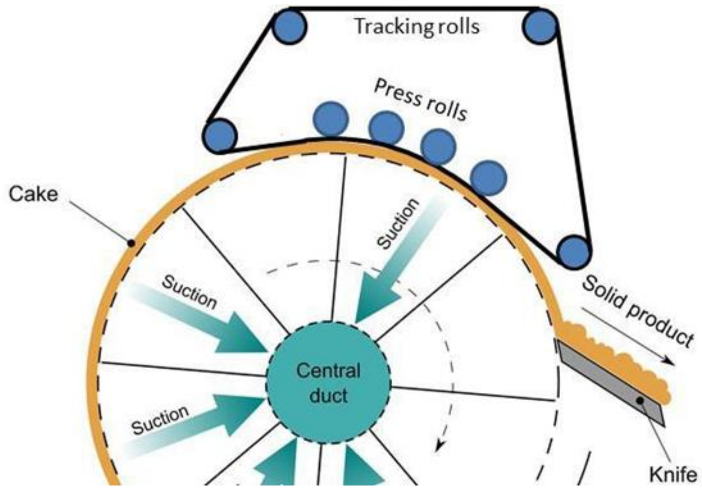
Pressing devices (such as belt press, screw press and diaphragm filter press) squeeze the liquid out of a filter cake. This method is especially beneficial if the particles are porous (by themselves porous, agglomerated or flocculated particles) and/or deformable and/or the original filter cake has a more open structure.

When applying only presses, the interstitial spaces between the particles are filled with liquid after the process. A combination of pressing and blowing can then offer advantages.

*Examples of applications*

- Roll presses on vacuum belt filter and on rotating vacuum filter



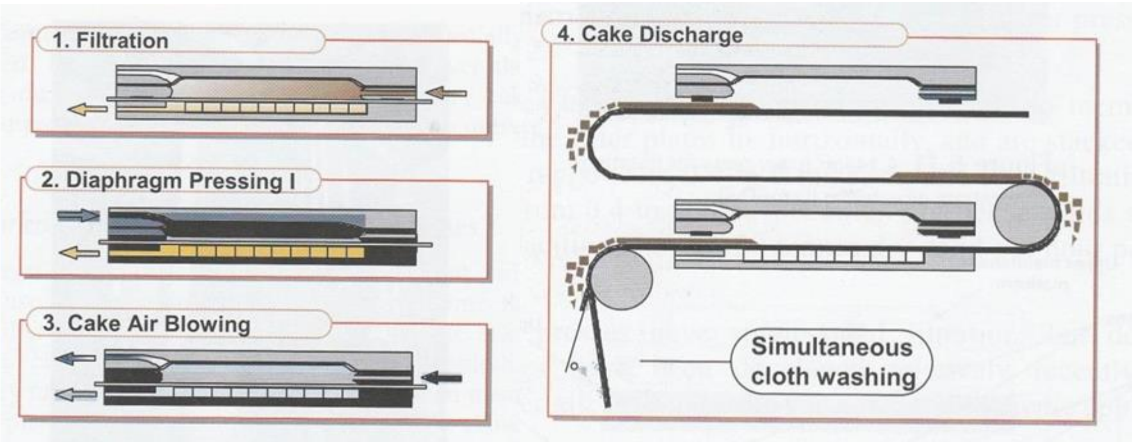

- Filter press machine

With a filter press machine, the position of the filter cloth is horizontal, so that the filter cake can be pressed, washed, possibly re-pressed, blown dry and unloaded.

Filter press machines are used in various applications. An example is a slurry of solids (waste) in a solvent. In the original process, the slurry was dried in a contact dryer. Because the dried substance contained traces of organic solvent, it was disposed of as chemical waste.

Replacement of the contact dryer by a diaphragm filter press machine, in which the filter cake is washed and then squeezed into a sting-resistant cake with a moisture content of 1.5 kg of moisture per kg of dry matter has meant that the cake could be dumped in designated places without further treatment.

Different process steps of the filter press machine (ref.3)




Another example stems from the starch industry. Here filter press machines replace vacuum filters or decanter centrifuges. The advantage is that the filter press machines generally achieve a 10% lower final moisture content than the centrifuges, which in turn results in energy and investment savings in the dryer.

- Press-blowing installation

With the pressure rollers on a belt filter, the cloth with the cake moves continuously. In a press-blowing installation, the cloth is transported discontinuously with the cake: the cake is pressed with a porous pressure plate and then gas (air) is blown through the cake. This system is mainly used in filter cakes whose rheology has thixotropic properties after vacuum dehumidification. These are filter cakes whose internal viscosity is high if no shear stresses are applied and which are difficult to dehumidify under vacuum but by means of pressing / blowing.

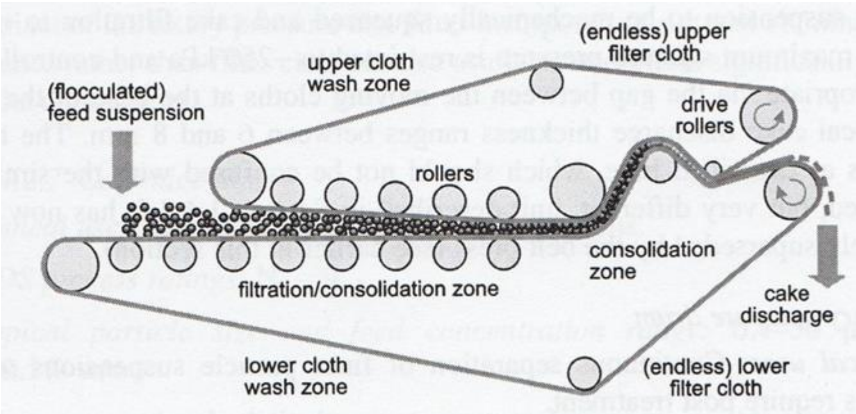
- Belt press after belt filter

To reduce the moisture content, a belt press can be placed behind a (vacuum) belt filter. If it is clear that a belt press will be used, a simple dewatering table as a first step may suffice if desired. The belt press can be directly connected to the dewatering table or stand separately behind it.

The next figure shows a schematic system in which the (flocculated) suspension is fed to the belt press from a dewatering table. In the first part of the belt press, a cake is formed which is then gradually squeezed out.

Example calculation (ref.9): The moisture content of the highly porous polymer particles after dehumidification on the belt filter is 6.5 kg of water per kg of polymer; after the belt press, the moisture content is 2 kg/kg, so ΔX = 4.5 kg/kg. The line pressure of the last rolls of this press is 200 N/mm, which is a high value for this type of devices. This high pressure is needed to squeeze enough water out of the particles. Because the solid-state flow is high (M is approx. 0.4 kg/s), the pressing achieves large energy savings in the dryer (3000 * ΔX * M = 3000 * 4.5 * 0.4 = 5400 kJ/s). The costs of the belt press are lower than those for the expansion of the dryer capacity, so that the investment is also lower.

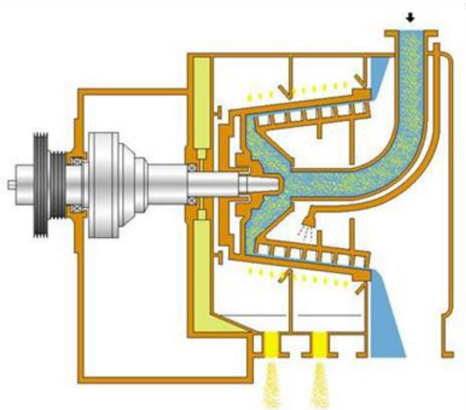
Impression of stand-alone belt press (ref.1)




- Centrifuge after belt filter

As already mentioned in section 4.1.3, a continuously filtering centrifuge can be used if the particles are sufficiently large and the solid is suitable for it. With a filtering screw centrifuge, operating at approximately 1000*g, much lower moisture levels can be achieved than with a vacuum filter. In a number of cases, therefore, a screw centrifuge is set up after a belt filter. The centrifuge can be fed directly with the wet filter cake or the cake from the belt filter can be slurred up and fed to the centrifuge as slurry. In the first case, the wet cake is fed into the centrifuge with a conveyor screw.

Filtrating screw centrifuge



Some examples where a screw centrifuge is installed after a vacuum filter:

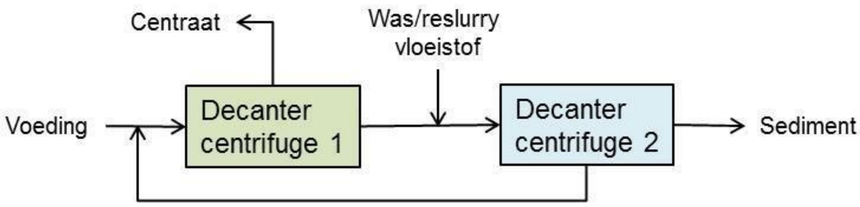
For a filter cake made up of fibrous material, the moisture content after dry suction on the belt filter is 1.5 kg of moisture per kg of dry matter. In connection with the layout, the cake is not fed directly to the screw centrifuge but as slurry. The moisture content after the centrifuge is 0.7 kg of moisture per kg of dry matter, so ΔX = 0.8 kg/kg. Savings in the dryer section (investment, energy) justify installing the centrifuge after the vacuum filter.

Another example concerns a granular product with an average particle diameter of approximately 100 µm. The wet cake that has been sucked dry on the belt filter still contains approximately 0.2 kg of moisture per kg of dry matter. The product is screwed into the centrifuge like a wet cake and comes out with 0.1 kg of moisture per kg of dry matter, so ΔX = 0.1 kg/kg. With a mass flow of 0.5 kg/s, this results in energy savings of 3000*0.1*0.5= 150 kJ/s. This energy saving in the dryer does not justify the investment in the centrifuge, but because it is an existing installation whose capacity must be increased and where the dryer is the bottleneck, switching the centrifuge is an attractive choice. An additional advantage is that less or no recycle of dry matter is needed for the dryer to function properly.

- Decanting centrifuges with reslurry washing

If it is necessary to work in a closed system and/or the filtration rate is low and therefore a (vacuum) filter becomes too large, systems with two or a maximum of three decanter centrifuges in series can be considered (Figure 8). This system is described in reference [8]. In the example given therein, the solid is biomass (waste) which, with the moisture content with which it comes out of the centrifuge, can be deposited without further drying. The liquid contains the product that is extracted as completely as possible with the reslurry wash.

Two decanting centrifuges in series with slurry rewash




## 6.3 Operating window

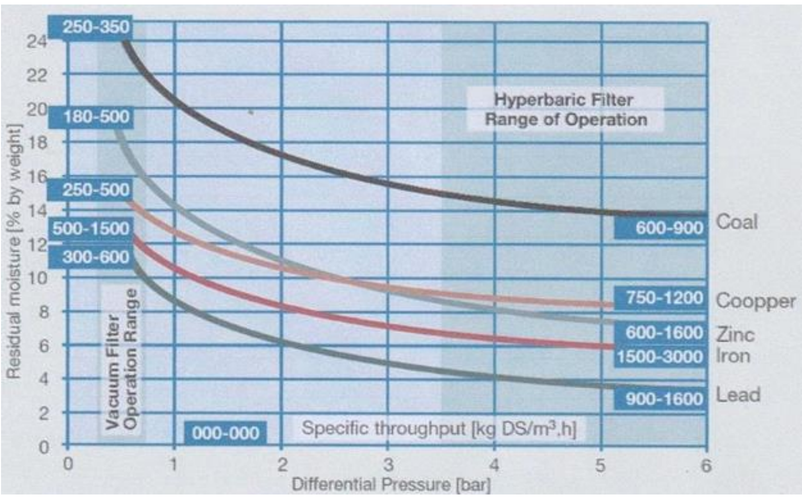
The operating window varies with the type of dehumidification:

a) Gas blow-through
b) Centrifugation
c) Mechanical pressing

Two parameters effectively describe dehumidification of filter cakes:

1. Equilibrium moisture content. This is the finally achieved value after sufficient time. The equilibrium curve indicates the size of minimum required driving force.

Equilibrium moisture content as a function of differential pressure

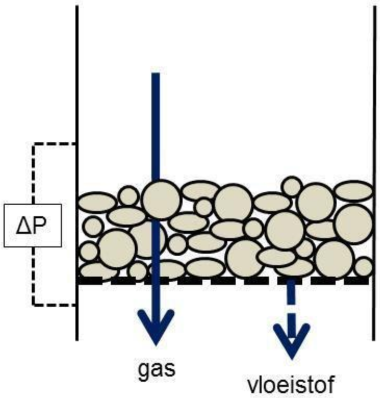


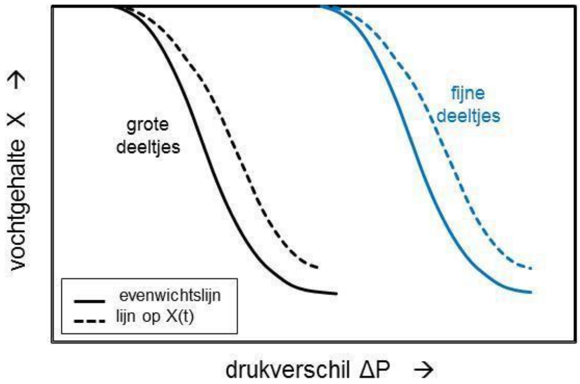

2. Kinetics of dehumidification. This is the course of the moisture content during dehumidification as a function of time. Kinetics indicate the minimum residence time in the dehumidifier.

