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Treball Final de Grau

Design of an industrial process for the Diacetone-β-Fructose (DAF) production.
Disseny d'un procés industrial de producción de Diacetona-β–Fructosa (DAF).

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Voldria agrair aquest treball principalment als meus tutors, el Dr. Manel Vicente i la Dra. Esther Chamarro, pel seu ajut i dedicació, des del primer dia fins l’últim.

Agrair també a la meva família el donar-me ànims i ajudar-me sempre a veure el got mig ple. Donar gràcies especialment al meu germà Carlos, per fer-me companyia a les llargues nits de treball.

De nou, a tots, moltes gràcies.

REPORT

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SUMMARY

A company is producing Topiramate from DAF and it is buying the DAF to chinese supplier. Now, it is considering the fact of produce the DAF on the same floor instead of buy it to avoid possible related problems with the supply of the raw materials or with the quality of the received product.

The Diacetone-β-Fructose (DAF) is an intermediate in the synthesis process of Topiramate, an antiepileptic drug which can block the spread of seizures. It is used to treat other ailments, such as Lennox-Gastaut syndrome, the bipolar disorder and migraine.

The aim of this project is to plan a batch process to industrial scale for the synthesis of Diacetone-β-Fructose. The size of the batch has to be big enough to allow the production of 20,000 kg/year of Topiramate.

The DAF synthesis is possible taking as a starting raw material both D-Fructose as Sucrose. From the bibliographic study of patents and the obtained data in pilot plant tests, it has been confirmed that the most profitable route is the synthesis of DAF from D-Fructose.

Taking in account that the production does not have limitations of resources but, it has limitations of time, as it seeks to meet the demand of annual desired production of Topiramate, and the fact of that one of the objectives of this project is to realize the production with the minimum number of necessary equipments, it has been detailed in this project the production of 40 batch of 3500kg of DAF each one with the following equipment: 2 vessels (reactors), 2 rotary filters and a rotary dryer, everyone with its auxiliary equipment, control and automation.

With these premises, it has also made the sizing of the equipments, the definition of the operational mode and of the conditions of work and the planning in time of all stages of the production process.

Finally, with an estimated initial investment of 4,200,000 €, the annual production of 140000kg of DAF with 99% of purity in sixteen weeks is achieved.

RESUM

Una empresa està produint Topiramat a partir de DAF i, actualment, compra el DAF a un proveïdor xinès. Ara, està considerant la possibilitat de produir el DAF en la mateixa planta en comptes de comprar-lo per tal d'evitar els possibles problemes amb la data de recepció i la qualitat del producte.

La Diacetona-β-Fructosa (DAF) és un compost intermedi en la síntesi del Topiramat, un fàrmac antiepilèptic que bloqueja la propagació de les convulsions i s'utilitza pel tractament d'altres dolències, com la Síndrome de Lennox-Gastaut, el trastorn bipolar i la migranya.

L'objectiu és planificar un procés de síntesis en discontinu de la Diacetona-β-Fructosa a nivell industrial que permeti la producció de 20,000 kg/any de Topiramat.

La síntesi de DAF es pot realitzar prenent com a matèria prima de partida tant la D-Fructosa com la Sacarosa. A partir de l'estudi bibliogràfic de patents i de dades obtingudes a partir d'assaigs anteriors en planta pilot, s'ha conclòs que l'opció més rentable és la síntesi de DAF a partir de D-Fructosa.

Tenint en compte que la producció no presenta limitacions de recursos, però sí de temps, ja que es pretén satisfer la demanda necessària per la producció anual de Topiramat desitjada i que es vol dur a terme la producció amb el mínim nombre d'equips, es detalla, en aquest projecte, la producció de 40 lots de 3500 kg de DAF cadascun amb els equips següents: 2 tancs (reactors), 2 filtres rotatoris i 1 assecador rotatori, cadascun amb el seus equips auxiliasr, control i automatització.

Amb aquestes premisses s'ha realitzat també el dimensionament dels equips, la definició del mode i condicions d'operació i la planificació en el temps de cada etapa del procés productiu.

Finalment, amb una inversió inicial estimada de 4.200.000 €, s'aconsegueix la producció anual desitjada de 140.000 kg de DAF al 99% en setze setmanes.

