Review on the "Agitated Thin Film Evaporator (*A.T.F.E*) "

Prepared By Dhaivat Rajenbhai Shah

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Used Abbreviations

A.T.F.E : Agitated Thin Film Evaporator

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Nomenclature

$\mathrm{Q} = \text{Heat transfer rate}, \mathrm{W}$

$\mathrm{U} = \text{Overall Heat Transfer Coefficient}, \frac{\mathrm{W}}{\mathrm{m^2K}}$

$\mathrm{A} = \text{Heat transfer surface(wall)}, \mathrm{m}^2$

$\Delta\mathrm{T_L} = \text{log mean temperature difference between process and heating fluid}, \mathrm{K}$

$\mathrm{h_O} = \text{film coefficent for heating medium outside wall}, \frac{\mathrm{W}}{\mathrm{m^2K}}$

$\mathrm{h_i} = \text{film coefficent for process fluid inside heating wall}, \frac{\mathrm{W}}{\mathrm{m^2K}}$

$\mathrm{t} = \text{Heating wall thickness}$

$k = heating\ wall\ thermal\ conductivity, \frac{\mathrm{W}}{\mathrm{m.K}}$

$f = scalling\ Facotr\ for\ h_i$

Chapter - 1: Introduction to Evaporation

1.1 Introduction to Evaporation

- Evaporation is the removal of solvent as a vapor from a solution or slurry.

OR

- Evaporation is the removal of volatile solvent from a solution or relatively dilutes slurry by vaporizing the solvent.
- The vapor may or may not be recovered, depending on its value.
- The end product may be a solid, but the transfer of heat in the evaporator must be to a solution or a suspension of the solid in liquid *if the apparatus is not to be classed as a dryer.*
- Evaporators are similar to stills or re-boilers of distillation columns, *except that no attempt is made to separate components of the vapor.*
- Evaporators are used to separate materials based on differences in their boiling temperatures
- Its purpose is to concentrate nonvolatile solutes such as organic compounds, inorganic salts, acids or bases. Typical solutes include phosphoric acid, caustic soda, sodium chloride, sodium sulfate, gelatin, syrups and urea.

The task demanded of an evaporator is to concentrate a feed stream by removing a solvent which is vaporized in the evaporator and, for the greatest number of evaporator systems, the solvent is water. Thus, the “bottoms” product is a concentrated solution, thick liquor, or possibly slurry.

Since the bottoms stream is most usually the desired and valuable product, the “overhead” vapor is a by-product of the concentration step and may or may not be recovered or recycled according to its value.

All evaporators remove a solvent vapor from a liquid stream by means of an energy input to the process.

The energy source is most usually dry and saturated steam, but can be a process heating medium such as:

- liquid or vapor phase heat transfer fluids (Dowtherm or Therminol),
- hot water,
- combustion gases,
- molten salt,
- a high temperature process stream,
- In the case of a solar evaporation plant, radiation from the sun.

Evaporation should not be confused with other somewhat similar thermal separation techniques that have more precise technical meanings, For example:

- distillation
- stripping
- drying
- deodorizing
- crystallization
- devolatilization

These operations are principally associated with separating or purifying a multi-component vapor (distillation), producing a solid bottoms product (drying, crystallization), or "finishing" an already-concentrated fluid material (stripping, devolatilization, deodorizing).

Engineers, scientists, and technicians involved in fermentation processes will usually be concerned with the concentration of aqueous solutions or suspensions, so the evaporation step will be the straightforward removal of water vapor from the process, utilizing steam as a heating medium.
The focus will be, then, on the evaporator itself and how it should be designed and Operated to achieve a desired separation in the fermentation facility.

Often an evaporator is really an evaporation system which incorporates several evaporators of different types installed in series.

1.2 Key Criteria of Design

Efficient Evaporators Are Designed And Operated According To Several Key Criteria,

- **Heat Transfer.** A large flow of heat across a metallic surface of minimum thickness (in other words, high heat flux) is fairly typical. The requirement of a high heat transfer rate is the major determinate of the evaporator type, size, and cost.
- **Liquid-Vapor Separation.** Liquid droplets carried through the evaporator system, known as entrainment, may contribute to product loss, lower product quality, erosion of metallic surfaces, and other problems including the necessity to recycle the entrainment. Generally, decreasing the level of entrainment in the evaporator increases both the capital and operating costs, although these incremental costs are usually rather small. All these problems and Costs considered, the most cost effective evaporator is often one with a very low or negligible level of entrainment.
- **Energy Efficiency.** Evaporators should be designed to make the best use of available energy, which implies using the lowest or the most economical net energy input. Steam-heated evaporators, for example, are rated on steam economy-pounds of solvent evaporated per pound of steam

1.3: Types of Evaporators

Following Types of Evaporators available,

- Long Tube Vertıcal Evaporator
- Short Tube Vertıcal Evaporator
- Fallıng Fılm Evaporator
- Rısıng Fılm Evaporator
- Rısıng/Fallıng Fılm Evaporator
- Agıtated Thın Fılm Evaporator
- Forced Cırculatıon Evaporator
- Horızontal Tube Evaporator

Possible Evaporator Arrangements are as follows :-

- Sıngle Effect Evaporator
- Multıple Effect Evaporator

1.4. Heat Transfer in Evaporators

Heat transfer in evaporators is governed by the equations for heat transfer to boiling liquids and by the convection and conduction equations. The heat must be provided from a source at a suitable temperature and this is condensing steam in most cases. The steam comes either directly from a boiler or from a previous stage of evaporation in another evaporator. Major objections to other forms of heating, such as direct firing or electric resistance heaters, arise because of the need to avoid local high temperatures and because of the high costs in the case of electricity. In some cases the temperatures of condensing steam may be too high for the product and hot water may be used. Low-pressure steam can also be used but the large volumes create design problems

1.5 Factors affecting rate of evaporation

The basic factors that affect the rate of evaporation are,

- Rate at which heat Can be transferred to the liquid
- quantity of heat required to evaporate each kg of water
- maximum allowable temperature of the liquid,
- pressure at which the evaporation takes place,
- Changes that may occur in the foodstuff during the course of the evaporation process.

1.6 Important practical considerations in evaporators

- Maximum allowable temperature, which may be substantially below 100°C.
- promotion of circulation of the liquid across the heat transfer surfaces, to attain reasonably high heat transfer coefficients and to prevent any local overheating
- viscosity of the fluid which will often increase substantially as the concentration of the dissolved materials increases
- Tendency to foam which makes separation of liquid and vapors difficult.

1.7 Evaporation of Heat Sensitive Materials

To understand evaporation procedure of heat sensitive material following points need to be kept in mind,

- In evaporators which have large volumes into which incoming feed is mixed, the retention time of a given food particle may be considerable.
- The average retention time can be obtained simply, by dividing the volume of the evaporator by the feed rate, but a substantial proportion of the liquor remains for much longer than this.
- Thus with heat sensitive materials a proportion may deteriorate and lead to general lowering of product quality.
- This difficulty is overcome in modern high flow-rate evaporators; in which there is a low hold up volume and in which little or no mixing occurs.
- Examples are long-tube evaporators with climbing or falling films, plate evaporators, centrifugal evaporators, and the various scraped-plate thin-film evaporators.

1.8 Thin film evaporation Basics

Thin Film Evaporation refers here to the thermal separation of products in a mechanically generated, thin and highly turbulent liquid film.

After entering the Thin Film Evaporator, the product comes into contact with the rotor:

it is uniformly spread on the periphery by the distribution ring, then picked up by the first rotor blades and immediately formed in to a film (0.5 - 3.5 mm) on the heat transfer surface. In front of each rotor blade, the fluid creates a bow wave (Fig. 1).

The fluid in the gap between the heat transfer surface and the rotor blade tip is highly turbulent and this leads to intensive heat and mass transfer rates.

This turbulence produces high heat transfer coefficients even with highly viscous products.

Due to the intensive mixing action within the bow wave, temperature sensitive products are prevented from overheating and fouling on the heat transfer surface can be reduced or eliminated.

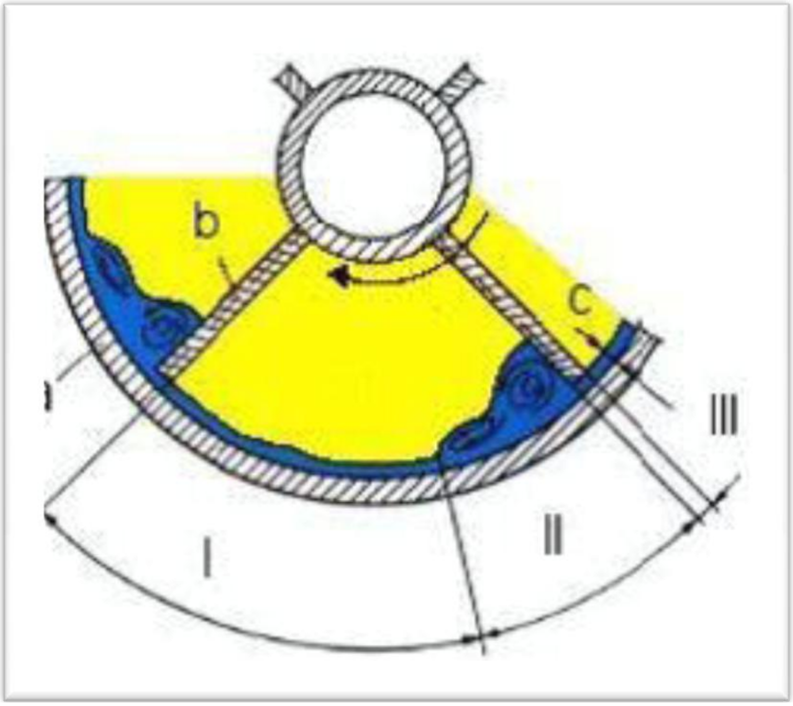


Figure 1 : Thin Film Evaporation

a) Inner Shell
b) Rotor Blade
c) Gap between Rotor and Inner Shell

I) Film Zone
II) Bow Wave
III) Gap Zone

1.9 Critical Operational and Product Characteristics

Critical operational and product characteristics of the solution to be evaporated have a major effect on the selection of the evaporator type most suited for the application.