**a) Gas blow-through**

The driving force when dehumidifying by means of gas blowing through is a difference in gas pressure over the filter cake. The interstitial fluid is pressed out of the cake by the gas and is dragged along. A channel between particles can only be emptied if the gas pressure is higher than the capillary pressure.

Dehumidification by blow-through of gas.




Qualitatively, this method of dehumidification for filter cakes that are made up of coarse and fine particles is shown in Figure x. It outlines both the equilibrium moisture content X and the value X(t) at the time t when the equilibrium has not yet been reached as a function of the pressure difference Δp.

The above figure shows the following:

- A certain pressure difference is needed (the capillary entry pressure) before the cake starts dehumidifying. This pressure difference is inversely proportional to particle diameter.

- If the pressure difference increases and more gas is blown through the cake, the moisture content decreases.

- In case of further increase in the pressure difference, a constant value is reached for the moisture content. With vacuum filters, the available pressure difference to suck gas through the cake is limited (< 0.6 bar). As a result, the moisture content of such filter cakes is high, especially if they are made up of fine particles. If a cake is made up of stable particles of an average of 100 µm, then in general the cake on a vacuum filter can be sucked dry fairly well; with a particle diameter of an average of 25 µm, this is usually no longer the case.

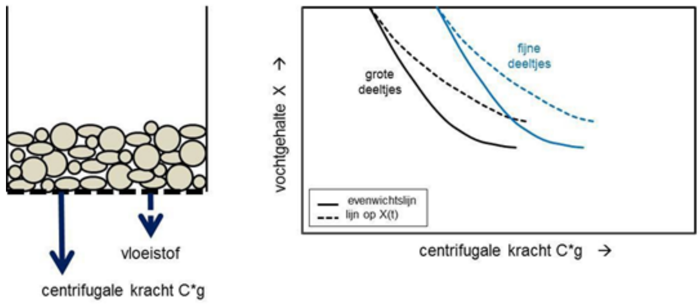
The final result depends on the shape of the particles, the porosity of the cake, the particle size distribution, the viscosity of the liquid and the temperature of the system.

Filters that can dehumidify the filter cake at higher gas pressure are disc filters, drum filters, belt filters built in a pressure vessel (continuous filters) and candle filters (discontinuous filters).

**b) Centrifugation**

The dehumidification of a filter cake in a centrifugal field is shown in the figure below in a similar way as the former figure. The driving force is the centrifugal acceleration C*g, in which g is the acceleration of gravity. The factor C shows how many times the acceleration is greater than gravity.

Dehumidification by means of a filtering centrifuge




Although the physical principles of gas blowing and centrifugation are different, the curves in the last two figures are fairly similar.

The above figure shows that a certain minimum C*g value is required before the liquid starts to run out of the spaces between the particles, that this value is higher for filter cakes made up of fine particles and that the decrease in the moisture content is achieved to a constant minimum value when C*g increases.

The effect of centrifugal force on the dehumidification of solids of different particle sizes can be explained as follows:

* Particles of 400 µm that do not deform too much and do not fall apart can already be dehumidified at 300*g in a continuously filtering centrifuge with a short residence time (e.g. sliding centrifuge).

* For particles of 100 µm, the same applies at 1200*g (e.g. in a screw centrifuge).

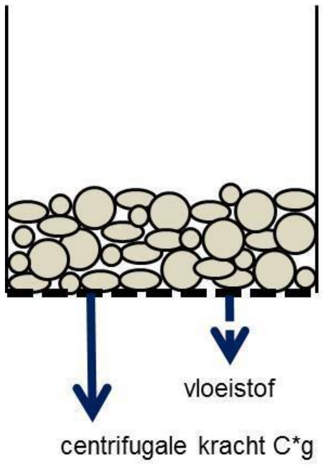
* For particles of 20 µm, a centrifugal force of approximately 2000*g and a residence time of a few minutes are required to dehumidify properly. These values cannot be achieved in a continuous centrifuge but can be achieved in a discontinuous (e.g. peeling) centrifuge.

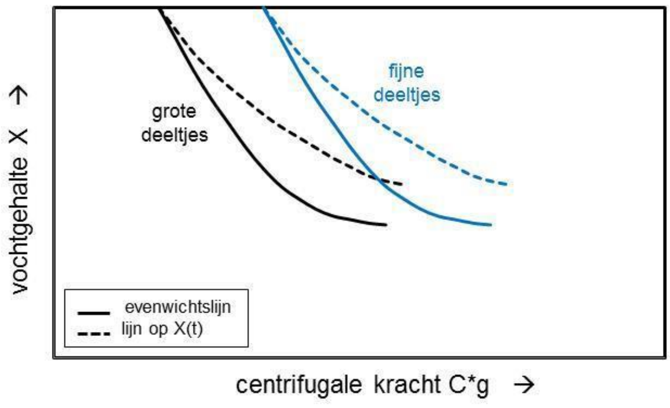
The above numbers are intended as an indication and apply if the viscosity of the liquid is sufficiently low (such as of aqueous systems). In addition to filtering centrifuges, decanting centrifuges (separation by sedimentation) are used on a large scale for fine particles to dehumidify.

**c) Mechanical pressing**

The behavior of a filter cake during pressing is described on the basis of the concept of porosity. The porosity ε of a filter cake is the volume of spaces between the particles divided by the total volume. Of a liquid-filled filter cake, the volume part is therefore ε filled with liquid and (1 – ε) with solid. The value of ε is between 0 (volume completely filled with solids) and 1 (no solid present). The extent to which liquid can be removed from a filter cake by pressing depends on the relationship between porosity and press pressure. If a cake is compactly stacked with dimensionally stable, non-porous particles, then when pressing the porosity will decrease little and therefore little liquid will be removed.

On the other hand, if the particles are porous (by themselves porous, agglomerated or flocculated particles) and/or deformable and/or the original filter cake has a more open structure, then the porosity during pressing will decrease sharply and a lot of liquid will be removed.



For a saturated cake, the relationship between the moisture content X and the porosity is ε: $X = \varepsilon * \rho_L / [(1 - \varepsilon) * \rho_S]$ where: X = moisture content in kg of moisture / kg of solid

ε = volume of the space between the particles / total volume (porosity) ρL = specific gravity of the liquid

$\rho_S$ = specific gravity of the solid

If the filter cake is sufficiently firm and the pressure forces and times are sufficient, the moisture content can be significantly reduced with roll presses on a belt filter or a rotating vacuum filter. The maximum line pressure is 12 (belt filter) to 25 N/mm (rotating vacuum filter).

## 6.4 Benefits and Costs

A good method to determine whether an investment in an improved dehumidification method pays off is to determine the size of the energy savings. A simple estimate can be made with the following equation:

Energy saving = 1.2 * ΔX * M *r kJ/s

where 1.2 = experience factor for evaporation in industrial dryers (this is minimum value; may be higher depending on the type of dryer).

ΔX = difference in moisture content before and after improved dehumidification in kg of moisture per kg of solid. M = mass flow of solid in kg of dry solid per second.

r = heat of evaporation of the liquid in kJ/kg.

If water is the liquid, the above equation is simplified to: Energy saving = 3000 * ΔX * M kJ/s

## 6.5 TRL and risks

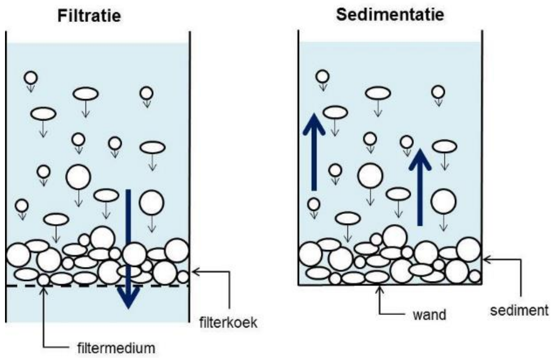
Dehumidification equipment has been around for decades. TRL of separation technologies on the market are invariably TRL=9. The risk associated with dehumidification techniques mainly lies in the combination of the specific liquid/solid mixture and the separation technique chosen. When prior experience with envisaged separation techniques is absent, it is best to set up small scale test programs in cooperation with equipment vendors. This is in fact common practice and many vendors offer test rigs, either on their own premises or mobile units which can be deployed at the customers site.

## 6.6 Working principle

Separation takes place by filtering or sedimentation:

- In filtration, the separation takes place using a porous filter medium, in which the solid-state particles are stopped and a filter cake is formed. The liquid (the filtrate) is discharged through the filter cake and the filter medium. The driving force for this process is a pressure difference. centrifugal force on a filtering centrifuge, under pressure on the filtrate side in vacuum filtration or overpressure on the slurry supply side in pressure filtration.
- Sedimentation occurs due to density differences between solid and liquid. The driving force here is gravity (in the case of thickeners) or a centrifugal force (in the case of a hydrocyclone or decanter centrifuge).

Liquid – solid separation by means of filtration and sedimentation




## 6.7 References

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5. Andritz Separation Systems; brochure Reference Description Alunorte; http://www.andritz.com/se- references-alunorte.pdf
6. Alan Records & Ken Sutherland; Decanter Centrifuge Handbook; Elsevier Advanced Technology, Oxford, 2001; ISBN 1-85617-369-0.

## 6.8 Suppliers

Below you find an overview of leading separation equipment manufacturers. Excerpts from their most recent publications have been added which focus on:

a) Application areas

b) Categories / classes of associated equipment

- Alfa Laval: http://www.alfalaval.com/

## Key application areas

Industry

**Water treatment for drill & blast tunnels**

Alfa Laval has a range of centrifuge decanters that meet the high environmental demands for solid-liquid separation in drill and blast tunnelling.

Industry

**Tailings**

Mining dams pose a substantial risk, and residue management clearly needs to change. Alfa Laval is leading that transformation with robust design and large capacity solutions.

Industry

**Tailings**

Mining dams pose a substantial risk, and residue management clearly needs to change. Alfa Laval is leading that transformation with robust design and large capacity solutions.

Industry

**Tailings**

Mining dams pose a substantial risk, and residue management clearly needs to change. Alfa Laval is leading that transformation with robust design and large capacity solutions.

Industry

**Precious Minerals and Mining**

Alfa Laval has a range of equipment to optimize key processes such as separation and heating and cooling in the beneficiation, leaching and extraction of precious mineral ores.

Industry

**Coal Beneficiation**

Alfa Laval is revolutionising the treatment and disposal of coal tailings. This is being led by a strong demand to look after the environment: to conserve water and remove tailing dams.

Industry

**Slurry treatment in tunnel boring**

Alfa Laval has a range of cost-effective centrifuge decanters for high volume slurry treatment in tunnel drilling applications that help you to increase site production.

Industry

**Slurry treatment for horizontal directional drilling**

Alfa Laval has a range of reliable centrifuge decanters for solids control in horizontal directional drilling (HDD) that help boost onsite productivity and working conditions.

Industry

**Liquid-solid mixing**

Alfa Laval Vortex products are simple, low maintenance solutions based on Venturi technology for the mixing of liquids and solids in a wide range of industrial processing applications

Industry

**Green liquor treatment**

Green liquor handling acts as the kidney of the pulp mill removing the non-process elements. At the same time, it ensures process chemicals can be recovered and reused time and time again.

Industry

**Industrial fluids**

Alfa Laval has a range of equipment for effective cleaning of coolants and wash liquids so that you can prolong you equipment life time and save money from reusing your industrial fluids.

Industry

**Base Minerals and Mining**

Alfa Laval has a range of equipment and the knowhow to help you optimize key processes in base mineral beneficiation, extraction applications and tailings dewatering.

Industry

**Plant-based drink production**
A variety of plant based drink processing equipment for all kinds of raw material from soy and oat to almonds, rice and beyond.

Industry

**Construction machinery**
Alfa Laval construction decanter centrifuges can be optimized in every detail to ensure the best solids removal for any construction drilling site.

## Equipment

Product

**P3**
Alfa Laval's P3 range of decanter centrifuges is built for the toughest applications and is specifically developed for solid-liquid separation in the mining and mineral industry.

Product

**FilmVap**
These evaporators can process clear, non-fouling liquids as well as moderately fouling liquids.

Product

**FOCUS**
Alfa Laval Fuel Oil Cleaning Unit Solutions (FOCUS) are automated modular systems for purifying the liquid fuel oils used in gas turbine power plants.

Product

**CDNX**
Alfa Laval CDNX centrifugal decanter efficiently remove solid particles from water and oil-based slurries resulting in better performance at construction sites.