1. INTRODUCTION

Topiramate is an anticonvulsant drug endowed of a broad spectrum antiepileptic activity.

It is used clinically as monotherapy in partial seizures, for treatment of seizures associated with Lennox-Gastaut syndrome in children over 2 years and how migraine treatment after ruling out other possible alternatives(1).

In 2010, Topiramate becomes a generic active ingredient and, as a result, many market studies are performed to assess the possibility of their synthesis and marketing. Following this study, existence of a potential market for Topiramate in Europe, USA and South America was discovered and, from that moment, many projects emerge that were aimed at obtaining a synthesis route of Topiramate.

Work Final Year: *Producción del Topiramato: Elección de la vía de síntesis y estudios en planta piloto*(2) is based on them. It contains a bibliographic review about process in question, obtained results in various pilot plant testing and the discussion about possible alternatives to carry out the synthesis.

Taking this data as reference, design of a process of industrial production of an intermediate compound in synthesis process of Topiramate, Diacetone-β-Fructose (DAF), will be performed.

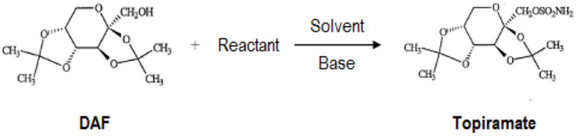

Figure 1. Forming reaction of Topiramate

1.1. SYNTHESIS OF DAF

From bibliographic studies of different patents it concludes that there are two main routes to synthesize DAF. The first route uses Fructose like raw material, while second route uses Sucrose.

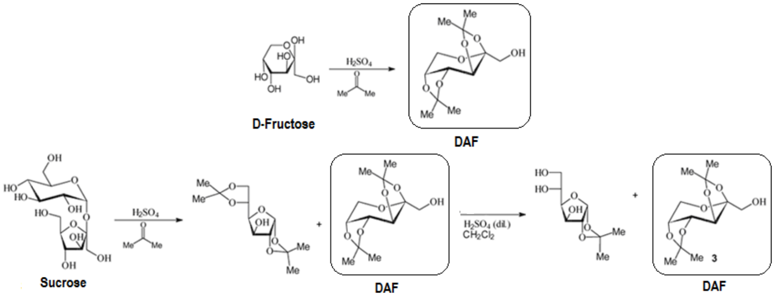

Figure 2. Routes of synthesis of DAF

The next tables contain a summary of the proposed synthesis processes by different patents.

Patent	Raw material	Phases	Conditions
US20050203287[3]	Fructose	1. Dissolution(Acetone+Fructose+ H_2SO_4 98%)	T=0ºC / P=1atm
		2. Reaction	T=25ºC / P=1atm / t=3-4h
		3. Neutralization(+ NaOH 50%)	T=10ºC / P=1atm / t=0,5h
		4. Filtration	
		5. Crystallization	T=65ºC / Vacuum
		6. Dissolution (Isopropyl alcohol, C_6H_{14}, H_2O)	
		7. Precipitation	T=10ºC / P=1atm
		8. Filtration	
		9. Drying	T<50ºC / HR<1%
EP0533483A2 US5387700[4]	Fructose	1. Dissolution (Acetone+ H_2SO_4 98%)	T<20ºC / P=1atm / t=0,5h
		2. Dissolution(+ Fructose)	8ºC<T<15ºC / t=2h
		3. Neutralization(NaOH 50%)	T<20ºC / t=1h
		4. Centrifugation	
		5. Distillation	Vacuum
		6. Dissolution (Isopropyl alcohol, C_6H_{14}, H_2O)	T=60ºC
		7. Cooling crystallization	
		8. Centrifugation	
		9. Drying	T=38ºC / Vacuum / t=8h

Table 1. Summary of patents of synthesis with D-Fructose

Patent	Raw material	Phases	Conditions
Docu	Sucrose	1. Dissolution (Acetone+ Sucrose)	T=5ºC / P=1atm

		2. Dissolution (+H_2SO_4 98%)	T=25ºC / P=1atm / t=2,5h
		3. Neutralization (+NaOH 50%)	0ºC<T<10ºC
		4. Filtration	
		5. Evaporation	T<55ºC / Low Pressure
		6. Dissolution(+CH_2Cl_2+ $H_2SO_4$0,5M)	t=2h
		7. Washing and drying	
		8. Evaporation	Low Pressure
		9. Dissolution (C_6H_{14})	
		10. Crystallization	
		11. Filtration	

Table 2. Summary of patents of the synthesis with Sucrose

The decision about which raw material is the best for DAF's production is based on data obtained in laboratory(2). The proposed processes by the patents are tried to put into practice in a laboratory scale but, they didn't give desired results. For that reason, they had to be modified.