Heat sensitivity. Many foods, pharmaceuticals, chemicals and resins are heat- or temperature-sensitive and require either low heating temperatures or a short residence time exposed to The heat or both. This can be accomplished by a combination of minimizing the volume of product in the evaporator at any one time, minimizing the time in the evaporator, and reducing the product's bulk boiling temperature by operating the evaporator at reduced pressures. Reducing the internal operating pressure may also allow operation at lower heating temperatures while still maintaining a reasonable heat-transfer driving

Fouling. Fouling of the heat transfer surfaces is usually caused by solids in the feed, precipitating solids in the concentrate, or degradation of the product. A slow buildup of a film On the heat transfer surfaces will cause a gradual reduction in the overall heat-transfer coefficient. Eventually this will require shutdown of the process and cleaning of the heat transfer surfaces, which results in production downtime and additional maintenance labor.

Foaming. Product foaming during vaporization is common. It may range from a small amount of unstable foam that breaks easily to a very stable foam that is difficult to break and tends to fill the entire void of the evaporator system. Foaming can often be minimized by special designs for the feed inlet (separation of feed from the vapor stream) and the vapor/liquid separation area (special disengaging designs). Also, reducing the boiling intensity of the liquid on the heat transfer surface (by operating at a lower temperature or at a higher pressure) and reducing the vapor velocity in the tubes may significantly reduce foaming. Where the product purity specifications allow, introduction of antifoam may solve or greatly reduce the problem.

Solids. The properties of the concentrate may change as the solids concentration increases. Solids may plug tubes, causing loss of heat transfer surface, in turn resulting in reduced heat transfer rates and requiring downtime for cleaning. Solids increase the tendency to foul the heating surface, which reduces the heat-transfer coefficient and boil-up rate. An increase in solids may also increase the concentrate viscosity, which affects the overall heat-transfer coefficient, reducing capacity.

Viscosity. Any increase in the viscosity of the concentrate will reduce the overall heat-transfer coefficient.

Required materials of construction (reactivity). A major consideration in evaporator selection may be the required materials of construction. The heat-transfer surface material is extremely important, because it not only affects the overall material cost, but also determines the thermal conductivity of the material, which impacts the overall heat-transfer coefficient And the required surface area.

1.10 Evaporator selection

The type of equipment used depends largely on the method of applying heat to the liquor and the method of agitation. Heating may be either direct or indirect. Direct heating is represented by solar evaporation and by submerged combustion of a fuel. In indirect heating, the heat, generally provided by the condensation of steam, passes through the heating surface of the evaporator.

Some of the problems arising during evaporation include:

(a) High product viscosity.

(b) Heat sensitivity.

(c) Scale formation and deposition.

Table. Product characteristic selection criteria for evaporators.

Type of Evaporator	Clean	High Capacity	Solids or Crystals	Fouling	Foamy	Temperature Sensitive	Viscous
Batch	x						x
Horizontal Tube	x						
Vertical Short Tube	x						
Vertical Long Tube	x	x					
Rising Falling Film	x	x			x		
Falling Film	x	x	x		x	x	
Forced Circulation	x	x	x	x	x		
Plate	x	x	x	x	x	x	x
Agitated Thin Film	x	x	x	x	x	x	x

Figure 2 : Evaporator Selection Criteria

Chapter - 2: Introduction to Agitated Thin Film Evaporation

2.1 Introduction to Agitated Thin Film Evaporation & Evaporator

The *Agitated Thin Film Evaporator* is best suitable for heat sensitive product where product drying time and drying temperature are very critical.

These evaporators, sometimes called wiped-film or scraped-film evaporators,

Rely on mechanical blades that spread the process fluid across the thermal surface of a single large tube, All thin-film evaporators have essentially three major components:

- a vapor body assembly,
- a rotor,
- A drive system.

In this thin-film evaporator design, product enters the feed nozzle above the heated zone and is mechanically transported by the rotor, and gravity, down a helical path on the inner heat transfer surface.

The evaporator does not operate full of product; the liquid or slurry forms a thin film or annular ring of product from the feed nozzle to the product outlet nozzle

Holdup or inventory of product in a thin film evaporator is very low, typically about a half a pound of material per square foot of heat transfer surface.

The high blade frequency, about 8 to 10 blade passes per second, generates a high rate of surface renewal and highly turbulent conditions for even extremely viscous fluids.

A variety of basic or standard thin-film evaporator designs is commercially available, including vertical or horizontal designs, and both types can have cylindrical or tapered thermal bodies and rotors.

The rotors may be one of several zero-clearance designs, a rigid fixed clearance type, or in the case of tapered rotors, an adjustable clearance construction type

One vertical design includes an optional residence time control ring at the end of the thermal surface to hold back product and thus build up the film thickness. The majority of thin-film

The mechanically Agitated Thin Film Evaporators give excellent performance with,

- Viscous
- Heat Sensitive Products.
- They are ideally suited for,
- Concentration,
- Evaporation,
- Distillation,
- De-Odourisation,
- Degassing,
- Reaction of Viscous, Heat Sensitive or Fouling Products.

Thin film Evaporators also known as wiped film evaporators are used to separate a mixture of liquids having different boiling points. It is also used to increase the concentration of liquids.

2.2 About A.T.F.E

Key Points to keep in mind when we are discussing about A.T.F.E.,

- Mechanically assisted to create a thin film on inside surface of evaporator
- Heat transfer from jacket on evaporator
- Film flows under gravity and becomes concentrated
- Evaporated fluid leaves through top
- Variation is to wipe the film if gravity is not enough – i.e. fouling is possible or liquid is viscous

2.3 Heat Transfer Rate Vs. Process Parameters (for LCI Make Thin Film Evaporator)

System design must consider many variables such as feed rate, temperature, rotor speed, blade clearance, wall thickness, construction materials, and the physical and thermodynamic properties of processed materials.

LCI thin-film separation technology quickly separates volatile from less volatile components using indirect heat transfer and mechanical agitation of a flowing product film under controlled conditions.

Its short residence time and open, low pressure drop configuration allow continuous, reliable processing of many heat sensitive or viscous materials without product degradation

Product enters above the heated zone and is evenly distributed over the unit's inner surface by the rotor.
As the product spirals down the wall, bow waves developed by the rotor blades generate highly turbulent flow, resulting in optimum heat flux and mass transfer

Volatile components are rapidly evaporated.
Vapors flow either counter currently or co currently through the unit, depending on the application. In both cases, vapors are ready for condensing or subsequent processing.

Nonvolatile components are discharged at the outlet .
Continuous washing by the bow waves minimizes fouling of the thermal wall where product or residue is concentrated most.

2.4 Types of Agitated Thin Film Evaporators

Following are the types of A.T.F.E.,

- Static Thin Film Evaporators
- Mechanicaly Agitated thin Film Evpaorator
    - Horizointaly Agitated Thin Film Evaporator
    - Verticaly Agitated Thin Film Evaporator

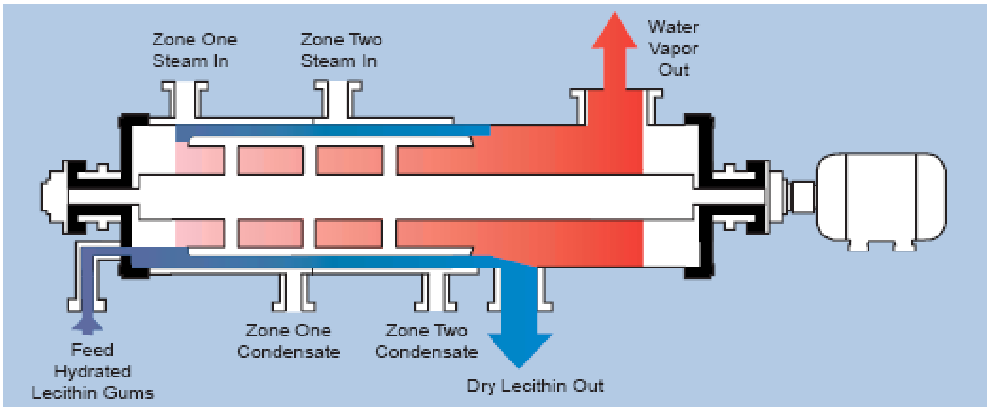


Figure 3 : Horizontal Mechanically Agitated Thin Film Evaporator

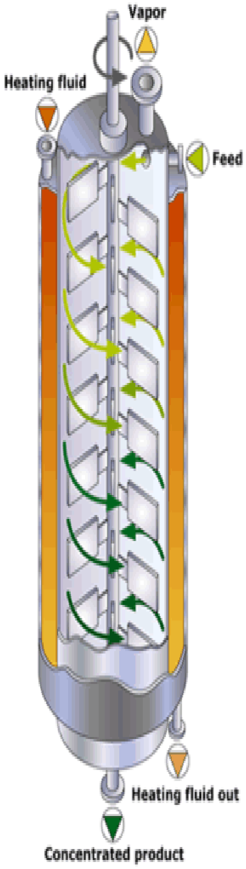


Figure 4 : Vertical Mechanically Agitated Thin Film Evaporator

2.5 Basic Construction of A.T.F.E

The Agitated Thin Film Evaporator comprises two major assemblies:

1. A jacketed shell precision machined from the inside
2. A rotor assembly that revolves at high speeds while closely fitting the shell.