Product

**Emmie 2**
This mobile centrifugal separator effectively removes both particles and water from oils widely used in industry.

Product

**Vortex Snub Radial Eductor**
Rapid volume turnover to ensure fast chemical reaction for swift product separation.

Product

**Alfie**
Alfie centrifugal separators remove the contaminating oil, grease and solid particles from coolants used in industry, helping prevent tool wear and avoid disposal problems.

Product

**Foodec**
Alfa Laval Foodec decanter centrifuges are ideal for industries where delicate food and beverage products are processed – and where easy cleaning is crucial.

Product

**Clara series**

Specially developed for food, beverage and industrial fermentation applications, the Clara range offers gentle product treatment, high separation efficiency and low power consumption.

Product

**AlfaPure**

The AlfaPure range comprises purpose-built centrifugal separator systems for removing oil, grease and solid particles from water and oil based liquids, such as coolants, lubricants and wash liquids.

Product

**BD series**

The critical technologies for biodiesel processing are heating, separation and mixing. Alfa Laval supplies products within all three technologies for the different production steps.

Product

**FESX**

The FESX separators are specially designed for industrial fermentation applications and are available in many different sizes and configurations.

Product

**PANX**

Alfa Laval PANX-series of decanter centrifuges is designed for palm oil clarification and purification.The units offer maximum oil recovery with low energy consumption.

Product

**OCM**

The Alfa Laval Oil Cleaning Module (OCM) provides rapid, effective separation of the oil, water and sludge components in contaminated mineral lubricating and hydraulic oils.

Product

**Vortex Radial Eductor**

A uniquely designed, low pressure mud gun to increase fluid movement in mud pits.

Product

**Vortex Shear-Mixer**

An advanced mixing solution that reduces additive waste, mixing time and cost.

Product Type

**Flat sheet membranes**

The range of membranes from Alfa Laval covers all filtration processes: reverse osmosis, nanofiltration, ultrafiltration and microfiltration

Product

**PilotUnit Multi**

The Alfa Laval PilotUnit Multi is ideal for membrane screening, process development and scale-up for MF,UF, NF and RO. Learn more.

Product

**Culturefuge**

The Culturefuge is a hermetic separation system, specially designed for gentle harvesting of shear-sensitive material in applications involving mammalian cell cultures and precipitated proteins.

Product Type

**Spiral membranes**

Alfa Laval produces various types of efficient and premium quality spiral membranes, including RO, NF, UF and MF. Learn more by clicking here.

Product Type

**Powder mixers**

Our mixers allow you to match the right mixing method to your needs, ensuring greater energy savings, superior cleanliness, and higher process efficiency in terms of reduced process time.

Product

**FEQX**

Specially designed for industrial fermentation applications, the FEQX separator range is adapted for dealing with the widely varying separation tasks required.

Product

**CH**

CH-range of separator systems are designed to meet the high and versatile demands of the various applications.

Product

**MF flat sheet**

The microfiltration (MF) membranes available from Alfa Laval are made of polysulphone polymer or fluoro polymer with pore sizes ranging from 0.1 to 0.5 µm. The membranes are available in two series

Product

**OFX**
The Alfa Laval OFX 20 disc stack centrifuge system is specially designed to provide the oil industry with a highly efficient way to remove water and solids from heavy crude oil.

Product

**Vortex Mixmate**
A safe, proven mixing and dispensing solution for caustic mud additives.

Product

**FilmVap**
These evaporators can process clear, non-fouling liquids as well as moderately fouling liquids.

Product

**MF flat sheet**
The microfiltration (MF) membranes available from Alfa Laval are made of polysulphone polymer or fluoro polymer with pore sizes ranging from 0.1 to 0.5 µm. The membranes are available in two series

Product Type

**Tank mixers**
Efficent, effective fluid agitation and shear

Product

**UF flat sheet**
The selection of ultrafiltration (UF) membranes from Alfa Laval covers a broad spectrum of flux properties and MWCO values ranging from 1,000 to 100,000. More series are offered for many applications

Product Type

**Plant-based protein and vegetable processing systems**
Boost the quality and yield of plant-based protein food and drink products with our plant-based protein and vegetable processing systems.

Product

**NF flat sheet**
For nanofiltration (NF) Alfa Laval offers a thinfilm composite polymeric membrane with a $MgSO_4$ rejection ≥99%. A unique construction on polyester support material provides optimum cleaning conditions

Product Type

**Edible oil refining process systems**
A full range of edible oil refining processes from crude to refined oils. Find out how we can help you.

Product

**FAME biodiesel pretreatment systems**
Alfa Laval's solutions for pre-treatment of fats and oils in FAME biodiesel production are characterized by the effective removal of impurities and low energy consumption.

Product

**HVO pretreatment systems**
Our automated HVO pretreatment systems produce feedstock free from impurities and adjust free fatty acids for conversion into renewable hydrocarbon transportation fuels.

Product

**Degumming systems**
Improve yield and crude oil quality further while minimizing 3-MCPD formation during edible oil refining.

Product

**Neutralization systems**
Systems for neutralization process of edible oil to remove free fatty acids and other impurities that impact edible oil quality, consistency, appearance, taste and shelf life.

Product

**Bleaching systems**
Solutions for optimal edible oil bleaching process, built on deep process knowledge and global services.

Product

**Compabloc**
Alfa Laval Compabloc range is compact and designed for optimum performance and serviceability across a broad spectrum of industrial process applications.

Product Type

**Fat modification process systems**
A full range of fat modification processes such as fat hardening, interesterification (chemical or enzymatic), dry fractionation and semi-continuous deodorization. Find out more.

Product Type

**Pretreatment systems for biofuels**
Alfa Laval has a market-leading position with respect to pretreatment process systems for any raw material for these biofuels. Find out how you can benefit from our experience.

## Main office

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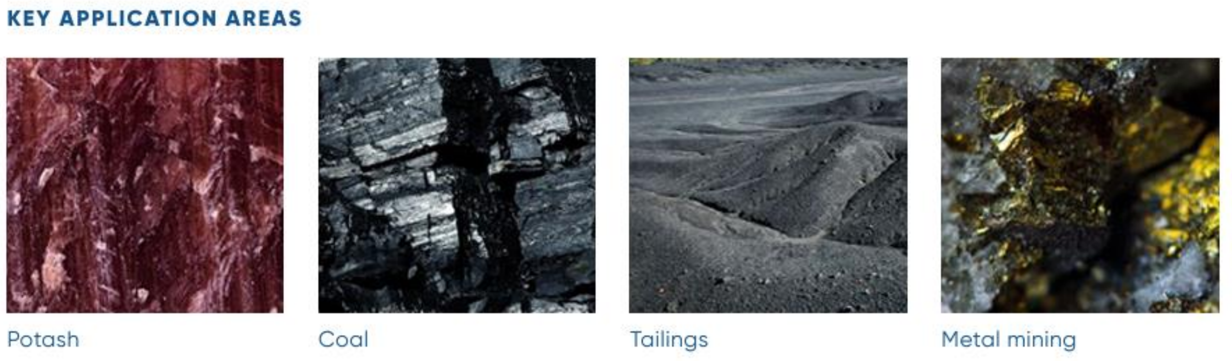
Andritz Separation: http://www.andritz.com/index/separation.htm

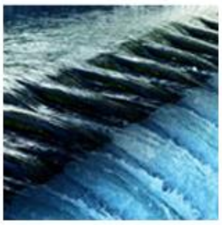
**Key application areas**





KEY APPLICATION AREAS


Industrial wastewater

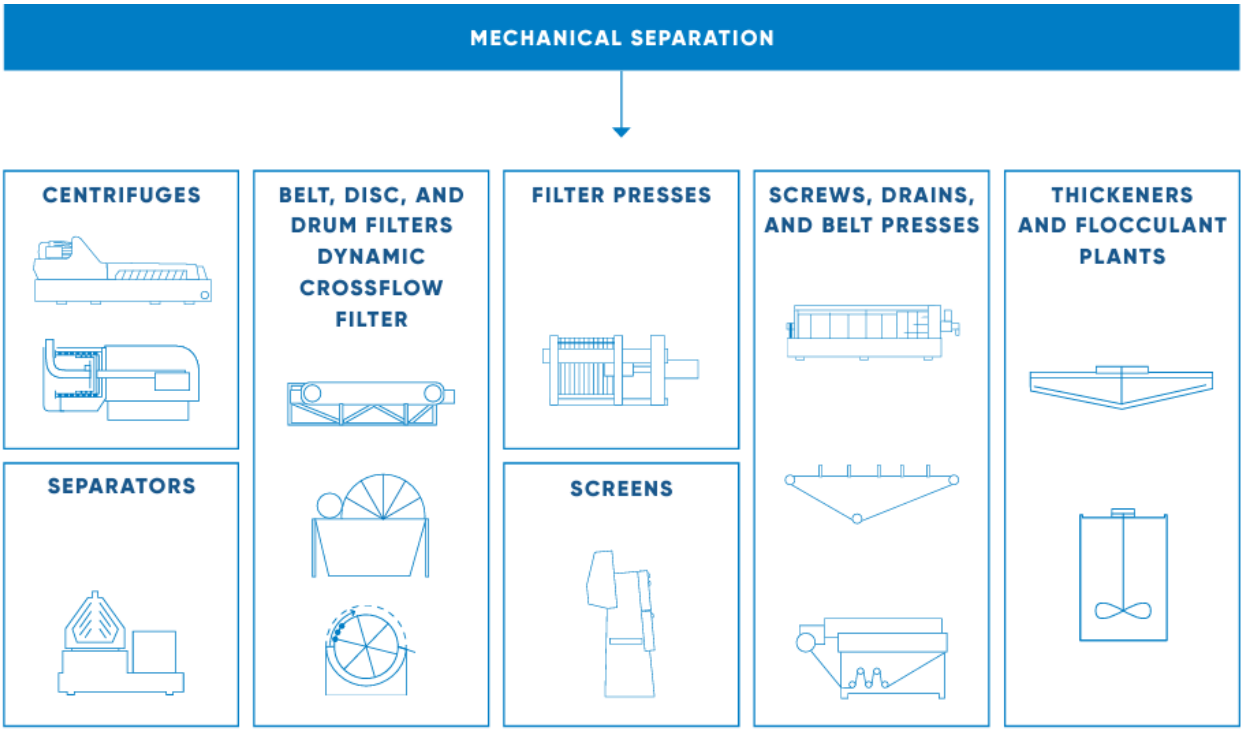

Municipal wastewater

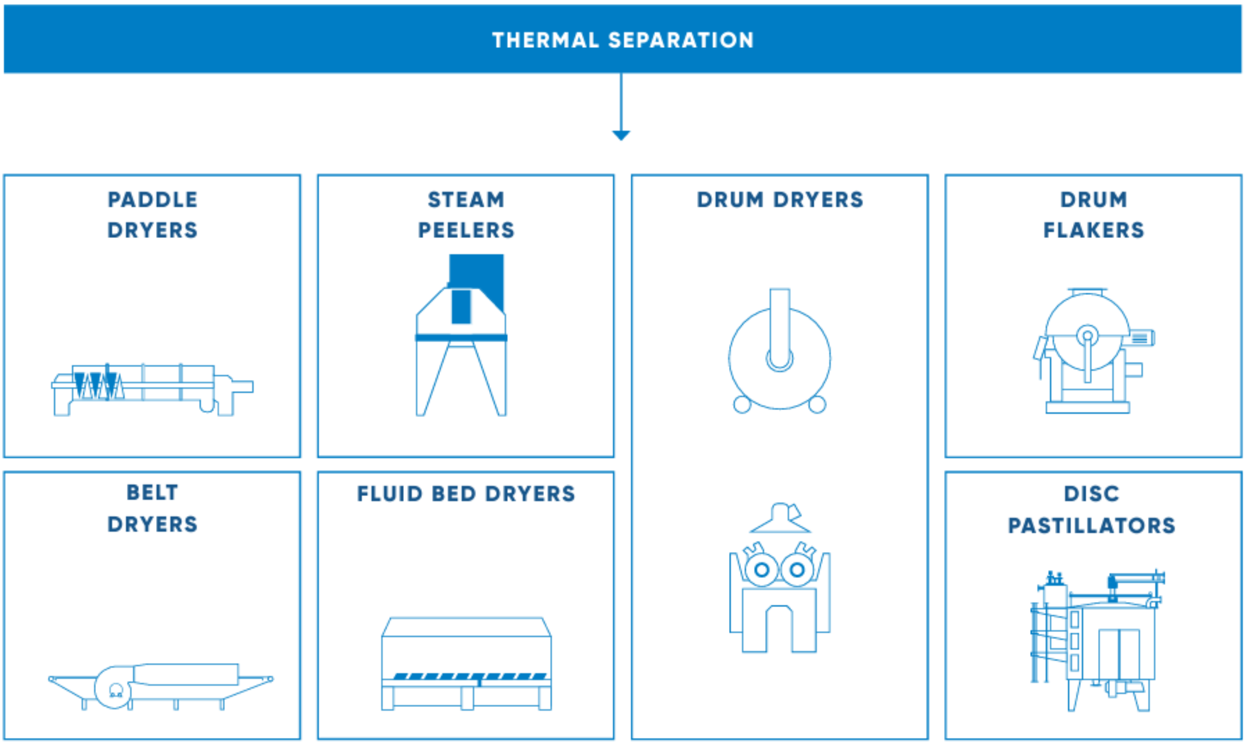

Potable water


Biomass production


Organic waste

## Equipment



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- Broadbent Industrial Centrifuges: http://www.broadbent.co.uk/

## Key application areas & Equipment

### Latest CL1800 Sugar Centrifuges Delivered

Having supplied our latest design CL range basket centrifuges last year, we are pleased to be delivering a further 3 units to our valued customer in the Philippines. These units were supplied from our facility in Thailand. The CL range of sugar centrifuges are fully...