Two different processes gave good results: the first one uses Sucrose like raw material and the second uses Fructose. By both routes, the purity level with would be obtained the DAF is quite good. However, it is appreciated that the average total yield obtained is quite low in the case of taking the Sucrose as starting material. Additionally, mass of raw materials required for the process with Sucrose is practically nine times mass of process with Fructose.

Therefore, it's concluded that synthesis route of DAF taking Fructose as raw material is the optimum.

1.2. BATCH PLANTS

Since the beginning of the modern chemical industry, processes characterized by discontinuous steps have been used for the development of a large number of products. Specifically, products called of fine chemical (pharmaceuticals, pigments, cosmetics, etc.), for its high profitability and its low production volumes, have resulted in an increased interest in batch processes(6).

In these processes, due to work with small volumes, it is not justified in a lot of cases the construction of a big plant dedicated to the production of one single product. By another side, interest of to fully benefit from the scale economies always exists. Answer which involves both factors is often a plant which allows consecutive and simultaneous elaboration of different products using the same installations flexibly(7).

As a result of all exposed, planning of production in plant is very important and it is performed taking in account the exposed factors(8) bellow.

PROCESS TOPOLOGY	Sequential	Single stage	Single unit / Parallel units
		Multiple stage	Multiproduct / Multipurpose
	Network (arbitrary)		
EQUIPMENT ASSIGMENT	Fixed		
	Variable		
EQUIPMENT CONNECTIVITY	Partial (restricted)		
	Full		
INVENTORY STORAGE POLICIES	Unlimited Intermediate Storage (UIS)		
	No intermediate Storage (NIS)		
	Finite Intermediate Storage (FIS)		Dedicated storage units / Shared storage units
	Zero Wait (ZW)		
MATERIAL TRANSFER	Instantaneous (neglected)		
	Time consuming		No-resources / Pipes / Vessels (pipeless)
BATCH SIZE	Fixed		
	Variable (Mixing and splitting)		
BATCH PROCESSING TIME	Fixed		Unit independent / Unit dependent
	Variable (unit/batch-size dependent)		
DEMAND PATTERNS	Due dates		Single product / Multiple product
	Scheduling horizon		Fixed requirements / Minimum or maximum requirements
CHANGE OVERS	None		
	Unit dependent		
	Sequence dependent		Product / Product and unit
RESOURCE CONSTRAINS	None (only equipment)		
	Discrete		
	Continuous		
TIME CONSTRAINS	None		
	Non-working periods		
	Maintenance		
	Shifts		
COST	Equipment / Utilities / Inventory / Changeover		
DEGREE OF CERTAINLY	Deterministic / Stochastic		

Table 3. Roadmap of production planning

The conditions of this project are summarized in the section 7.

2. OBJECTIVES

A company is producing Topiramate from DAF and it considers the fact of produce the DAF on the same floor instead of buy it.

Purpose of this project has been to design a production process of DAF that allows answering to the demands of the production of 20 annual lots of 1000 kg each of Topiramate. For it, more concrete aims have been fixed:

- To select the necessary equipments for the annual production of 40 batch of DAF of 3500 kg each one, taking as premise that the number of equipments must be minimum.
- To select batch size of DAF and to realize sizing of involved equipments in the process.
- To determine necessary time for production of one batch of DAF and to plan production of the annual demanded quantity.
- To value the economic viability of the project by means of the calculation of Present Value (NPV), Discounted Payback and Internal Rate of Return.

3. PRODUCTION PROCESS

DAF production process comprises several stages. The first stages are related to synthesis itself of DAF and the following are related to its purification.