- The feed enters the shell tangentially and spreads along the periphery through the Distributor. The rotor blade tips slides with a close clearance with the wall and Spread the feed uniformly on the heated surface into a thin film and then agitate it.
- The heating medium in the provides the necessary heat for evaporating the volatile Component of the feed.
- The vapor transmits counter current to the film and gets Cleared in the entrainment separator before being left through the vapor nozzle.
- The concentrated product leaves the evaporator bottom through the concentrate Nozzle

2.6 Principle of Operation

- The liquid feed is distributed on the heated wall of the evaporator to form a uniform thin film with the help of suitable configuration of blades.
- The volatile component or the component with lower boiling point gets evaporated and is vacuumed out of the evaporator, while the component with higher boiling point flows down the wall and is collected at the bottom.
- The vapors are passed through a condenser and collected separately.

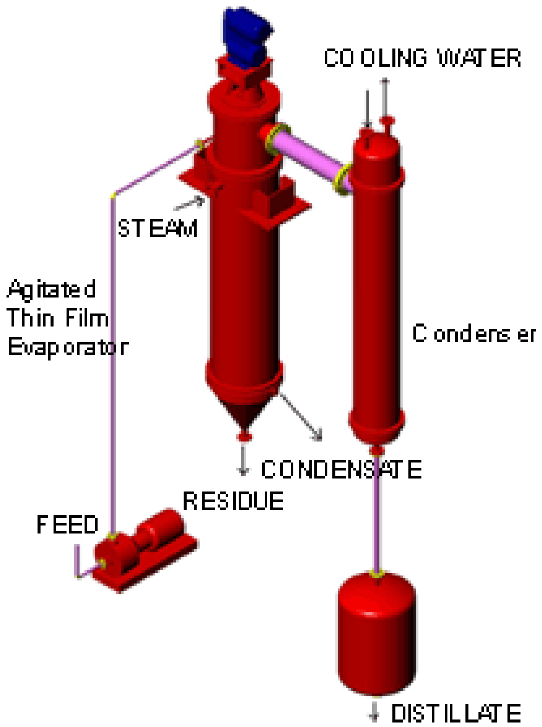


Figure 5 : General Evaporator Operating Principle

2.6.1 Working principle of vertical ATFE

- The product to be treated is continuously fed into the vertical Thin Film Evaporator above the heating jacket and is spread on to the periphery by the distribution ring.
- The product is then picked up by the rotor blades and immediately formed in to a thin turbulent film on the heat transfer surface.
- The volatile components of the feed stock are therefore very quickly vaporated and flow counter-currently with reference to the feed, up towards the top of the evaporator to the rotating separator.
- Here, entrained droplets or foam are knocked out of the vapor steam and return to the evaporation zone.
- The evaporated components (low boilers) then flow out of the evaporator in to the condensation stage, column or to another downstream process step.
- For special applications co-current vapor/product flow can be used in which case a separation vessel is fitted at the bottom of the evaporator below the rotor in place of the normal rotor mounted separator and the upper vapor outlet nozzle.
- The non volatile components of the feed stock (high boilers) flow in a spiral path down the heat transfer surface to the bottom of the evaporator, arrive to the bottom part of the heat transfer zone in a single pass within a matter of seconds and leave the evaporator.

2.6.2 Working Principle of horizontal Thin Film Evaporators

- The product is fed continuously to the horizontal Thin Film Evaporator (Fig. 4) at the larger diameter end, picked up by the rotor blades and spread immediately in a thin turbulent film on the heat transfer surface.
- The evaporator's conical form results in a centrifugal force being imparted on the product by the rotor which effectively has two components: one perpendicular to the heat transfer surface and the other in the direction of the body's larger diameter end (Remark: the same effect occurs in the vertical conical Thin Film Evaporator also).
- The product hold up created by these forces and that of the incoming product ensures that the heat transfer surface is fully wetted independent of the evaporation ratio and/or the feed rate.
- Localized product overheating and thermal degradation are thereby reduced or avoided altogether.
- The product vapour (low boilers) flows co-currently through the horizontal Thin Film Evaporator and in to the rotating separator.
- Here, entrained droplets and foam are knocked out and pass in to the liquid phase outlet (high boilers).
- The dry vapour then passes in to the condensation stage, column or to another downstream stage.

2.6.3 Thin Film Evaporator type "LUWA"

- The Thin Film Evaporator type "LUWA" is equipped with a rigid-blade rotor.
- It handles products with viscosities up to about 50,000 mPas.
- The rotor with his closed-type construction and his very smooth surfaces is easy to clean and is therefore used for a wide range of products, particularly in the food industry but also in the pharmaceutical industry

2.7 Features of A.T.F.E.

- Residence time of a few seconds with a narrow spread an important feature for heat sensitive products
- Required evaporation is achieved in a single pass ,avoiding product recirculation and possible degradation
- Scale formation on the heat transfer surface is avoided due to the intensive agitation of the liquid film
- Excellent turn down capability
- Low product holdup, ideal for hazardous applications
- Operating pressure as low as to 1 mbar and operating temperature up to 400 degree c
- Special designs for clean room applications

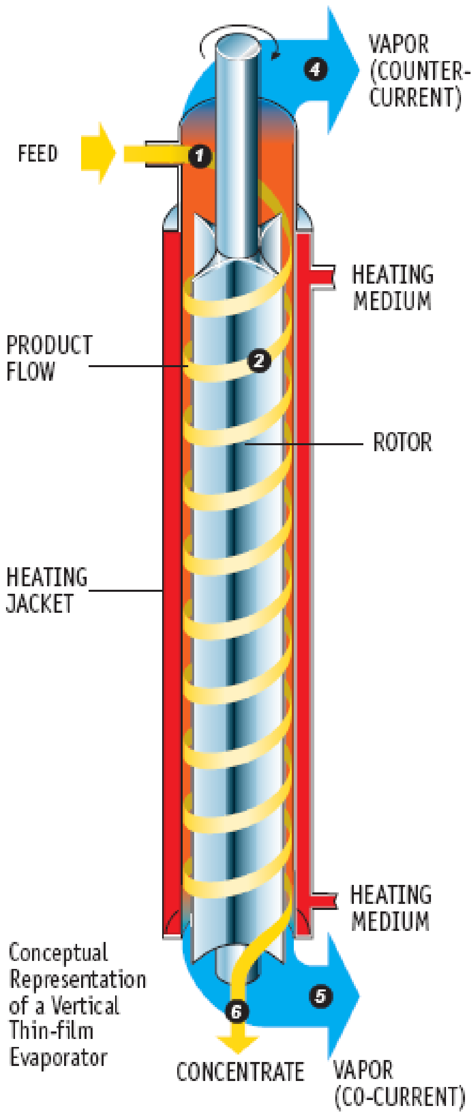


Figure 6 : Flow In Agitated Thin Film Evaporator

2.8 General Operating Features

- The heat transfer in thin film evaporator is very quick and efficient, thus demanding lower surface area and heat input as compared to other types of evaporator.
- Due to high vacuum distillation and very short residence time the thin film evaporator are suitable for handling wide range of heat sensitive, high boiling and viscous feeds.
- Due to low rotor speeds in the range of 100 to 150rpm, the horse power requirements are very low.
- To reduce the pressure drop between the evaporator and condenser, the internal condensers can be provided to achieve short path distillation.
- The thin film evaporators are designed to handle various products with operating pressures up to 0.1torr.
- Liquids with viscosities above 2,00,000cps can be handled in these evaporators.