### Latest Minerals Tailings Centrifuge

We are very pleased to be delivering our latest solids bowl decanter centrifuge for the Minerals Tailings Application. This heavy duty range has been developed to handle anything up to 250 TPH Feed with solids concentration in the region of 20%. It is equipped with...

### Minerals Tailings Dewatering Lab and Pilot Testing

A new greenfield mine in North America decided to dry stack tailings. Their tailings however posed several challenges: Very high capacity, A difficult to dewater particle size distribution consisting of a high proportion of fines and ultra fines, A small proportion of...

### Back in time – 1978

Just looking at some old photos showing the 4 off 900mm diameter Solid Bowl Decanter Centrifuges we supplied via Flottweg to the Basel Municipal Waste Plant in 1978 - Even now the machines look awesome in size. Our Chairman at that time Mr Peter Broadbent stands...

### Complete MEG Processing System

Broadbent have engineered, manufactured and supplied a complete MEG recovery package. The system includes continuous decanter centrifuge technology complete with module frame, wash system, receiving vessels, master PLC controls and integrated pipework. The unit was...

## Contact

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- Flottweg: www.flottweg.com

## Key application areas

**A**
Algae harvesting
Avocado oil extraction

**B**
Beer production
Biodiesel manufacturing
Bioethanol manufacturing

**C**
Casein manufacturing
CRUD processing

**D**
Drilling mud treatment

**F**
Fermenation broths
Fish processing
Food residue processing

**I**
Instant coffee production
Instant tea and tea extract production

**J**
Juice manufacturing

**L**
Lactose manufacturing
Limed fleshing
Lupin protein extraction

**M**
Manure processing
Mining

**O**
Oil sludge treatment
Olive oil extraction

**P**
Paint sludge dewatering
Palm oil extraction
Paper sludge
Pea starch production
Plastic recycling
Potato starch extraction
Press oil extraction
Protein extraction
PVC dewatering

**S**
Sand and gravel wash water
Seed oil extraction
Sewage sludge dewatering
Sewage sludge thickening
Slaughterhouse waste recycling
Sludge thickening with starch polymer
Steelwork sludge treatment
Surimi processing

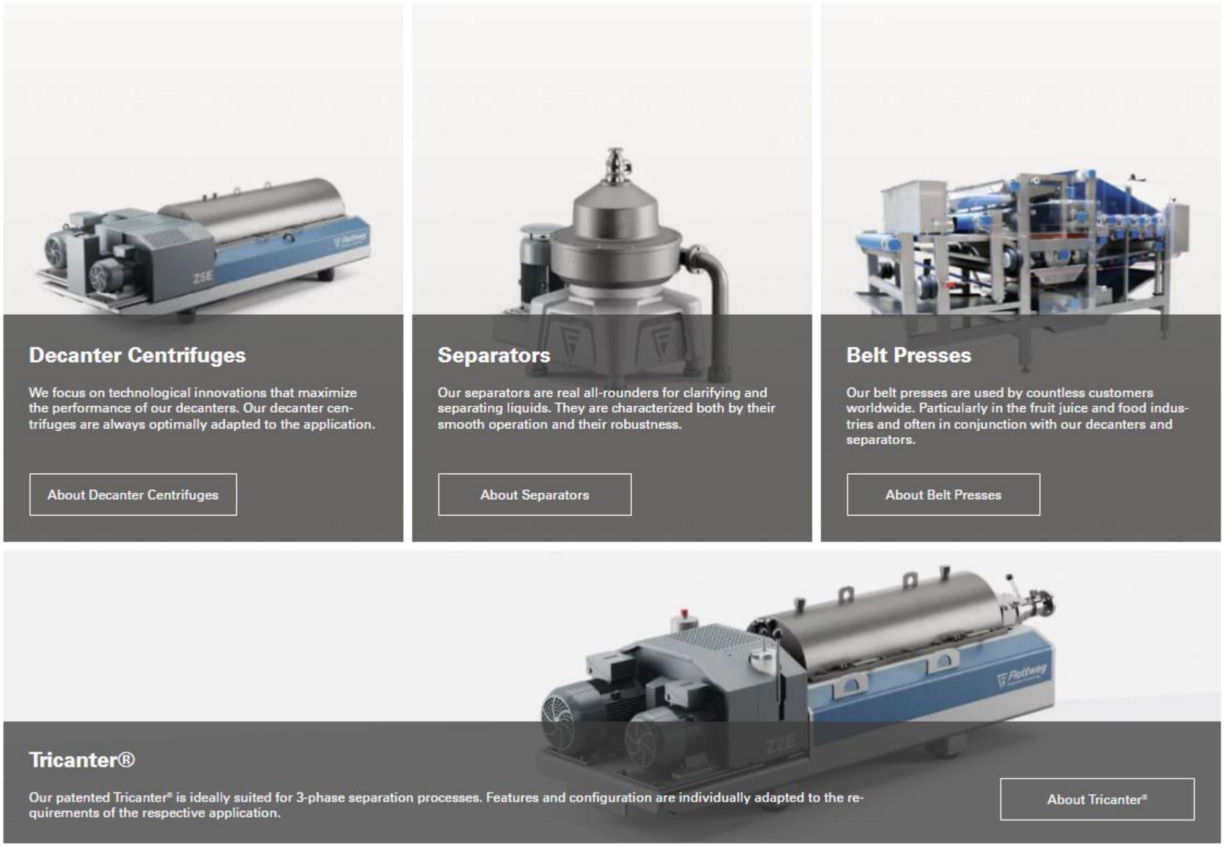
**T**
Tailings
Tapioca starch production
Tar cleaning

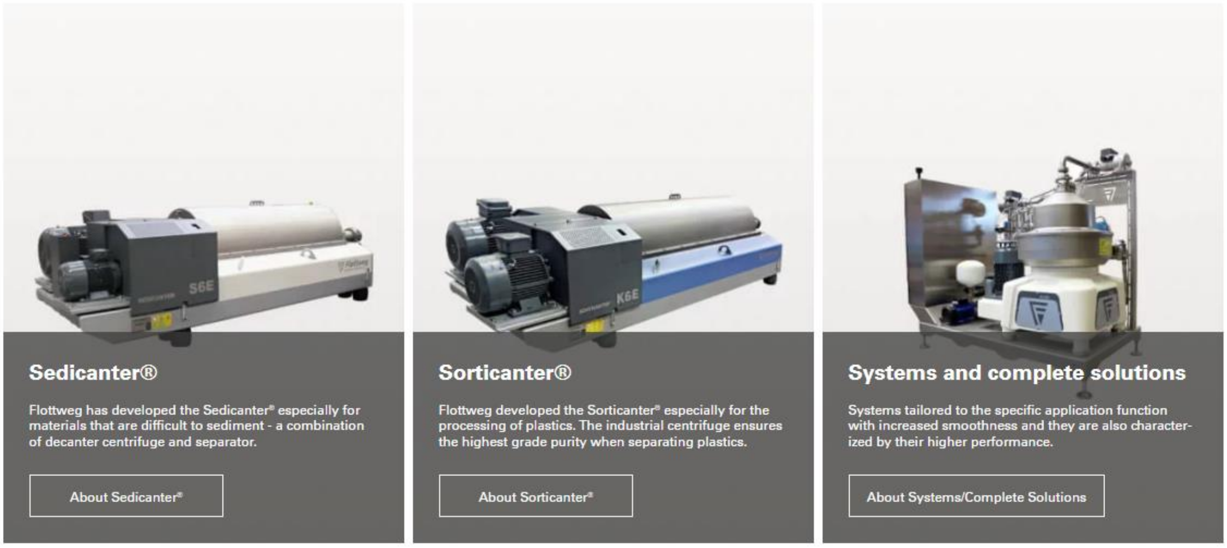
**U**
Used cooking oil processing

**V**
Vegetable milk alternatives production

**W**
Waste oil processing
Waterworks sludge dewatering
Wheat starch production
Whey processing
Wine clarification

# Equipment


Decanter Centrifuges
We focus on technological innovations that maximize the performance of our decanters. Our decanter centrifuges are always optimally adapted to the application.
About Decanter Centrifuges
Separators
Our separators are real all-rounders for clarifying and separating liquids. They are characterized both by their smooth operation and their robustness.
About Separators
Belt Presses
Our belt presses are used by countless customers worldwide. Particularly in the fruit juice and food industries and often in conjunction with our decanters and separators.
About Belt Presses
Tricanter®
Our patented Tricanter® is ideally suited for 3-phase separation processes. Features and configuration are individually adapted to the requirements of the respective application.
About Tricanter®


Sedicanter®
Flottweg has developed the Sedicanter® especially for materials that are difficult to sediment - a combination of decanter centrifuge and separator.
About Sedicanter®
Sorticanter®
Flottweg developed the Sorticanter® especially for the processing of plastics. The industrial centrifuge ensures the highest grade purity when separating plastics.
About Sorticanter®
Systems and complete solutions
Systems tailored to the specific application function with increased smoothness and they are also characterized by their higher performance.
About Systems/Complete Solutions

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- GEA Westfalia: http://www.gea.com/global/en/productgroups/centrifuges-separation_equipment/decanter-centrifuge/index.jsp

## Key application areas

- Beverage
- Chemical
- Dairy
- Dairy farming
- Environment
- Food
- Heating & refrigeration
- Home & personal care
- Marine
- Oil & gas and energy
- Pharma & healthcare

# Equipment

**2-Phase Separating Decanter chemMaster**

For clear clarification and dewatering in chemical and mineral processing applications. The clarified liquid is discharged under pressure by use of a centripetal pump. CIP-compatability of the decanter can be assured.

**2-Phase Separating Decanter cutMaster**

For clear classification in chemical and mineral processing applications. The clarified liquid is discharged freely into a liquid catcher and flows off under gravity. CIP-compatability of the decanter can be assured.

**2-Phase Separating Decanter dryMaster**

For clear clarification and dewatering in chemical and mineral processing applications. The clarified liquid is discharged freely into a liquid catcher and flows off under gravity. CIP-compatability of the decanter can be assured.

**2-Phase Separating Decanters for Oil Recovery**

The big advantage of the 2-phase separating decanter for olive and palm oil recovery is the enormous savings when it comes to dilution water.

**3-Phase Separating Decanter for Industrial Fluids**

For the treatment of waste oil, MARPOL liquids, waste emulsions and oily waste water

**3-Phase Separating Decanter meatMaster CF for Animal By-Products**

For the recovery of animal oils, fats and proteins

**3-Phase Separating Decanters for animal and fish by-products**

For the recovery of fish oil, proteins and meal

**3-Phase Separating Decanters for Oil & Gas**

For the Oil & Gas industry GEA offers 3-Phase separating decanters for the treatment of waste and slop oils.

**3-Phase Separating Decanters for Oil Recovery**

For the recovery of olive, palm and other vegetable crude oil the decanter is always the heart of the installation. 3-Phase decanters separate both, the olive pulp or the palm oil sludge into oil, water and solids.

**Bacteria Removal Separators for Milk and Whey**

Bacteria removal separators from GEA efficiently remove bacteria and spores from the raw and vat milk and whey.

**Chamber Bowl Separators Blood Processing**

GEA chamber bowl separators for blood processing

**Chamber Bowl Separators Pharma Biotech**

This separator has been designed for protein recovery. PKB 25 - 300-600 l/h* & PKB 45 - 500-1000 l/h*

**Clarifiers for Beverages**

High performance GEA clarifiers for beverages with continuous and automatic operation in hygienic design.

**Clarifiers for Biochemicals**

The self-cleaning GEA clarifiers for biochemical ensure high product quality and yield. According to model, they are designed to resist concentrated acids, high pressures and inflammable or even explosive substances.

**Clarifiers for Blood Processing**

GEA clarifier hycon are a two room concept designed for a sterile process in clean rooms while achieving highest concentrations of solids in aseptic processes. According to model, low-temperature applications are available.

**Clarifiers for Food Ingredients**

For the food ingredients and protein industry GEA clarifiers are used to concentrate algae, recover soy, rice, pea and other vegetable proteins and amino acids.