The reactants of the process are acetone and fructose. Their reaction, favored in acidic medium, leads to formation of DAF.

After stopping reaction by neutralization with sodium hydroxide, solution is subjected to filtration and concentration processes for obtaining desired product.

Finally, a recrystallization with hexane and other processes of filtration and drying give rise to final product in the desired specifications.

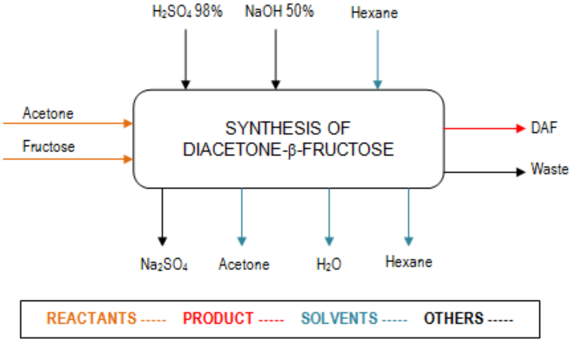

Figure 3. Overall diagram of the inputs and outputs of the production of DAF

3.1. RECIPIE

First, the reactants are fed into the vessel V-01. Feeding of acetone was done automatically by pipeline, while fructose will be added manually by plant personnel in big bags through a hoist.

Once elapsed filling time, which is assumed approximately around 2h, coolant circulation is connected across jacket of the tank to lower temperature of reaction volume until 5ºC. Thus, maintaining low temperature, it is controlled that fructose is not consumed resulting in unwanted secondary products.

Maintaining temperature at 5°C, sulfuric acid is added slowly to the dissolution to provide the required acid medium by the reaction. After adding all sulfuric acid, the reaction system is heated to 20°C and it is kept under stirring for 2.5 hours, to ensure maximum possible obtaining product. Finally, solution is neutralized to stop reaction and prevent side reactions which could consume the DAF.

Neutralization with sodium hydroxide causes the formation of sodium sulfate, which is removed by filtering the solution through a rotary filter working at low pressure. Salt is washed with acetone to recover as much product as possible.

Once filtered, solution is conducted to a second vessel where it proceeds to the evaporation of most of the solvent under reduced pressure to obtain desired product precipitated. Steam from this stage is conducted at a barometric condenser, where complete condensation for recovering solvent and help maintain low pressure occurs.

Considering that wet solid obtained still it contains impurities from reaction step, a recrystallization with hexane is performed. For this, the necessary amount of hexane is added and solution is brought to an elevated temperature, about 60ºC, for total dissolution of solid. Then solution is brought to oversaturation by cooling until 0ºC and precipitation of DAF is produced.

Again, solution containing the precipitated solid is fed to a rotary filter where solid from the mother liquor is separated.

Finally, solid is introduced into a rotary dryer working at 40ºC, thus avoiding the need to work at high temperatures which could harm the end product. Once dry, product is taken out of the rotary dryer and it is ready for his use.