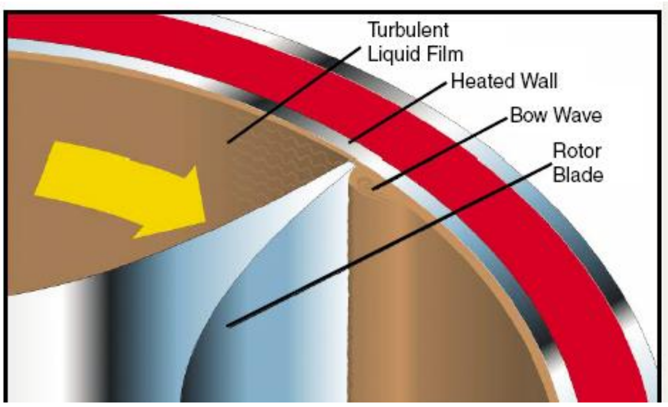


Figure 7 Thin Film Building Region

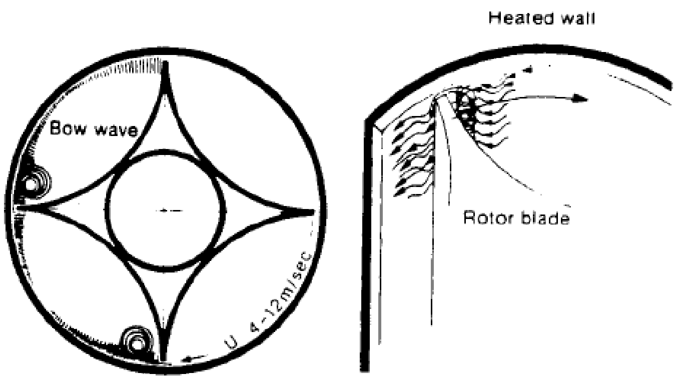


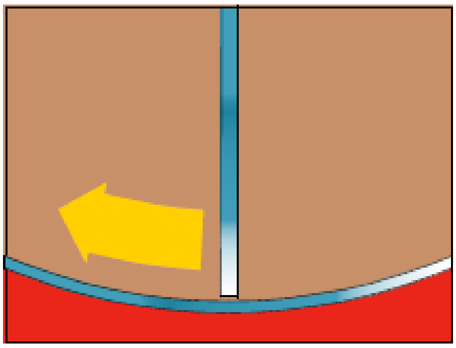
Figure 8 Bow Wave /Fillet, Thin Film

2.9 Rotor-Blade Configuration

The different types of Rotor-blade configurations available are:

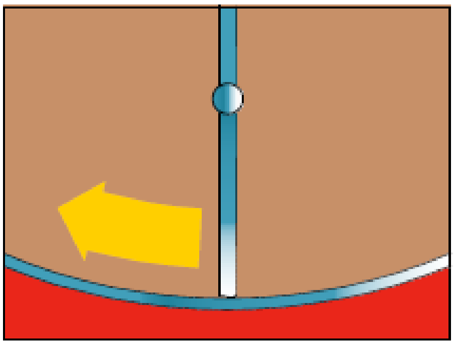
- Fixed blade rotor
- Spring loaded rotor
- Cylindrical wiper rotor
- Centrifugal blade rotor

On the basis of Application following are Different Rotor Design Recommendations,



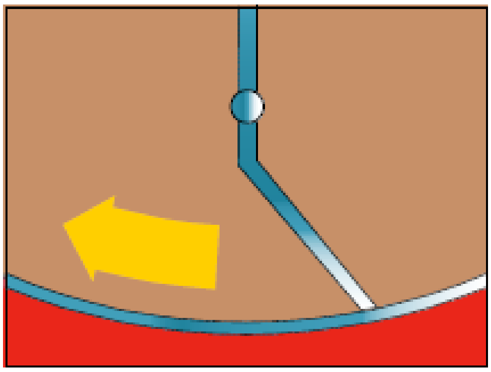
Fixed Clearance

For all horizontal designs and most vertical applications for less viscous liquids, generally less than 50,000 cps



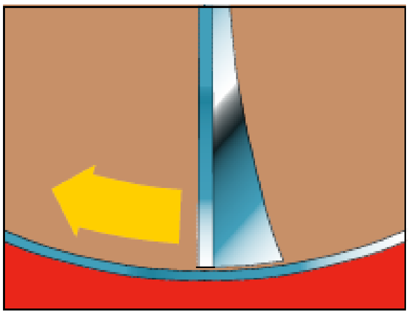
Drying

For solids-containing streams from which liquid must be evaporated or distilled



Wiped Film/Hinged Blade

For materials with very high fouling tendencies or vaporization ratios



Transported Flow

This rotor design provides positive transport for viscous materials which do not flow by gravity—usually those of 50,000 cp or more

2.10 Flow Arrangements in A.T.F.E

In an A.T.F.E Vapors flow in Following Two Directions

- Counter Current Flow
  - In most vertical applications
  - As it maximizes both heat and mass transfer efficiencies
  - Accommodates internal vapor/liquid entrainment system
- Co current Flow
  - For Applications involving Heavy Vapor Loading/Flashing/Foaming

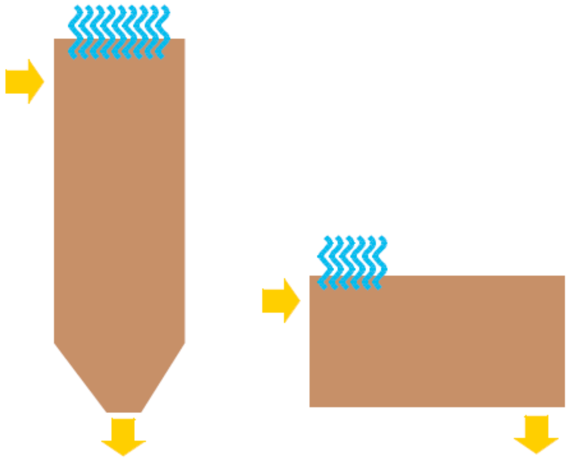


Figure 9 : Countercurrent Flow

Figure 10 Cocurrent Flow

2.11 Orientation of rotor

1) Horizontal Rotor Arrangement

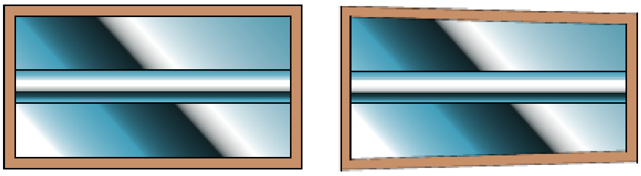


Figure 11 Horizontal Rotor

- For Longer Residence Time Applications specifically for mass transfer and reactions
- Where Head Room is limited
- Tapered Configuration allows to Control Residence Time and assures heat transfer Surface wetting Low Throughout Rates

2) Vertical Rotor Arrangement

- For almost applications
- Reliable, efficient processing of viscous and fouling fluids
- Either with internal/external bearings