**Clarifiers for Industrial Fluids**

For the treatment of cooling lubricants, washing liquids, oil-water mixtures, lube oil, fuel oil, waste oil, etc.

**Clarifiers for Milk, Whey and Calcium Phosphate**

GEA clarifiers are used in the dairy industry to improve quality.

**Clarifiers for Pharma Extraction**

GEA clarifiers for pharma extraction are used in solid-liquid extraction processes with low solid contents (up to approx. 7 % by vol.).

**Clarifiers for Pilot Scale/ Lab Scale**

GEA clarifier for pilot scales are the reliable solution to set up new processes. They offer two key advantages: maximum scale-up reliability with minimal installation work input as well as optimum process safety for every process with only low capital expenditure. Fully equipped with the renowned GEA technology features, they are the best technical and economic solution to start a new process.

**Clarifying Decanter chemMaster**

For clear clarification and dewatering in chemical and mineral processing applications. The clarified liquid is discharged under pressure by use of a centripetal pump.

**Clarifying Decanter drymaster**

For clear clarification and dewatering in chemical and mineral processing applications. The clarified liquid is discharged freely into a liquid catcher and flows off under gravity.

**Clarifying Decanter gMaster CF for Beverages**

For the clarification of beverages

**Clarifying decanters for animal and fish by-products**

Processes in the fish and animal by-products industry usually impose particularly stringent requirements on the hygienic design as well as the robustness and corrosion-resistance of the materials. These tasks have been solved by the design features of GEA ecoforce generation; high-performance stainless steels, special chute designs for ease of cleaning, additional spray nozzles at critical points as well as high quality wear protection have been installed.

**Clarifying Decanters for Cheese Curd, Casein and Lactose**

The decanters ensure the efficient production of processed cheese base, raw goods for curd cheese bars or bakers cheese. The decanters are also ideally suited for reprocessing cheese fines and for lactose and casein production thanks to their design, which has been optimized for the production of delicate foods.

**Clarifying Decanters for Edible Oil Refining**

In oil refining processes clarifying decanters are used for press oil clarification. Compared to conventional hot seed pressing plants with leaf filter the process setup becomes much simpler when using a decanter.

**Clarifying Decanters for food ingredients**

For food ingredients and protein recovery GEA offers clarifying decanters for applications like the recovery of soy, rice, pea and many other vegetable proteins, for the concentration of algae or amino acids like lysine.

**Clarifying Decanters for Industrial Fluids**

For the treatment of waste oil, MARPOL liquids, waste emulsions and oily waste water

**Clarifying Decanters for Oil & Gas**

GEA has developed special decanters for treating drilling fluids. Apart from high-performing and top separation efficiency the decanter centrifuges distinguish themselves through safe operation and robust design.

**Clarifying Decanters for Starch Recovery**

For starch recovery clarifying decanters are installed in different process stages depending on the raw material.

**Classifying Decanter for Oil & Gas**

GEA offers classifying decanters for barite recovery in drilling mud treatment.

**Compact Milk Pasteurizer MWA for Milk, Cream and Whey**

Pre-assembled and pre-tested compact milk pasteurizer units with integrated skimming separator for milk, cream and whey pasteurizing (2000 - 35,000 l/h).

**Decanter pharmMaster for Extraction Products**

This decanter has been designed for extraction products.

**Dewatering Decanter crudMaster**

For clear clarification, liquid separation and solids dewatering in chemical and mineral processing applications. The heavy or light liquid phase is discharged under pressure by use of a centripetal pump while the other liquid phase is discharged by drain tubes. CIP-compatability of the decanter can be assured.

**EnergyMaster**

In traditional lube oil treatment systems the hot oil flows back to the engine sump tank to be cooled by the engine cooling system. Therefore the energy for heating the lube oil upstream of the centrifugal separator is lost. GEA EnergyMaster recovers part of this energy.

**GEA bilge Separator**

GEA bilge Separator with integrated direct drive is designed for cleaning oily water and producing minimum residual oil contents in all performance classes.

**GEA biosolids Decanter**

The GEA biosolids Decanter is a continuously operating centrifuge with horizontal solid-wall bowl developed specifically for (pre-) dewatering and thickening of municipal sludge.

**GEA biosolids Granulator**

The GEA biosolids Granulator is an innovative dry-on-demand solution for biosolids treatment from municipal and industrial wastewater treatment plants. It combines existing centrifuge-based dewatering with established drying technology.

**GEA Crude Oil Treatment Systems**

These ready-to-use treatment systems have been designed for the efficient dehydration and desalting of crude oil. At the heart of each modular system is a high-performance centrifugal separator which can be flexibly supplemented by additional units. The easy-to-integrate treatment system can be customized for various process setups and stages in both upstream and downstream processes.

**GEA manure Decanter**

The GEA manure Decanter is a continuously operating centrifuge with horizontal solid-wall bowl for the treatment of manure and digestate.

**GEA pathfinder GMP**

The GEA separator skid in the sophisticated compact format for pharmaceutical applications requires little space in the technical centre and, thanks to its sensible design, reliably fulfils even the most demanding technical tasks. You can easily scale the results to any desired production size with no problem. As such, the full functionality of large pharmaceutical centrifuges is available to you in the simplest way, allowing you to concentrate fully on the creative development of your products.

**GEA pectinMaster**

Optimizes the entire number of process steps thanks to its maximized separation efficiency. The fleet comes in a hygienic design, is protected against corrosion and abrasion. Explosion-proof designs are also available.

**GEA pharma separator aseptic C**

Smooth handling of biopharma products, high separation performance, all features for highest cleanability requierements included: automatic SIP, easy validation and and high-end qualification package.

**GEA pharma separator aseptic N**

Smooth handling of biopharma products, high separation performance, all features for highest cleanability requierements included: automatic SIP, easy validation and and high-end qualification package.

**GEA pharma separator aseptic X**

The freedom to produce any product on the same skid. Turns a static production into a flexible one while ensuring optimum yield with every process step. Smooth handling of biopharma products, high separation performance, all features for highest cleanability requierements included.

**GEA pharma separator pure C**

Smooth handling of biopharma products, high separation performance, all features available for an optimum cleanability according to your process requirements: automatic CIP, easy validation and more.

**GEA pharma separator pure N**

Smooth handling of biopharma products, high separation performance, all features available for an optimum cleanability according to your process requirements: automatic CIP, easy and fast validation and many more.

**GEA pharma separator pure X**

The freedom to produce any product on the same skid. Turns a static production into a flexible one while ensuring optimum yield with every process step. Smooth handling of biopharma products, high separation performance, all features available for an optimum cleanability according to your process requirements.

### GEA proplus

GEA proplus extends the ejection intervals of milk separators from 20 – 30 minutes to up to 90 minutes. This ensures added value, a significant increase in protein yields from the quantity of milk used and a clear reduction in fresh water consumption and waste water creation.

### GEA sludge Decanter

GEA sludge Decanters provide an energy-efficient solution for dewatering of industrial waste water and water treatment sludge.

### GEA vaculiq Vacuum Spiral Filter

GEA vaculiq Vacuum Spiral Filter for industrial juicing of niche products as well as for small and mid-sized juice producers.

### GEA Wine Decanter Skids

Make every grape count. The GEA Wine Decanter is the first decanter centrifuge specially engineered for grape extraction, clarifying and recovering. A single machine that does the work of multiple wine presses and other equipment, adding modern, competitive efficiency, versatility and speed to all processes. With five applications to achieve greater yield and taste, the GEA Wine Decanter has it all.

### GEA “Plug & Win” Centrifuge Skids for Craft Brewers

Hop is hip! But a large volume of perfectly brewed beer is lost in the process with hop solids, surplus yeast and trub. It's all money going down the drain. But with a GEA “plug & win” centrifuge skid you can exploit it to the maximum and sell more beer. We have the right solution ready for brewers small and large!

### Mobile Decanter Systems

Mobile decanter systems from GEA are designed for flexible process integration. They have a modular, plug-and-play design – as lorry trailers or standardized sea containers.

### Multi-Functional Centrifuges for Small and Mid-sized Cideries

This versatile GEA equipment has a variety of applications in the cidery. Each application benefits the cidery by improving the consistency of the product, minimizing product losses, accelerating production time and, ultimately, increasing profitability. In fact, the payback for this equipment has proven to quickly justify the investment.

### Nozzle Separators for Baker's Yeast and Yeast Extract

GEA yeast separators are used for the processing of baker's yeast as well as yeast extract for more than a century now. Stable process condition due to the GEA viscon nozzle as well as our direct drive systems are the latest in a long list of innovations we have specifically developed for the yeast industry.

**Nozzle Separators for Chemicals and Minerals**

GEA nozzle bowl separators for chemicals stand for utmost security of the investment, products and processes. They insure high product quality and yield.

**Nozzle Separators for Oil & Gas**

For the recovery of crude oil from bitumen

**Nozzle Separators for Oil Recovery**

Nozzle separators are used in the conventional process with vertical clarifiers in palm oil mills. GEA also offers special nozzle separators to the palm oil industry in order to recover oil from sterilizer condensate.

**Nozzle Separators for Starch Recovery**

Nozzle separators are used for washing and concentrating the crude starch as well as for gluten thickening. A high quality starch can only be obtained if the small fiber fragments, lipids, proteins and dissolved substances are washed out from the starch fraction efficiently. For this process steps GEA offers 2-phase and 3-phase nozzle separators, each available with either flat belt or direct drive.

**Nozzle Separators for Strained Yoghurt, Quark and Fresh Cheeses**

GEA has developed highly flexible centrifuges for versatile soft cheese and yoghurt applications.

**pilotMaster**

Robust decanter for up-scaling tests, available in ATEX design and protected against erosion and corrosion.

**PROFI System for Kieselguhrfree Beer Clarification**

The PROFI beer filtration is a combination of high performance centrifuge and membrane filtration. It enables optimized beer filtration without kieselguhr.

**Separator RSE / RSI for Oil Refining**

GEA separators are used for degumming, neutralization, and dewaxing of vegetable as well as animal oils and fats. Special applications for our centrifuges in this industry are Ni-catalyst removal, lecithin deoiling, bleaching earth deoiling, re-refining of used frying fats as well as transesterification processes (e. g. for making biodiesel), epoxidized oils and mono- / diglycerides processing and others for oleochemical applications.

**Separators for Animal and Fish By-Products**

Rapid and clean processes, high yields and excellent product quality – our customers benefit in many ways with our machines and process lines in a very wide range of different applications

**Separators for Beverages**

GEA separators are used for the de-oiling of citrus juices and separating citrus oil emulsions

**Separators for Biochemicals**

GEA separators for biochemicals stand for utmost security of the investment, products and processes. Pre-Testing and development at own labs is possible.

**Separators for Chemicals and Minerals**

GEA separators for chemicals stand for utmost security of the investment, products and processes. They insure high product quality and yield fulfills international safety requirements.

**Separators for Double Cream Fresh Cheese**

For the production of double cream fresh cheese from fat milk of 8 to 12 percent fat content. Driven by a frequency-controlled 3-phase AC motor without clutch via a flat belt.

**Separators for Industrial Fluids**

For the separation of cooling lubricants, washing liquids, oil-water mixtures, lube oil, fuel oil, waste oil, etc.

**Separators for Marine**

Marine separators cover all capacities up to 80 m³/h for oil and water treatment.

**Separators for Milk Skimming**

GEA dairy separators are used for warm and cold milk separation, whey separation, buttermilk separation, cream concentration and butter oil concentration and polishing.

**Separators for Oil & Gas**

GEA separators for the oil & gas industry are used in various applications, e.g. dewatering and desalinating heavy crude oil, processing contaminated drilling suspensions and sludges or de-oiling bilge, drain and produced water.

**Separators for Oil Recovery**

Polishing separators from GEA ensure the required premium quality of olive, palm, avocado and many other recovered vegetable oils by removing all residues while handling the product with extreme care

**Separators for Pharma Extraction**

GEA separators for pharma extraction are designed in accordance to GMP requirements.

**Separators for Power Plants**

High-performance centrifuge for efficient treatment of fuel oil and lube oil in power plants

**Separators for recovering plasma and meal from animal blood**

GEA offers entry-level separators with smaller capacities which are easy to operate and handle for small scale blood processors, e.g. small abattoirs as well as fully automatic, high efficiency and high capacity centrifuges for full scale blood processing specialists.

**Solid-Wall Bowl Separators for Chemical Products**

GEA solid-wall disc-type separators are used primarily for separating liquid mixtures with no or with only minimal solid contents (less than < 0.1 % by vol.).

**Solid-wall bowl separators for Marine**

Manual cleaning separators with solid-wall bowl and single centripetal pump are today used mostly for the treatment of diesel oil and lube oil on smaller ships. They are suitable for clarifying or purifying oils with a low solids content of up to 0.01 percent by vol..

**Solid-Wall Bowl Separators for Milk & Whey**

This belt-driven solid-wall bowl separator has been designed for milk or whey skimming and milk standardizing.