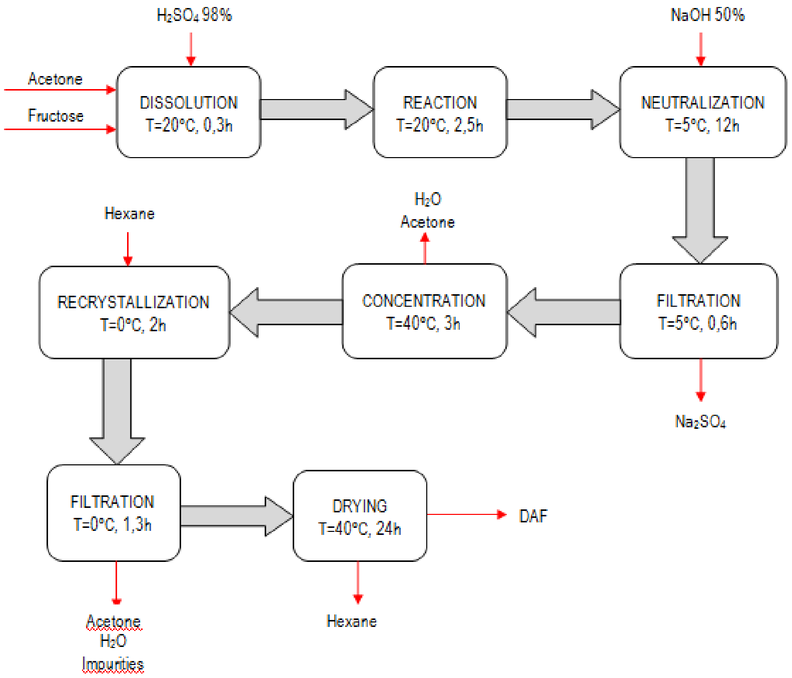

Figure 4. Stages of the synthesis process of DAF

3.2. DESIGN BASES

Since ultimate aim of this project is to produce an amount of DAF annual sufficient to meet the needs of production of 20,000 kg/year of Topiramate, it has taken this data as a calculation base for the design of production process.

In a beginning, to avoid problems of uniformity in the product, it tried to produce batches of sufficient DAF to produce one batch of Topiramate. Nevertheless, the size of the batch of Topiramate fixed by the *Agencia Española del Medicamento* is of 1000 kg, which would imply sizes of batch of DAF of 7000 kg. Provided that this size of batch would involve a too big size if the equipments, it has been decided that the best option is to produce batches of 3500 kg of DAF. That way, a few smaller equipments are possible and only two batches of DAF would be needed for one batch of Topiramate, for what the uniformity of the product should not be a seriously problem either.

As for mode of operation, it will work in batch, because for this type of production volumes is common practice in the pharmaceutical industry to work in batch since the plants are usually multipurpose.

3.3. EQUIPMENT SELECTION

The aim is to plan the process so that it can carry out production with the minimum number of equipment or what is the same, making the maximum number of tasks in each of equipment.

Therefore, it was decided that will be needed:

- 2 vessels (V-01 and V-02)
- 2 rotary filters (RF-01 and RF-02)
- 1 rotary dryer (RD-01)

In first vessel is carried out the dissolution of fructose in acetone, addition of sulfuric acid, reaction and neutralization. Formation of sodium sulfate as a result of neutralization involves the filtering of the solution. Due to the large volume to be filtered, you have chosen to use a rotary filter. Since this type of filter operates continuously, the need for a second vessel (V-02) to go feeding filtered volume of solution is inevitable. In this second vessel, concentration and recrystallization stages will take place.

As for the rotary filters, it has chosen to use two different rotary filters because of the different nature which have the two solids to be filtered during the process. The first is a crystalline solid (sodium sulfate), while the second is a porous solid with pharmaceutical purposes (DAF). Since particle size in both cases is different, solvent used for the washing is also different and taking in accounts that, as the DAF is desired in high purity, a single filter should be subject to a thorough cleaning each once it should be used, it has decided to use two different rotating filters.

Finally, a rotary dryer working in batch for drying final product obtained will be necessary.

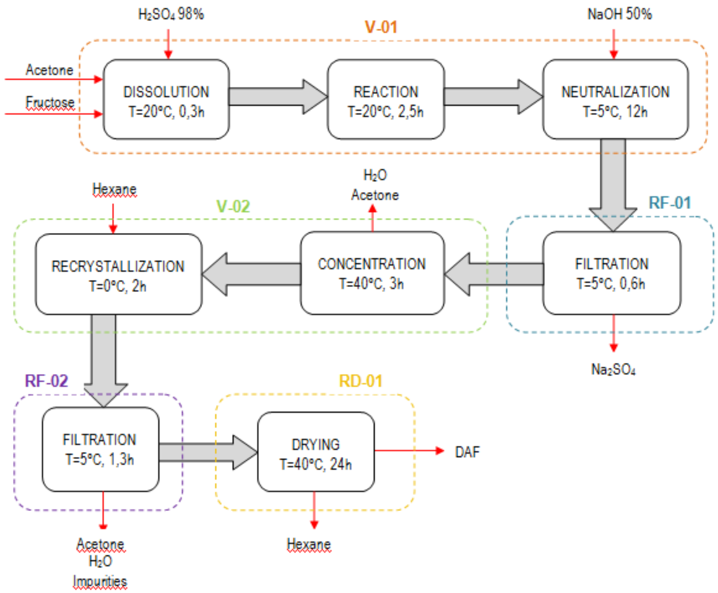

Figure 5. Distribution of the tasks on the equipments

3.4. CALCULATION BASES

For the correct sizing of the necessary equipments for production process design, it has made the material and energy balances in the system. For its resolution, the application of a set of assumptions has been necessary, which are shown below.