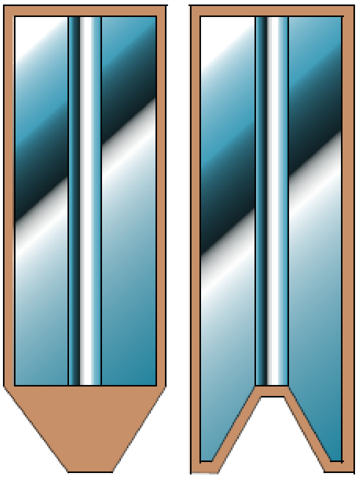


Figure 12 Verticle Rotor

2.12 Types of Rotors

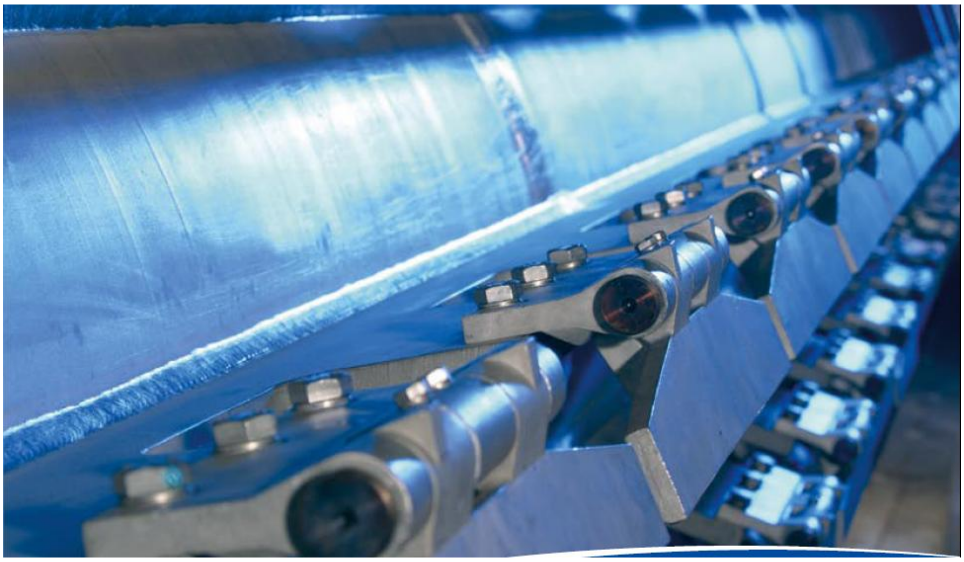


Figure 13 :Additionally Mounted Blades

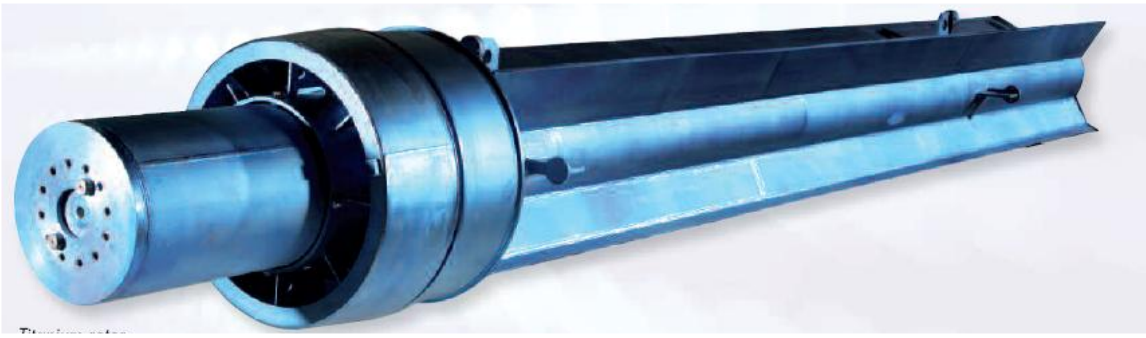


Figure 14 : Single Aligned Blade Design

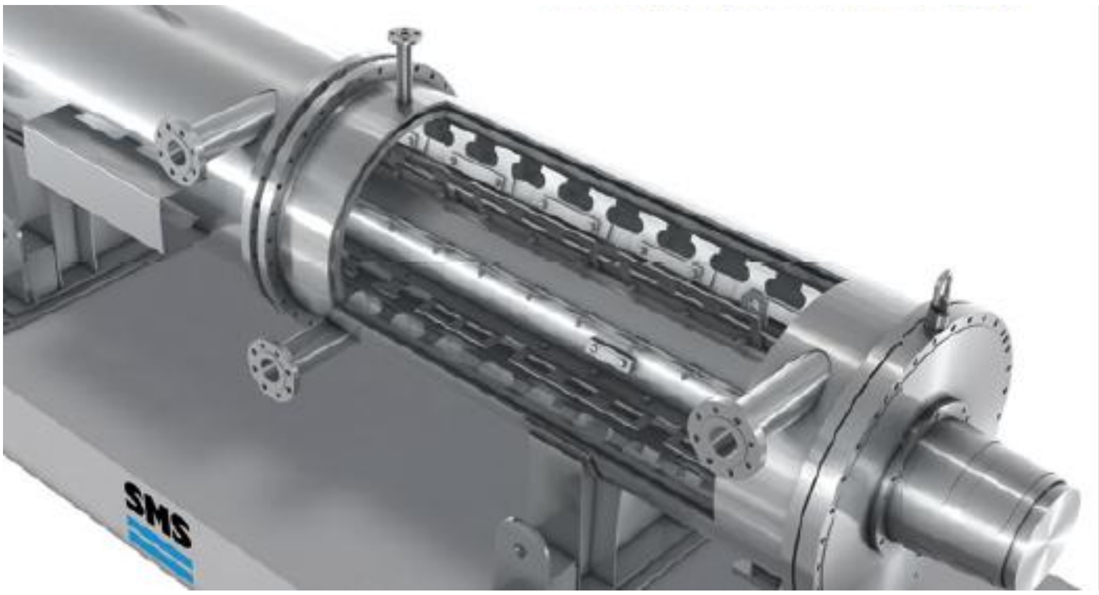


Figure 15 :Horizontal Rotor, Blades Mounted with Zero clearance

2.13 Other Types of Rotors

Rigid blade rotor
with fixed clearance

Rotor with hinged metal
wiper blades

Rotor with radially moving
PTFE or graphite wiper
elements

Rotor in hygiene design

2.14 Different Blade Configurations

Different Blade Configurations (attached with rotors) available in the market are as follows

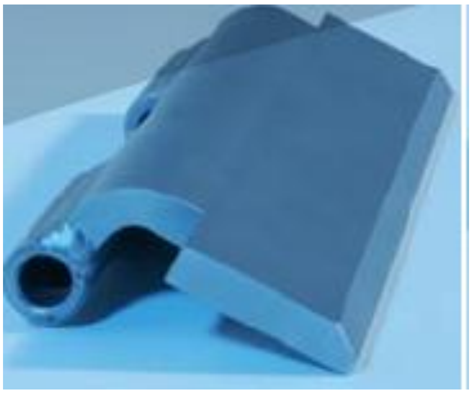
Starrflügelrotor.
Rigid blade rotor.

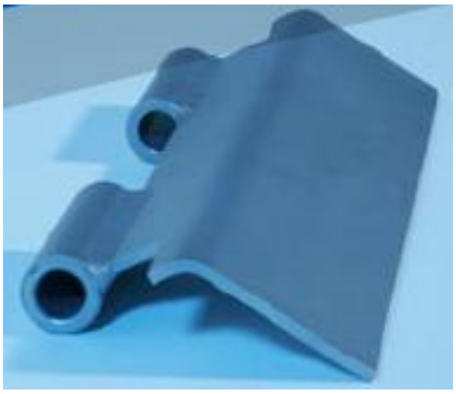
Bewegliches
Blatt mit Anschlag.
Mobile blade with limiter
(B-Type).

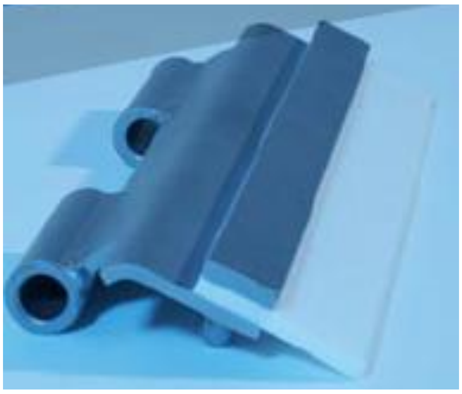
Bewegliches Blatt mit PTFE Kante.
Mobile blade with PTFE bar
(B-Type).

Bewegliches Blatt
mit Wandkontakt.
Mobile blade with wall
contact (B-Type).

2.15 Blades of A.T.F.E







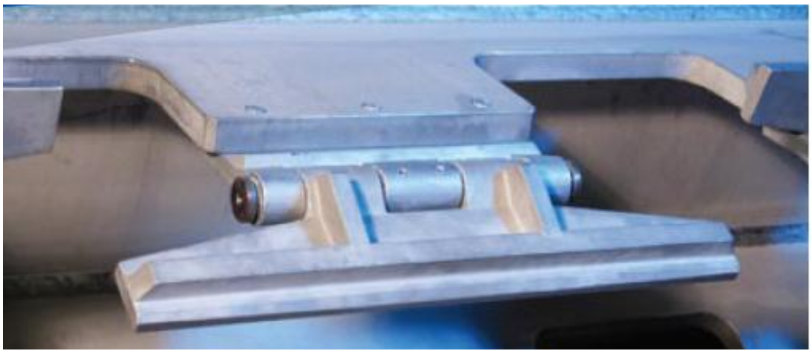


Figure 16 Close-up of Blade Mounted On Rotor

2.16 Different Types of Rotor-Blades Combinations

The construction of the evaporator is such that different types of rotors can be mounted In the same equipment for different products.