**Solid-Wall Bowl Separators for Pharma Extraction**

GEA solid-wall disc-type separators are used for liquid-liquid extraction processes

**Solid-wall bowl separators for Power Plants**

The continuous treatment of lube oil with centrifugal separation technology significantly extends the service life of diesel engines and gas/ steam turbines

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Contact us

- Larox: http://www.outotec.com/en/Products--services/Process-equipment/Filters/Pressure-filters/

## Key application areas

**MINING**

Supporting your mining operations, from plant design expertise to equipment, parts and services for every stage of your process.

**AGGREGATES**

Whether you run a quarry or carry out contract crushing, we take your business personally

**METALS REFINING**

Cost-effective solutions for metals recovery and refining

**RECYCLING**

Scrap and waste processing equipment for the steel industry, scrap yards and waste handling plants. Plant solutions for renewable or conventional energy production.

## Equipment

Product

**Dual Media (DM) Filter**

Cost efficient, reliable and proven filter for high-capacity, polishing applications

Product

**LSF filter**

Cost efficient, reliable and proven filter for high-capacity, polishing applications

Product

**Larox® PF filter**

Larox® PF filters are designed for easy maintenance, superior performance, and consistent results under varying process conditions.

Product

**Larox® PF-DS filter**

Flexible filter for difficult applications enabling consistent production with reduced downtime

Product

**Larox® RT filter**

Safe and optimized multi-step processing in a single unit for a wide range of complex Industrial & Chemical Processing Industry applications

Product

**Larox® RT-GT filter**

Safe and optimized single unit, multi-step processing for a wide range of complex Industrial & Chemical Processing Industry applications.

Product

Tube press filter

Metso Outotec tube press technology is proven to produce drip-free cakes from concentrate with less energy.

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## Key application areas

- Environmental
- Food and beverage
  - Olive Oil
  - Fruit and vegetables
  - Animal dairy
  - Plant milk
- Recycling
- Vegetable oils
- Mineral fuels and lubricants
- Chemical and pharmaceutical
- Animal by-products

## Equipment

- Decanter centrifuges
- Centrifugal separators
  - Separators with manual discharge
  - Separators with automatic discharge
  - Separators with nozzles
- Other components
- Olive Oil Plants
  - Washing
  - Crushing
  - Malaxing
  - Extraction

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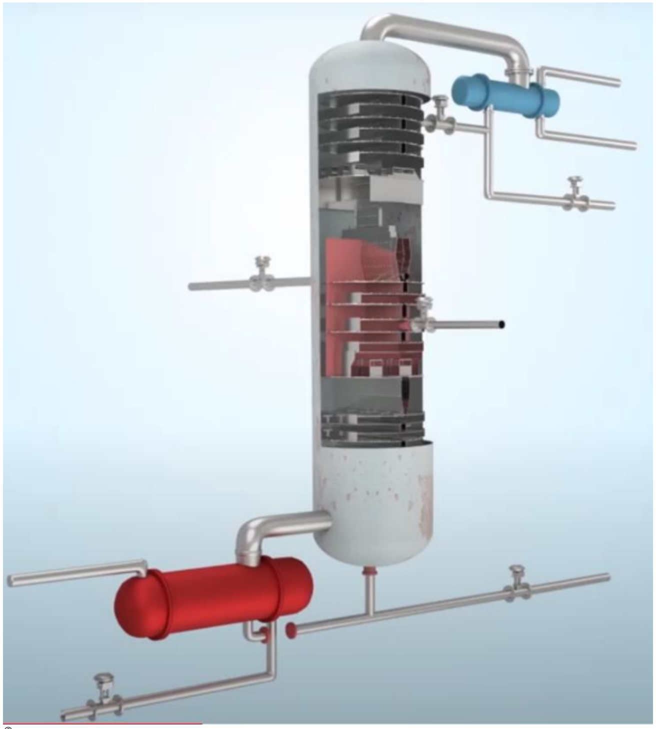
7. BP Dividing Wall Columns

# Best Practice Dividing Wall Columns



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| | |
|---|---|
| 7.1 Technology function | what does it do? |
| 7.2 Application window | what are known applications with which I can compare my issue? |
| 7.3 Operating window | what temperatures / pressures / flow regimes / concentrations? |
| 7.4 Benefits and Costs | what are the profit incentives and how does compare with cost? |
| 7.5 TRL and Risks | is the technology mature? Does it involve HSE- / financial risks? |
| 7.6 Working principle | how does it work? |
| 7.7 References | where can I find more information? |
| 7.8 Suppliers | which companies sell this technology? |

## 7.1 Technology function

A dividing wall distillation column separates mixtures into pure components.
When the column contains one vertical wall it separates a three component mixture into three pure components. When the column contains more than one vertical wall it separates a multicomponent mixture into its pure components.

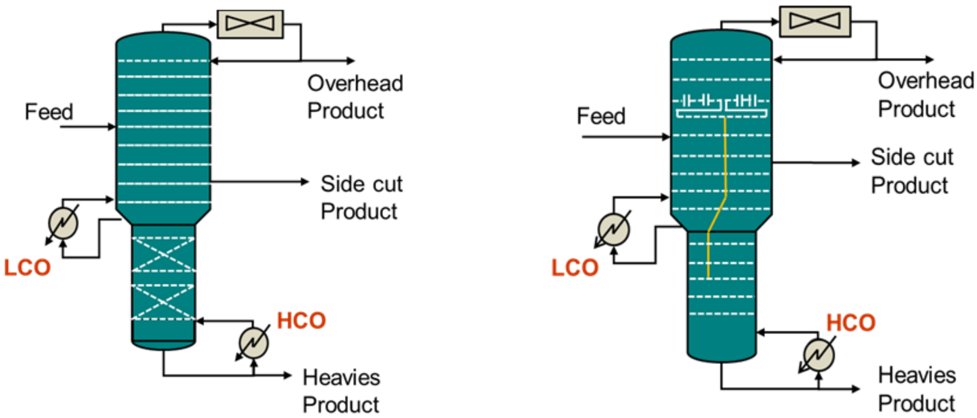
Dividing wall column tray

## 7.2 Application window

Application examples

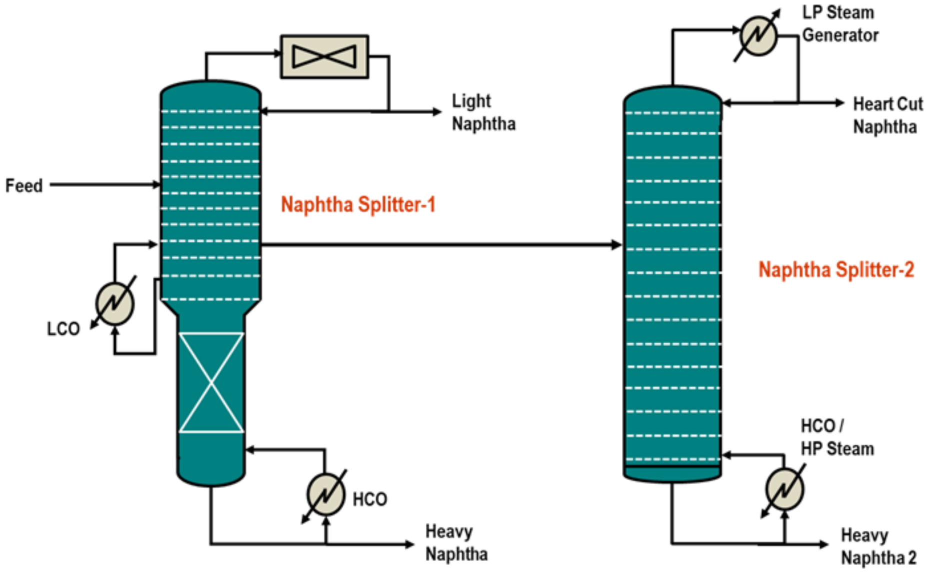
1. Refinery: retrofit FCC unit naphtha splitter column into light naphtha, heart-cut naphtha and heavy naphtha 2018 (ref.2)