Vessel V-01

As for the feeding of raw materials needed for the reaction step, it has been assumed:

– Production of 1 kg of DAF requires(2):

Fructose [kg]	0.73
Acetone [kg]	7.82
Sulfuric Acid 98% [kg]	0.70
Sodium Hydroxide 50% [kg]	1.11

Table 4. Mass of raw materials for 1kg of DAF production

- Yield of DAF forming reaction is about 97%.

In reference to energy balances:

- Dissolution of sulfuric acid in acetone is exothermically and enthalpy of dissolution is similar to that would correspond if the solvent was water.
- The above assumption is also applied to sodium hydroxide dissolution.
- During the stages of heating and cooling, heat transfer is the limiting step of the stage.

Rotary filters RF-01 and RF-02

The simplifications applied in filtration steps and on which is based sizing of the filters, are the following:

- Filters work under vacuum and are able to retain 100% of solid present in solution.
- For washing the solid that is to be removed, it is necessary a mass of solvent equivalent to 20 wt% of filtered solid. In addition, since washing occurs at a low temperature of the solvent, the calculation is simplified by assuming negligible loss of solid by dissolution.
- During washing, get yourself thoroughly wash filtered solid, which leaves filter moistened with a solvent content of 15 kg/kg of dry solid.

Vessel V-02

In vessel V-02, stages of concentration and recrystallization of DAF occur. The assumptions made are:

- After concentration step, the solid obtained inside tank contains about 15 kg solvent / kg of dry solid.
- As acetone is more volatile than water, it has been assumed that condensate consists of 90% acetone and 10% water.
- Again, according to the data obtained in the pilot plant, it has been supposed the need 2.64 kg of hexane / kg DAF recovered at the end of the process.

In reference to energy balances, again it is assumed that the transfer stage is the limiting stage.

Rotary dryer RD-01

In case of rotary dryer, it has been taken the psychrometric data(9) of the system hexane-nitrogen as an approximation to the reality of the system hexane-air. In addition, it is known that drying rate of a solid has constant and variable periods that depend on solid and solvent but, has only used the period of constant speed to obtain guidance on drying time.

3.5. MASS AND ENERGY BALANCES

Based on these assumptions, the material and energy balances have been solved and it has been possible to get composition and temperature of system in each point of production process of a batch.

To continue, is shown a diagram with all the inputs and outputs which are produced along one productive cycle. Is important to remember that production of DAF is done in discontinuous and diagram only gives visual information.

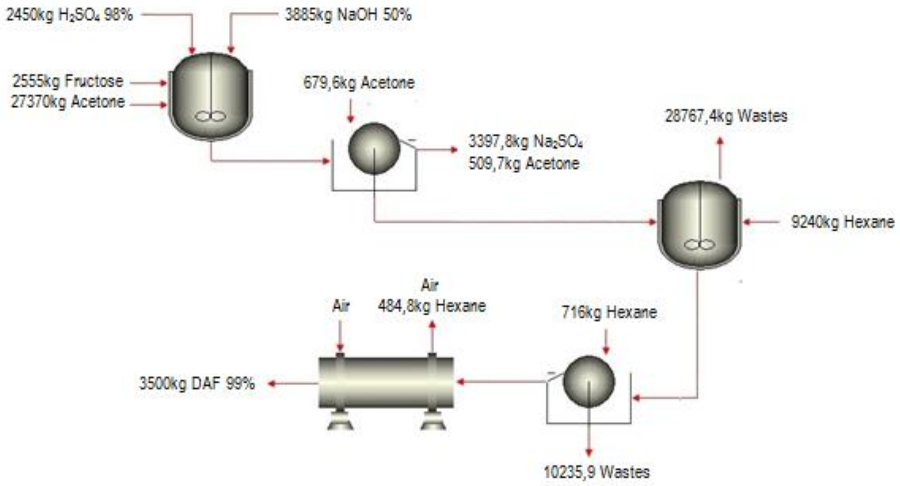

Figure 6. Material balance representation

The complete diagram is collected in Appendix 2, along with a table which contains the system composition at the end of each stage.