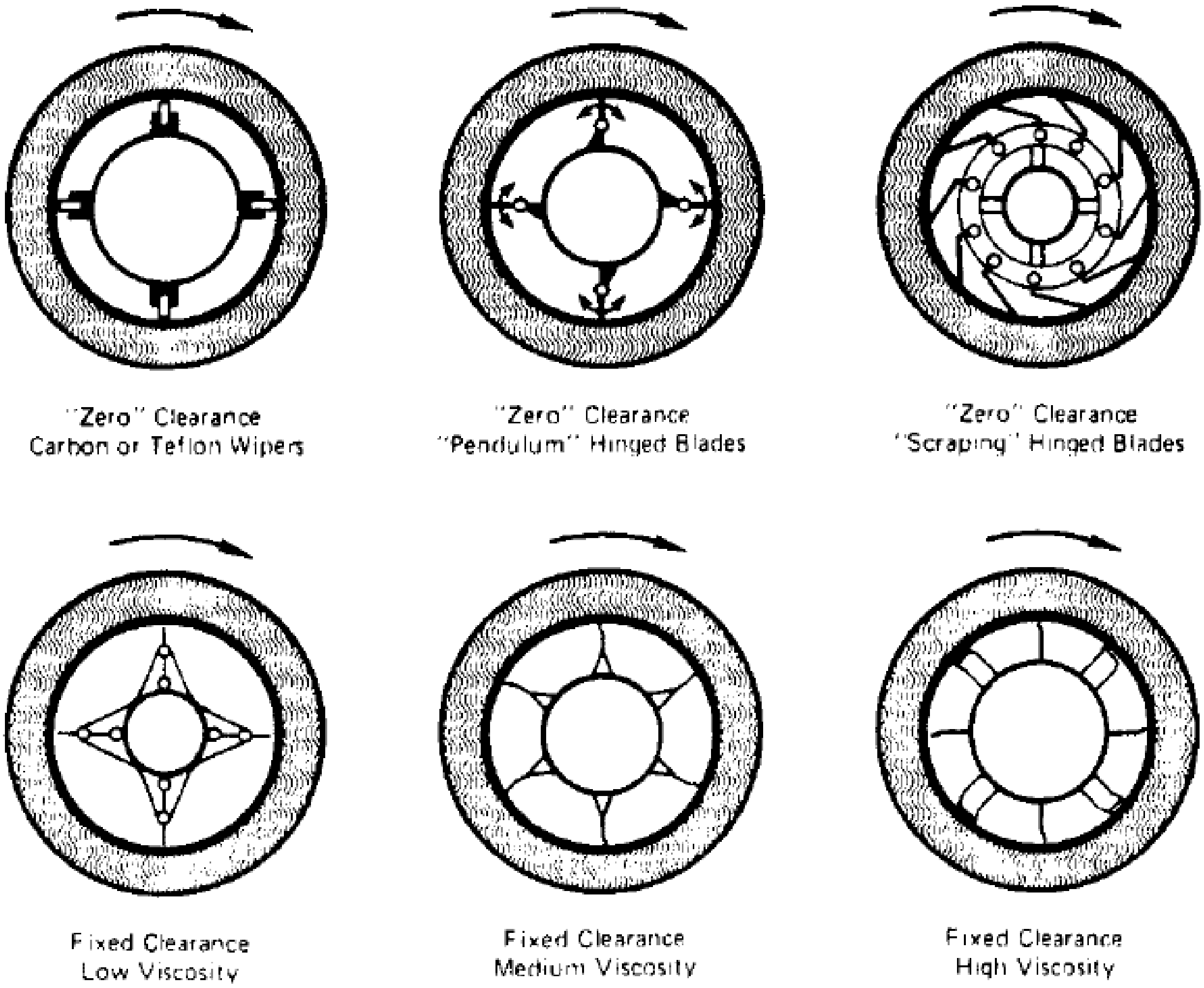
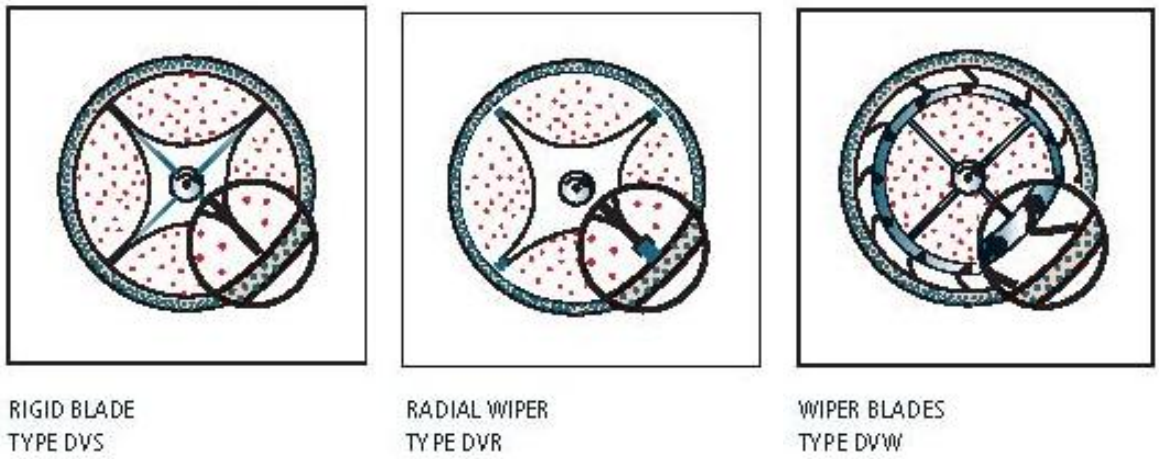


Figure 17: Clearance & Viscosity Based Rotor-Blade Arrangement

2.17 Comparison of Different Rotor Arrangements



Type	DVS	DVR	DVW
Rotor Speed	High (up to 8 m/s)	Low (up to 3 m/s)	Low (up to 3 m/s)
Wall Contact	No	Yes	Yes
Necessity of Bearing Lubrication	Yes	No	No
Temperature Range	Max. 300ºC	Max.250ºC	Max.400ºC
Pressure-Vacuum	>10^{-1} kPa	>10^{-1} kPa	>10^{-1} kPa
Viscosity	Max.40000 mPa.s	Max.20000 mPa.s	Max. 20000 mPa.s
Evaporation Grade	Max. 80 vol %	Max. 98 vol%	Max. 95 vol%
Solids Contents(Suspension)	No	Yes	Yes
Crystallization	No	No	Yes

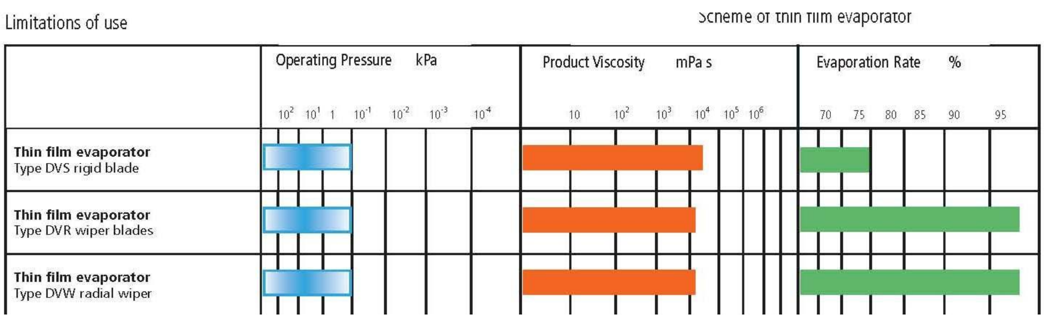


Figure 18 DVS,DVR,DVW Type Rotors

Construction of ATFE the Agitated Thin Film Evaporator consists of,

1. A jacketed shell having a machined surface on the inner side.
2. The rotor assembly consisting of different configuration of blades depending upon the nature of product is mounted in the shell.
3. Feed inlet is provided at the top side.
4. Specially designed feed distributor is integral with the rotor at the top side.
5. The rotor is also fitted with an entrainment separator.
6. Generally the vapor outlet is provided on the top side of the shell.

As well,

- Materials of construction
- Material thickness
- Rotor speed
- Rotor clearance
- Internal diameter of Shell
- Length of body
- Liquid and vapor rates
- Operating pressure
- Type and temperature of heating medium



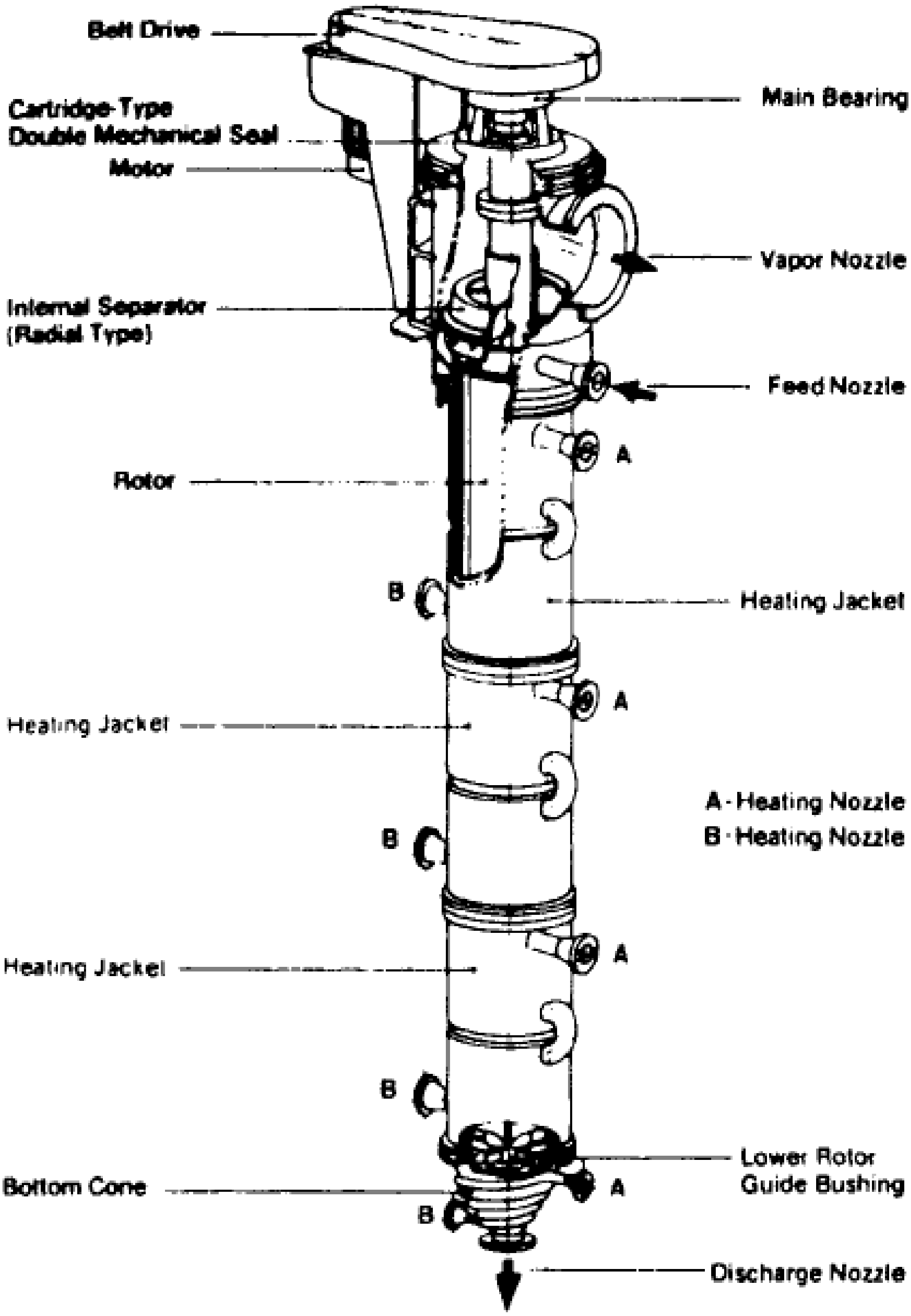


Figure 19 : Diagram of A.T.F.E

4.1 Brief about Flows, Processes in A.T.F.E

Mechanically agitated thin-film evaporators are used for four general types of applications:

- Heat sensitive products
- Fluids with fouling tendencies
- Viscous materials
- Liquids containing a large amount of dissolved or suspended solids

The one-pass, plug flow operation of a thin-film evaporator is an advantage for minimizing thermal degradation of a heat sensitive product in an evaporation step.