Left: old situation Right: new situation

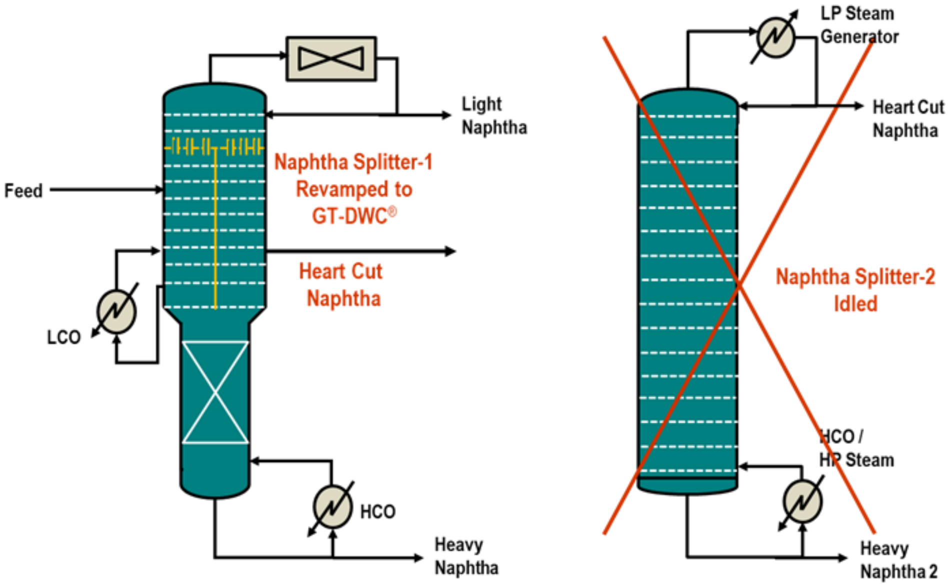


2. Refinery: naphtha splitting from two column to one column operation 2018 (ref.3)

Old situation

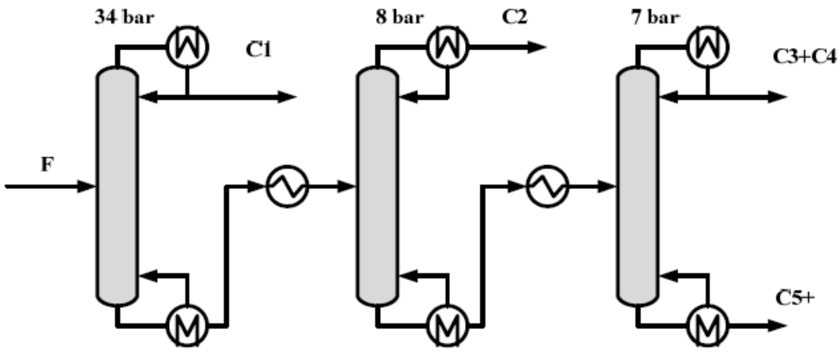



New situation

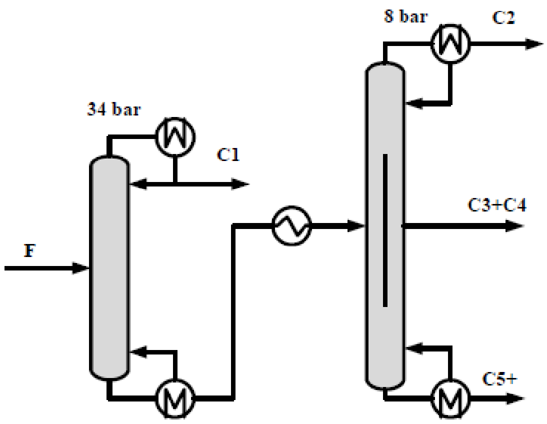


3. Natural gas liquefaction 2018 (ref.4)

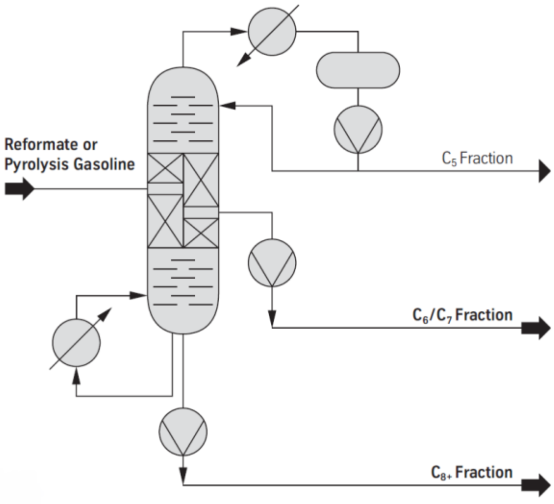
Traditional line up




Line up with DWC replacing column 2 and 3

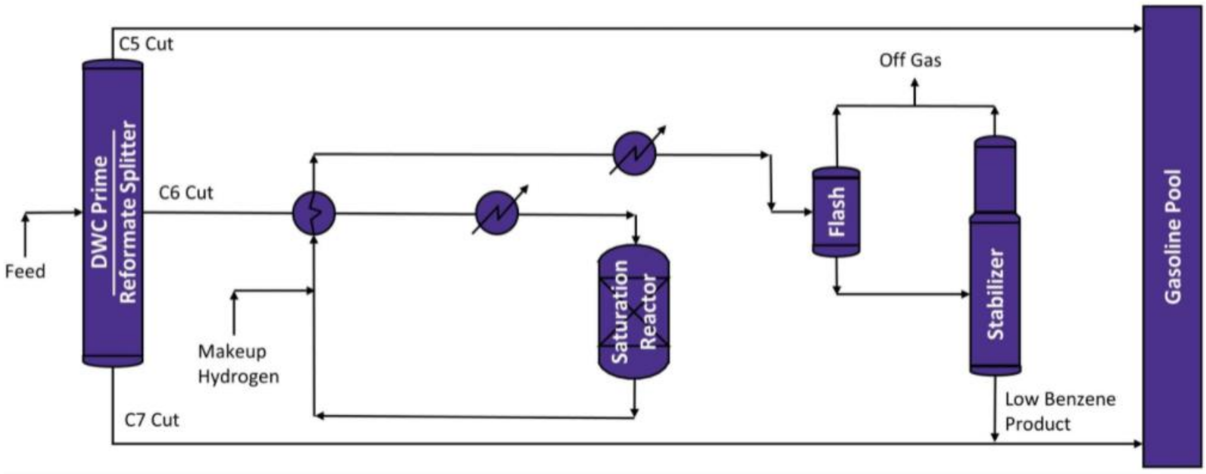


4. Benzene removal from gasoline 2022 (ref.5)

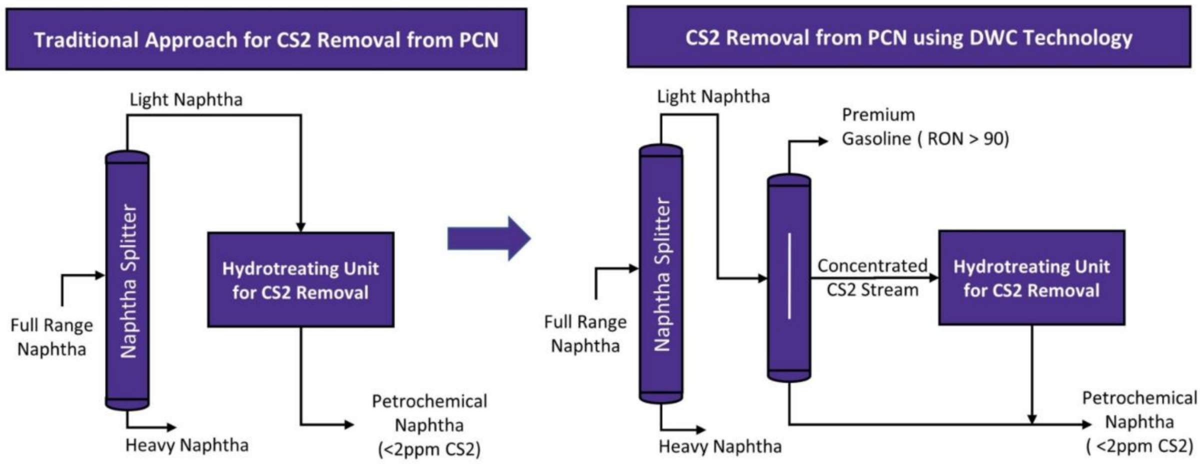



Installation of column on site

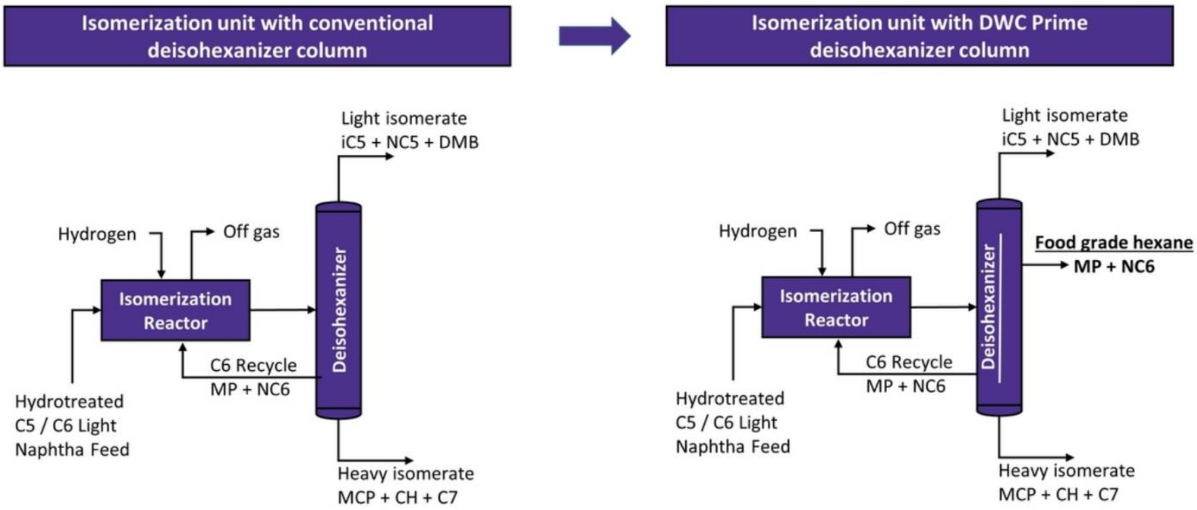
5. Concentrating benzene in a C6 cut (ref. 25)



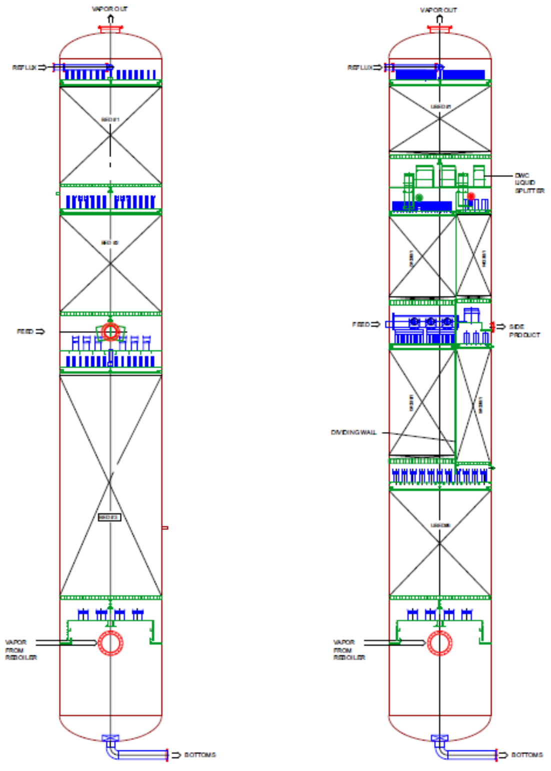

6. CS2 removal from petrochemical naphtha (ref. 26)



7. Boosting food grade hexane production (ref. 27)




8. Revamping a side cut packed column into a DWC to improve component purities (ref. 28)



Existing column elevation

Column elevation after revamp to DWC PRIME

## 7.3 Operating window

Since DWC's essentially are common distillation columns, their operating window in terms of pressures, temperatures, component concentrations, liquid and vapor flows resembles that of the unit operation "distillation" in general. This being said, there are a few additional limitations:

- Operation pressure variation between column sections is not possible
- The temperature difference between reboiler and condenser is higher compared to a two column set up for a three component mixture
- Column length is larger compared to two separate columns in parallel
- Modeling is generally more complex, as is design and control
- Non ideal mixtures require specific research

Next to this, DWC's have to deal with the same limitations as conventional distillation. Examples of this comprise the impact of too high bottom temperatures on product degradation, tray weeping or flooding due to too low/too high vapor flows resulting in poor separation performance, undesired pressure drops across the column, uneven liquid distribution over trays / structured packing, etc.

## 7.4 Benefits and Costs

- Converting two sequential columns into one by inserting a dividing wall in column one (ref.2)

| Parameters | Units | Conventional Design | DWC Design |
|---|---|---|---|
| Feed Rate | t hr-1 | 308.0 | 308.0 |
| C8/C9 (naphthenes and aromatics) | t hr-1 | 110.6 | 110.6 |
| C8/C9 (naphthenes and aromatics) Concentration | wt.% | 63.9 | 66.5 |
| C8/C9 (naphthenes and aromatics) | t hr-1 | 105.4 | 108.6 |
| C8/C9 Recovery in Heart-cut Naphtha | wt.% | 95.0 | 98.0 |
| Reboiler Duty (LCO) | MW | 12.8 (NS-1) | 14.5 |
| Reboiler Duty (HCO) | MW | 10.5 (NS-1) and 6.4 (NS-2) | 21.7 |
| Reboiler Duty (HP Steam) | MW | 14.3 | - |
| Condenser Duty | MW | 23.2 (NS-1) and 19.3 | 37.2 |

  - Heating duty is reduced by approximately 25% (LCO and HCO data combined)
  - High pressure steam use in the reboiler is eliminated
  - Heart-cut naphtha is obtained in one column, resulting in an idle second column
  - Product recoveries are increased by 3.2 t/h as compared to the original design
  - Equipment modifications outside the column are avoided

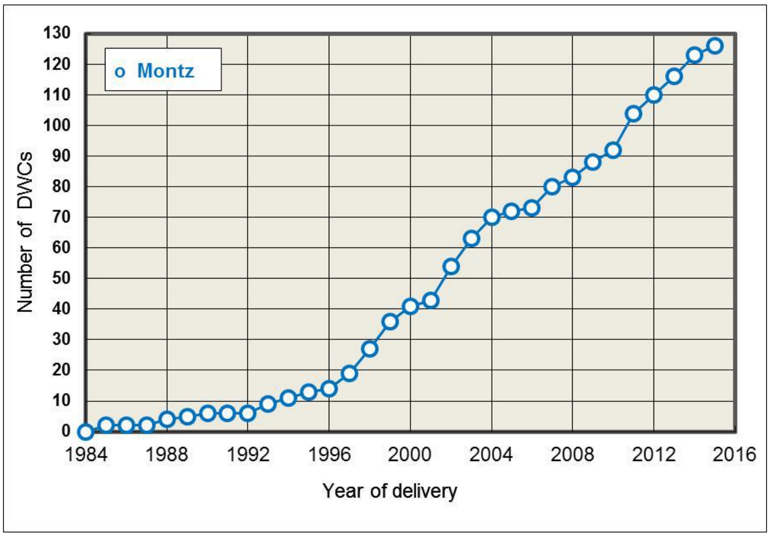
- Installation of benzene removal column 160.000 ton/jr (ref.5)

  - Capacity is increased from 128.000 to 160.000 ton/yr
  - Yield is increased from 86,6% to 89,1%
  - Plotspace is reduced by 50%
  - Steam consumption is down from 0,244 t/t to 0,21 t/t
  - Benzene content in gasoline is down from 5,2 wt% to 0,76 wt%

## 7.5 TRL and Risks

Commercial sales of dividing wall column technology began in 1984 and reached a worldwide total of 250 columns in 2016 as is shown in graph and table below. This implies TRL=9.

Number of world-wide installed DWC's by various vendors (status May 2016) (ref.1)




| | |
|---|---|
| Sulzer: | 45 |
| Koch-Glitsch: | 30 |
| UOP: | 10 |
| KBR: | 5 |
| UHDE: | 5 |
| Air Products: | 5 |
| Linde: | 5 |
| Sumitomo (Japan): | 5 |
| S. Korean: | 5 |
| Indian: | ? |
| Chinese: | 10 |

Despite DWC's well-established commercial status there are risks involved in choosing for the DWC approach. These risks concentrate on two areas:

- Design - ability
- Control - ability

Design – ability

Rigorous mathematical models, physical and chemical property databases and computer tools that simulate conventional distillation have matured over decades. Nowadays these aids often have reached a "near perfection" state of being, supplying output data with mind boggling accuracy and predictive power.
Obviously, there is a reason for this. Distillation is the most important separation technique in the process industries. Even today it is the workhorse of most companies, still beating all new kids on the block.

However, this picture slightly shifts when someone suddenly puts one or more vertical walls inside your trusted and familiar shell and tray design. Some things change and some things stay the same. Which exactly?

Dejanovic, Dimian, Bildea and Kiss came up with a practical list of heuristics to tackle these questions. First they suggest to carry out a brief analysis of your specific separation issue. Then they show steps how you can arrive at your first DWC design.

*Analysis of separation issue*

- Consider ternary and quarternary liquid mixtures in your process which are now separated by distillation, consider regular distillation and removal of impurities
- Analyze vapor-liquid equilibria if they are not too far from ideal
- Analyze existing operation – prepare mass and energy balances
- Make a quick design of a DWC using heuristic rules given above
- Consider profit of 30% energy reduction and potential profit for improved separation
- Check literature for data of application of the specific mixture or similar
- Check vendor documentation of Montz, Sulzer, Koch-Glitsch, etc.
- Contact consulting and design companies like Montz, Sulzer, etc.