4. PROJECT SPECIFICATIONS

In this chapter, it will be detailed the specifications of the above mentioned equipments. It will be talked about their size, materials and their auxiliary equipments if they are required.

In addition, it will be talked too about the connections between equipments, automation and control parameters, without to deepen too.

4.1. VESSEL V-01

In the vessel V-01, the next stages take place: feeding of raw materials, dissolution, reaction and neutralization.

Design calculations of vessel can be seen with detail in the Appendix 3. However, the next table contains a summary of his characteristics.

Maximum content [kg]	36260
Diameter [m]	3.20
Section [m²]	8.00
Height [m]	5.50
Wall thickness [m]	0.01
Capacity [m³]	44.20

Table 5. Characteristics of vessel V-01

4.1.1. AUXILIARY EQUIPMENT

For all tasks that are performed in the vessel as possible, it is required:

- Good level of homogenization. For it, it will be necessary to include an agitation system.
- One jacket and two cooling coils which allow keeping tabs on the temperature inside the tank, allowing its increase for to favor the steps of dissolving and reaction, and its decrease to avoid problems due to the highly exothermically nature of the dissolution of sulfuric acid and sodium hydroxide and the neutralization reaction between them.

Agitation system

Due to the large volumes with which it works and the presence of solids in the solution which can accumulate in the bottom of the vessel, it has opted for the use of a double agitator which consists an anchor stirrer, to prevent accumulation, and a blades stirrer at half height to ensure good homogenization.

The procedure for the design of agitation is found in Appendix 3. Anyway, below can be seen a summary table.

Anchor stirrer	**Impeller diameter [m]**	3.10
	Height [m]	3.10
	Thickness [m]	0.32
	Agitation speed [rpm]	12
	Agitation power [kW]	3.7
Paddles stirrer	**Impeller diameter [m]**	2.2
	Paddle length [m]	1.10
	Agitation speed [rpm]	60
	Agitation power [kW]	2.3

Table 6. Characteristics of agitation system

Impellers should be of steel AISI 304L for to resist to the fatigue effects and also covered with polyester resin for do them resistant to corrosion effects.

They and the vessel will be required periodic reviews for to prevent abrasive effects due to continuous contact between them and the produced solid in neutralization stage.

Jacketed

The fact that in the same vessel various tasks take place forces to have a cooling and heating system that supplies or removes power needed to ensure their good development.

It will be necessary to cool prior to and during addition of sulfuric acid and sodium hydroxide. The heating system will be necessary once all sulfuric acid has been added and reaction is occurring.

To do so, will circulate through the jacket coolant flow rate (mixture of glycol and water) at -35°C for cooling and medium pressure steam at 143°C for heating.

According to the legislation, the surface of those equipments through the interior of which circulates a fluid at temperatures below 5°C or exceeding 50°C, should be isolated(10). Therefore, the outside of the jacketed with glass wool of 70 mm thick, which is considered the minimum required for industrial equipment will be covered.

Coils

As already said before, the dissolution of sulfuric acid is highly exothermically, but still the temperature can be controlled only through coolant circulating through jacketed.

Not so in the case of addition of sodium hydroxide. Its dissolution releases energy, and so does its reaction with sulfuric acid that there is in the middle. Consequentially, controlling temperature only through circulation of coolant through the jacketed is not possible.