The mean residence time in the evaporator can be just seconds, rather than minutes or hours in a re-circulating evaporation system.

For this reason, thin-film evaporators are widely used for heat sensitive food, pharmaceutical, and other chemical products.

Also, it should be noted that the thin-film evaporator can be operated at a higher temperature to make a better separation, whereas care must usually be taken to keep the product temperature lower in an evaporation system with longer residence times.

Thin-film evaporators are frequently used for extremely viscous fluids, those in the range of 1,000 to 50,000 centipoise, and for concentrating streams with more than 25% suspended solids.

Heat transfer coefficients for these types of materials in a thin-film evaporator are typically much greater than coefficients in any other type of evaporator for the same conditions.

Very high temperature difference (e.g., 100 to 200'F) can be maintained to better utilize the heat transfer area by increasing the heat flux, Q/A.

These evaporators are necessarily precision machines and therefore are more expensive than other types, particularly so if compared strictly on equivalent heat transfer area.

When the performance for a specific evaporation duty is the basis of comparison, the thin-film evaporator is often the more economical choice because the larger heat transfer coefficient and higher driving force mean much less surface is required than for other evaporators (A = Q/UAI).

Thin-film evaporator cost per unit area decreases significantly with unit size

4.2 Process requirements

- Before the process and equipment can be evaluated, the requirements, specifications, and value for a marketable product must be determined.
- Then, the general process specifications required to produce the marketable product must be determined.
- The process should make a quality product with a good yield and minimum waste.

4.3Process Design Parameters

For process design following parameters should be considered,

- Latent heat of vaporization
- Thermal conductivity
- Density
- Specific heat of both heating medium and process fluid
- Optimal heat transfer area
- Overall heat transfer co efficient
- Degree of separation
- Feed rate and temperature
- Type and temperature of heat transfer fluid
- Physical properties required
- Viscosity

The following factors should be considered as well

- start-up time for the process to maximize on-stream time and minimize loss of product during process stabilization
- minimum hold-up of product at shutdown to minimize loss of product
- short residence time to minimize product loss due to degradation
- prevention of fouling that causes loss of on-stream time for cleaning
- the ability to squeeze valuable products from the concentrated residues where the distillate is the product,
- which reduces waste and the need for recycle (or a second stage) to recover additional product
- Ability to strip volatiles to low levels in the concentrate (mass transfer) where the concentrate is the product.

4.4 Questionnaire For Evaporator

1. Feed

Rate: _____________ kg/hr.
Composition: _____________ % W/W.
Form: Liquid/Solid.
If liquid, Specific gravity:
If solid, melting point:

2. Distillate

Rate: _____________ kg/hr.
Composition: _____________ % W/W.
Form at ambient temp. : Liquid/solid.

3. Concentrate

Composition: _____________% W/W.
Form at ambient temp. : Liquid/solid.

4. Valuable product: Distillate/Concentrate/Both.
5. Recommended operating conditions.

Operating pressure: _____________ Torr.
Operating vapor temperature: _____________ dg.C.
Operating concentrate temperature: _____________ dg.C.
Heating temperature: _____________ dg.C.

6. Safety Details

Is the material () toxic
() lethal
() inflammable

7. General Information

Recommended material of construction: ______________
8) Existing process details with reference to the operating problems faced.
____
____
____
9) Can 0.5 lit. Of feed material be made available for free laboratory scale investigations?
____
10) Can 30-100 lit. Of feed material be made available for pilot plant trials at our test Centre at a nominal charge to cover operating & handling expenses?
____

11. Physical Properties

Feed
Specific heat (Kcal/kgdg.C.):
Viscosity at operating temperature (cps):
Melting point:

Distillate
Specific gravity:
Latent heat (Kcal/kg):
Molecular weight:
Viscosity at operating temperature (cps):
Boiling point (dg.C.):
Melting point (dg.C.):

Concentrate
Specific gravity:
Viscosity at operating temperature:
Melting point:

Name & designation of contact person:
Name of the company:
Address:
Telephone No. :
E-mail:
Fax No. :

Other process design parameters were studied by going through several case studies and research work done by different people mentioned below

4.5 Case Study-1 Flow and Mixing Characteristics in an A.T.F.E.

Why A.T.F.E. is preferred over other evaporators?

It can operate under vacuum

Low residence time

Which forces are applied on the falling film?

Radial drag flow due to motion of blades

Downward force due to gravity

Formation around blades

Falling thin film behind the blade

Falling fillet in front of blade

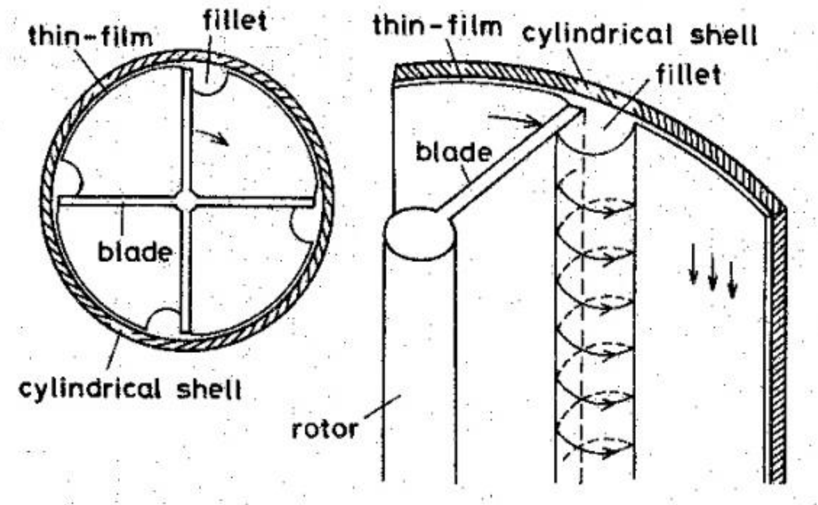


Fig. 1. Schematic diagram of flow field in an agitated thin-film evaporator with high viscosity fluid

Contribution of film for the evaporation

Heat transfer through the walls to the film fluid

Evaporation from the film surface to the atmosphere inside the shell

About Fillet Formation

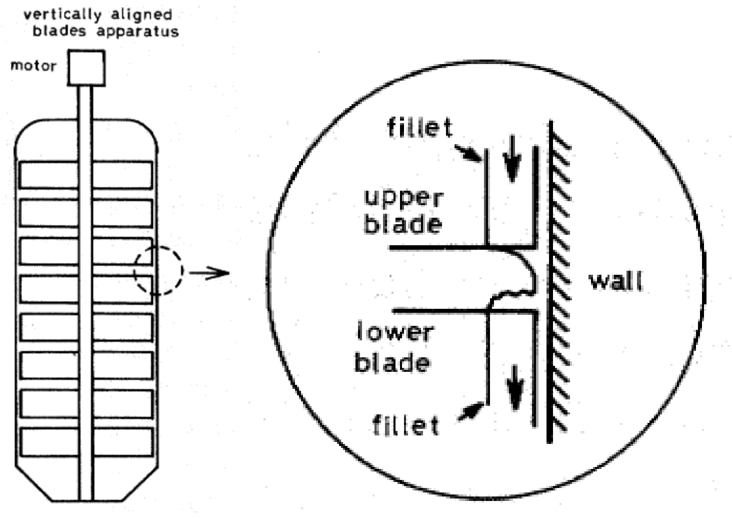
More than 7-% fluids has extreme low material exchange rate

If more blades are used then evaporation will be enhanced

To promote material exchange rate between fillet and film use of vertically aligned multiple

Blades are advised.

Formation of fillets and film Due to rotation of blades



Material Exchange rate depends on Mixing Reynolds Number

Optimum Distance between Two blades

Calculation for number of blades required

4.6 Case Study-2 Mass Transfer during Thin Film Evaporation of Liquid Solutions

Mass transfer in during thin film evaporation of liquid solutions

For the system of

- methyl alcohol - water
- Ethyl alcohol - water solution

Separation efficiency during thin film evaporation a theory by Billet

4.7 Case Study-3: Hazardous Waste Treatment

Processing actual radioactive waste streams to monitor the performance and physical behavior of the process.
The ATFE will be used to remove water from streams of supernatant tank waste.
It is a continuous evaporation process
Which is fed waste through a feed tank where waste is loaded?
The system takes that waste and evaporates the water from it, condenses the water and collects it, and sends the concentrated waste back to the feed tank.