*Steps towards DWC design*

- Design a conventional two-column system as a base case (e.g. in-/direct sequence)
- Take the total numbers of stages for DWC as 80% of the total number of stages required for the conventional two-column sequence: $N_{DWC}$=0.8 (N1+N2)
- Place the partition (i.e. dividing wall) in the middle third of the column (e.g. 33–66% H)
- Set the internal flow rates in the DWC, as determined by the reboiler or condenser duty, at 70% of the total duties of two conventional columns: $Q_{DWC}$=0.7 (Q1+Q2)
- Use equalised vapour and liquid splits ($r_L$=0.5, $r_V$=0.5) as initial values

Control - ability

The spreading of DWC at industrial scale is still limited to only a few companies (ref.11). One of the major reasons for this status quo is the insufficient insight in operation and control of a DWC. This lack of knowledge makes most chemical companies reticent to large-scale implementation.

Many articles on the controllability of DWC's have been published between 2010-2022, a small yet relevant selection of which can be found below (ref. 7-15).

These publications clearly show, DWC's can be operated and controlled in a reliable and robust way. In view of the obvious advantages of DWC over conventional sequential distillation the best advice this Best Practice can give you is to disclose and absorb the insights and control methods of DWC's described in literature and to follow the analysis / design steps given above.

## 7.6 Working principle

The working principle of DWC's is identical to that of conventional distillation columns. It is based on the difference in volatility of individual components at varying pressure and temperature, leading to different liquid and vapor compositions inside the column.

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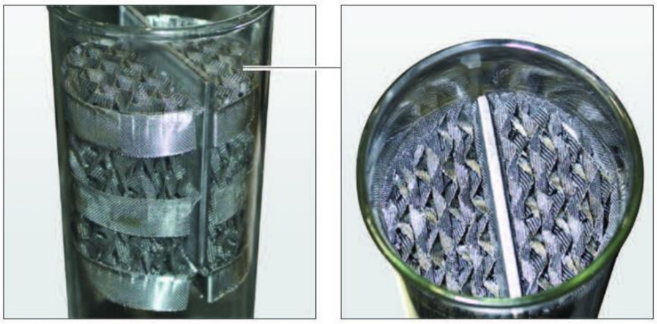
## 7.8 Suppliers

- Montz / Koch-Glitch (ref. 20)

Montz is part of Koch-Glitch. With Montz as one of their subsidiaries, Koch offers a broad capacity range of DWC's ranging from labscale to full scale equipment.

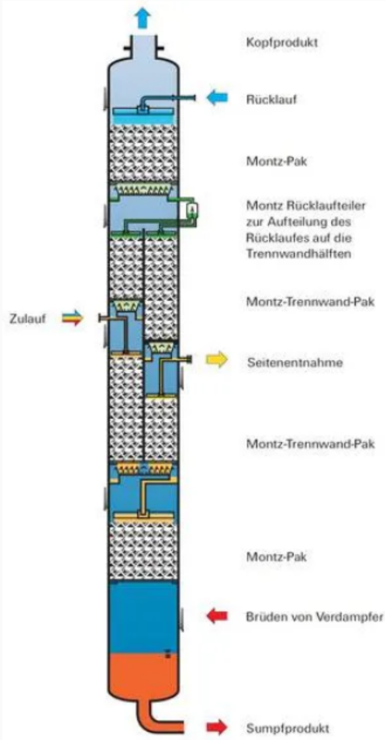
Labscale



Full scale

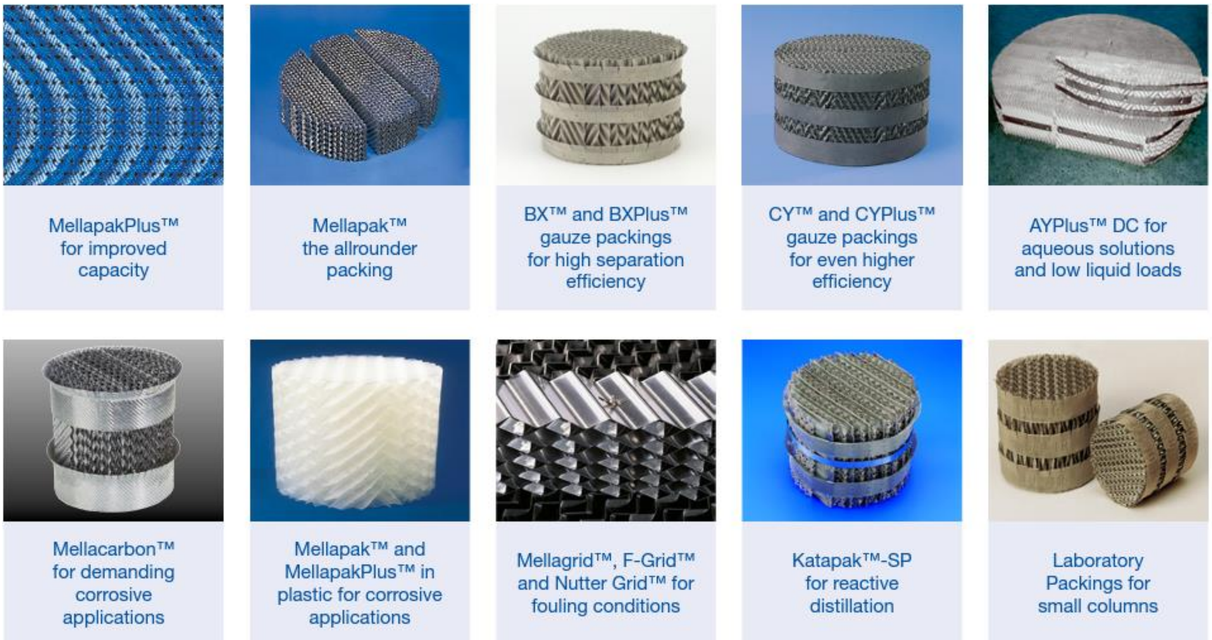
### Dividing wall columns

- Dividing wall columns can be used anywere when complex mixtures are to be split into pure fractions. It is particularly advantageous for the production of pure mid-boiling fractions.
- The separation of a ternary mixture into pure constituents with conventional columns requires a sequential circuit of two columns or a configuration of main columns with side columns. Using a dividing wall column, this task can be achieved in a single distillation column.
- In dividing wall columns, a vertical wall is positioned in the center part of the column shell. The divided wall separates thefeeding section from the draw-off section. The gas-tight and liquid-tight separation wall enables an energy efficient separation of low boiling and heavy boiling constituents in the feeding section working as a pre-fractionator. The draw-off section is designed for purification of the mid-boiling species.
- Such setup saves a second column for purification of the mid-boiling fraction. Column shell, internals, evaporators and condensers of a second column are not necessary. Further, the control and maintenance efforts are drastically reduced.
- Dividing wall columns are an alternative to multi-column circuits, which reduces investment and operation costs. As a rule of thumb, investment costs are reduced by minimim 20 - 30 % and operations costs by minimum 25 %.



- Sulzer (ref. 22)

Sulzer offers a wide range of column internals. When asked (ref.21) the company states it can deliver complete DWC's including internals. Sulzer positions DWC as another type of separation technology next to their conventional distillation columns with structured packing. This proves DWC has become a mature technique.



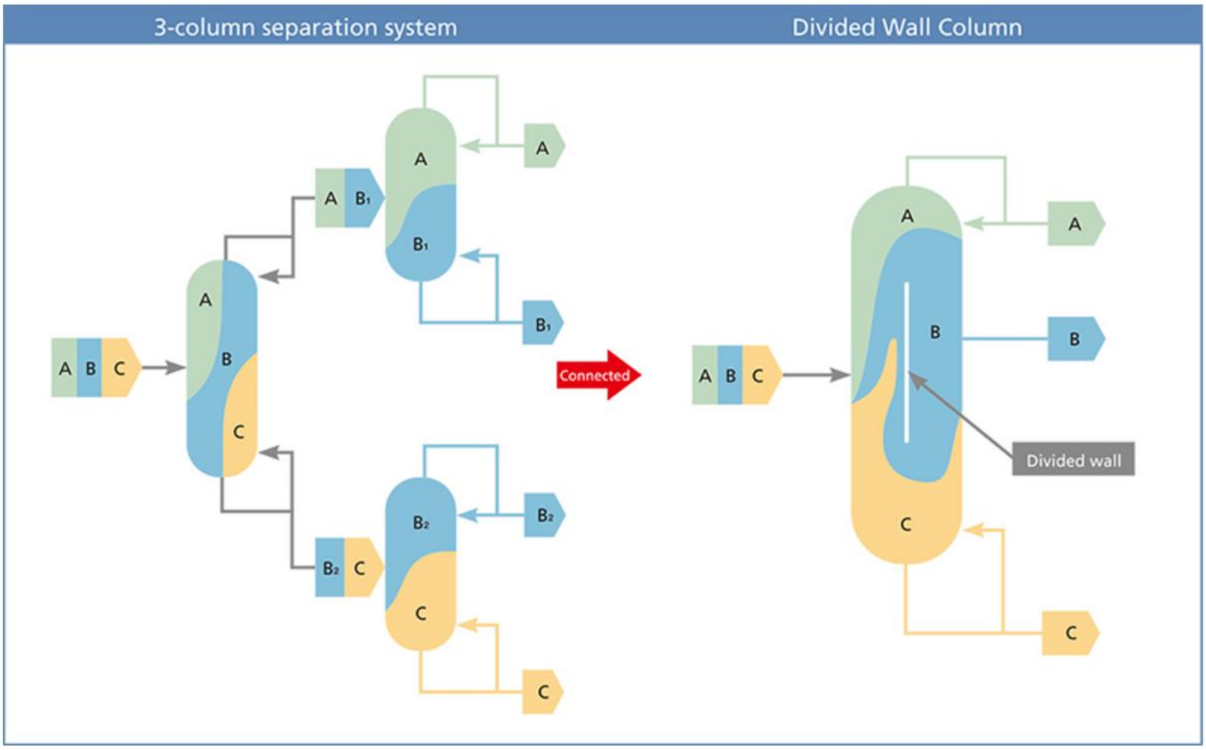

Sulzer has taken over GTC Technology (based in Houston Texas) in 2019. Before the takeover, GTC has built up a track record of successful DWC implementations. The new company is now operating under the name Sulzer GTC Technology Licensing (ref. 38).

- Linde (ref.23)

The company presents Dividing Wall Columns as one of their technology propositions next to a multitude of other solutions for separation issues. Linde puts no special emphasis on DWC. This in fact proves the fact that DWC has become a mature separation technique among others.

- Sumitomo Heavy Industries (ref.35)

Sumitomo tends to describe DWC as “ Column in column” technology.

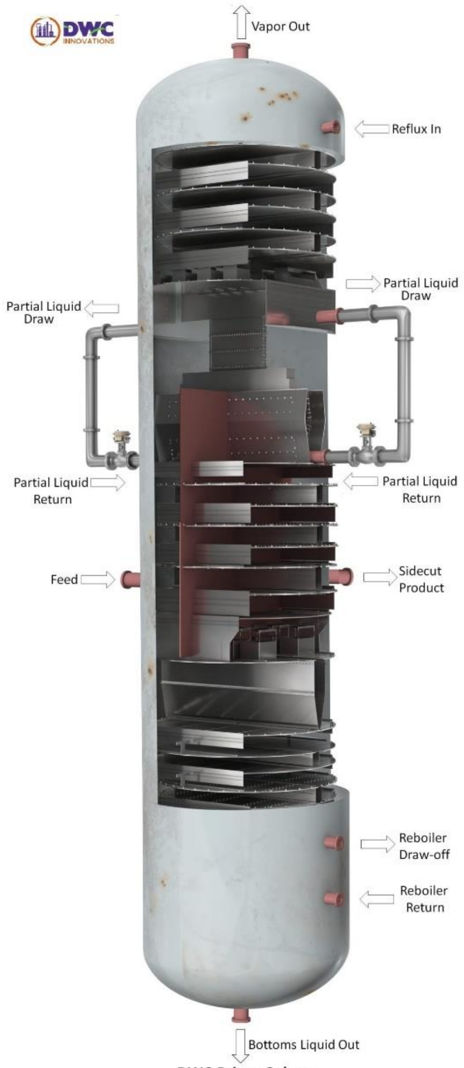


- Koch-Glitsch / Montz (ref. 36)

Koch-Glitch owns Montz. With Montz as one of their subsidiaries, Koch offers a broad capacity range of DWC's ranging from labscale to full scale equipment (See Montz).

- DWC Innovations (ref. 37)

DWC (Houston, Texas) is an independent company that has gained considerable momentum and growth in the area of DWC over the past 7 years. Their track record shows they offer DWC-solutions for complex multicomponent separations.




DWC Prime Column