4.8 Case Study-4 Selection of an A.T.F.E for Processing a Radioactive Waste

Hazardous Waste Treatment Solution at Oak Ridge National Labor

4.9 Sample A.T.F.E Configurations

High viscosity polymer concentration

Product viscosity at operating conditions	:	400,000 CP
Heat transfer area	:	10 sq.m.
Rotor diameter.	:	800mm
Rotor length	:	4.4 m
Design code	:	ASME Sec VIII Div I
Material of construction	:	SS316

Process conditions	Limits
Feed rate	20-100000 kg/h
Evaporating performance	Up to 40000 kg/h
Heating temperature	Up to 380 Degree C
Heating media	Saturated vapors, liquid medium
Process side pressure	-1 to 30 bar(g)
Flow rate with viscosities up to 10 Pa.s	50- 1000 kg/h.m2
Product viscosity at process temperature	Up to 70000 mPa.S
Residence Time	< 1 min
Loading Range	20-100%

Chapter 5 - Selection of Agitated thin-film evaporators

Tubular evaporators have been used successfully with a variety of materials; they have been less successful with heat-sensitive, viscous, fouling or high-boiling liquids. Degradation due to long residence time, fouling of the heat transfer surfaces, plugging of tubes, and low heat transfer and high pressure drops due to high viscosities are common problems.

Agitated thin-film evaporation successfully overcomes problems with difficult-to-handle products. Simply stated, the method quickly separates the volatile from the less-volatile components using indirect heat transfer and mechanical agitation of the flowing product film under controlled conditions.

The separation is normally made under vacuum conditions to maximize the temperature difference while maintaining the most favorable product temperature, as well as to maximize Volatile stripping and recovery.

Various thin-film evaporator designs are commercially available. The agitated thin-film, or wiped-film, evaporator consists of two major assemblies — a heated body and a rotor
.
Both vertical and horizontal designs are available. The rotor may be one of several designs, with the clearance between the rotor and the heating jacket wall varying from a fixed distance To essentially zero and actually wiping the wall.

The majority of thin-film evaporators in operation today are of the vertical, cylindrical, fixed-clearance rotor design.

- The feed enters the unit above the heated zone and is distributed evenly over the inner circumference of the body wall by the rotor.
- Product spirals down the wall, while bow waves developed by the rotor blades generate a highly turbulent flow, leading to high heat flux.
- Volatile components evaporate rapidly. Vapors can flow either co-currently or counter-currently, and are ready for condensing or subsequent processing as they leave the unit. Nonvolatile components are discharged at the bottom outlet.
- Continuous washing by the bow waves minimizes fouling of the thermal wall, where the product or residue is most concentrated.
- The combination of short residence time, narrow residence time distribution, high turbulence, and rapid surface renewal permits the agitated thin-film evaporator to successfully handle
- Heat-sensitive, viscous and fouling materials.
- A "standard" thin-film evaporator can normally process materials with viscosities of 1–50,000 cP. Special transporting-rotor designs can be operated in the range of 50,000 to 20 million cP.
- Low product inventory and operation at near-equilibrium conditions in the process zone are important for highly reactive products.
- Agitated thin-film evaporators have a wide processing flexibility, and a single system can often be designed to process different products under varied operating conditions.
- Normally, a thin-film evaporator is operated under reduced pressures in the range of 2–250 mmHg abs. either steam or liquid heating medium is used to heat the evaporator.

Chapter 6 Advantages and disadvantages of A.T.F.E.

Advantages of an agitated thin-film evaporator are,

- short residence time in the heated zone, measured in seconds to minutes high heat-transfer coefficients due to the turbulence imparted by the rotor
- plug flow with minimum back-mixing
- ability to handle high solids concentrations and viscous materials
- less product decomposition, resulting in higher yields
- high recovery because of the "squeezing" of residues by the rotor.
- High tolerance of fouling materials
- High viscosity handling capacity
- Low pressure drop
- Short residence time
- High evaporation ratios

Disadvantage

- Its higher cost compared to standard evaporation equipment. In addition, staging or vapor recompression for energy recovery are not practical.

Chapter 7 – Scaleup of Agitated Thin-Film Evaporators

There are following parameters to be considered prior for the scale up procedure

- Maximum heat and mass transfer
- Maximum product yield and quality (purity, color & other parameters)
- Minimization of operating cost (energy consumption) & capital cost (evaporator size)
- Minimum heat transfer area needed could be one imp. Factor to achieve above mentioned goals

For scale up following three major areas need concentration they are,

1. Process Design
2. Mechanical design
3. Physical properties of the process fluid

Physical properties required,

- Viscosity
- Latent heat of vaporization
- Thermal conductivity
- Density
- Specific heat
- Of both heating medium and process fluid
- Pilot testing required for the Optimal heat transfer area
- Overall heat transfer co efficient

In Process Design Following Parameters are to be taken care of,

- Degree of separation
- Feed rate and temperature
- Type and temperature of heat transfer fluid

In Mechanical Design,

- Materials of construction
- Material thickness
- Rotor speed
- Rotor clearance
- Id of body
- Length of body
- Liquid and vapor rates
- Operating pressure
- Type and temperature of heating medium

Heat transfer calculations

Following heat calculations are necessary for the scale up operation

- **Sensible heat** for initial heating to reach boiling point
- **Latent heat** to boil up the liquid
- **Super heat** for any boiling point raise as the liquid becomes concentrated

Basic heat transfer equation for convection and conduction between two Medias separated by walls,

$$\mathbf{Q = UA\Delta T}$$

Here **U** depends on the physical properties of the process material and heating medium and the mechanical configuration of heat transfer device

$\Delta \mathbf{T_L}$ is affected by the internal operating pressure which changes the boiling points of the volatile materials and inlet & outlet temperature of the heating medium

Resistance during heat transfer as it depends on the inner product film, Inner fouling factor, metal wall of the vessel, outer fouling factors, and outer heating medium film

Neglecting Fouling Factors Relationship Becomes,

$$\mathbf{\frac{1}{U} = \frac{1}{h_0} + \frac{1}{k} + \frac{1}{h_i}}$$

Value of U can be calculated from data developed during the pilot runs.

From mechanical configurations of the test evaporators. And the heating medium used & from conventional calculations for fluid flow and heat transfer the outside heat transfer coefficient $\mathbf{h_0}$ can be calculated.

Since the thickness t, and thermal conductivity k, of the wall material are readily available the inside heat transfer co efficient $\mathbf{h_i}$ can be calculated.

Inside heat transfer co-efficient $\mathbf{h}_{i,2}$ respectively for pilot scale and full scale evaporator

$$\mathbf{h_{i,2} = fh_{i,1}}$$

Heating wall resistance

$$\mathbf{\frac{t_2}{k_2}}$$

Outside heat transfer co-efficient

$$\mathbf{h_{0,2}}$$

Above mentioned parameters can be calculated from the data available from vendors and other research work done previously based on pilot runs.

From obtained values U_2 for the full scale evaporator can be obtained from

$$\frac{1}{\mathbf{U}} = \frac{1}{\mathbf{h_0}} + \frac{1}{\mathbf{k}} + \frac{1}{\mathbf{h_i}}$$

Finally with use of U_2 the required area A_2 for full scale evaporators can be calculated from

$$\mathbf{A_2} = \frac{\mathbf{Q_2}}{\mathbf{U_2 \Delta T_{L,2}}}$$

Chapter 8 - Applications

Agitated thin-film evaporators are typically used in such applications as:

- purification of sensitive organic chemicals, such as natural oils, fatty acids, isocyanates, herbicides and insecticides
- concentration of foods and pharmaceuticals, such as lecithin, enzymes, fruit and vegetable purees, biological solutions, vegetable and plant extracts, and fermentation broths
- recovery of valuable resources from waste streams, such as solvents from paints, purification of used motor oil, glycerin from crude streams, and volume reduction of inorganic salt streams
- devolatillization of thermoplastics, acrylic resins, phenolic resins, silicone polymers, polyester and naylon

Industry wise applications of A.T.F.E

Fine Chemicals:

- Separation of nitric acid from organic high boiling liquids
- Separation of butane (butyne) diol from high boiling liquids
- Recovery of methanol from high boiling liquids
- Recovery of xylenol (dimethylphenol) from a purification
- solution
- Removal of hexane from PP and PE waxes
- Drying of salt via the evaporation of water and solvent
- Separation of phenol from bituminous coal pitch
- Distillation of starting products for the production of
- insecticides
- Separation of byproducts in the production synthetic fibers

Polymers:

- Distillation of TDI, HDI and MDI (isocyanates)
- Final removal of toluene from epoxy resin
- Separation of THF from polymers
- Distillation of trimethylpropane from high-boiling liquids
- Recovery of solvents from synthetic resin production
- Lactic acid, starch and sugar:

Lactic acid, starch and sugar:

- Upgrading and distillation of lactic acid
- Upgrading of tartaric acid derivatives
- Concentration of sweetening agents
- Concentration of modified starch

Pharmaceuticals:

- Concentration of active ingredient solutions
- Distillation of pharmaceutical substances
- Upgrading of substances for artificial feeding

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