Therefore, it was considered necessary to include two coils with approximately the following characteristics:

Internal diameter of the tube [m]	2.55
External diameter of the tube [m]	1.65
Diameter of a round [m]	0.50
Number of rounds	90
Length [m]	11.70
Height [m]	4.50

Table 7. Characteristics of coils

4.1.2. OPERATING CONDITIONS

Throughout the entire period of occupation of vessel, it is worked at atmospheric pressure. However, numerous variations are produced with regard to occupancy level and temperature. These variations are shown in the following diagrams:

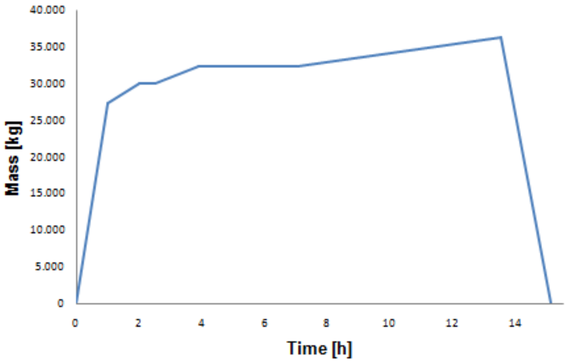

Figure 7. Variations of mass in the vessel V-01

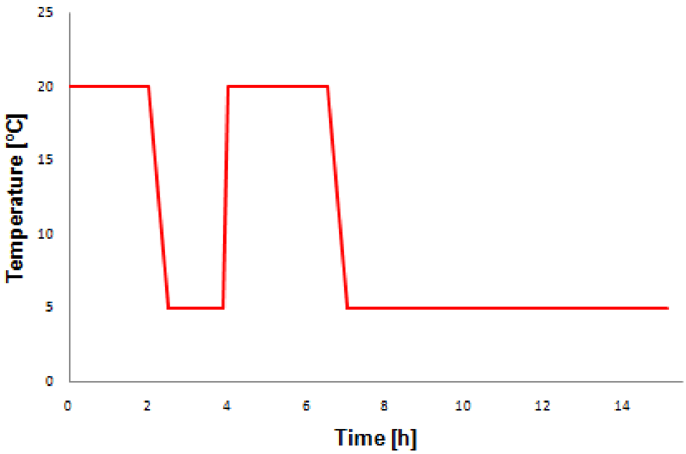

Figure 8. Variations of temperature in the vessel V-01

4.1.3. CONTROL PARAMETERS

Taking into account the parameters which are interesting to control, it has considered that it will be required:

- A level meter that provides information about the fill level of the tank. The option to control the addition of raw materials by weight was considered, but given that the quantities are very large, this would present much error and provide little information.
- A temperature meter that allows taking steps of correction in the case of an increase or decrease of the same through the regulation of the circulation of coolant or steam.
- A pH meter which allows the continuous measure of itself inside of the vessel for to ensure that the neutralization stage has completed.
- A vent valve. It will take care of liberate the gases if they accumulate. Working with volatiles compounds can give problems of overpressures and to endanger the physical integrity of the tank.

4.2. ROTARY FILTERS RF-01 AND RF-02

The RF-01 rotary filter is used for filtering and removing sodium sulfate generated during neutralization step. The rotary filter RF-02 is used for filtration of DAF once recrystallized.

The characteristics of chosen filters(11) are:

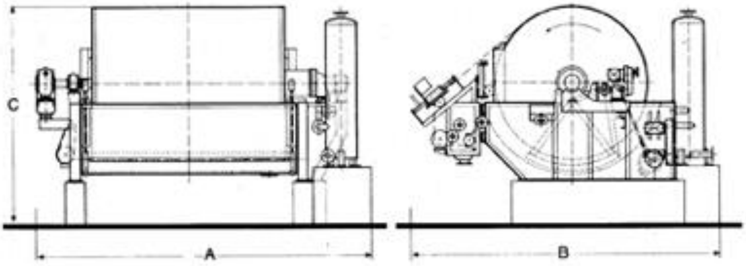

Figure 9. Rotary filter

	RF-01	RF-02
Filter type	TSF 9,2/20	TSF 13,1/25
Filter area [m^2]	5.8	10
Drum diameter [mm]	920	1310
Drum width [mm]	2000	2500
Number of cells	14	14
A [m]	3.80	4.30
B [m]	2.05	2.30
C [m]	1.70	2.00
Operating weight [Tm]	4.1	6.5
Energy consumption [kW]	1.5	3.0

Table 8. Characteristics of rotary filters RF-01 and RF-02

In addition, they must have a mobile base to end the filtration of solution when its quantity becomes low and a vacuum pump to perform filtration.

4.2.1. OPERATING CONDITIONS

Based on heuristics(12)(13), it was been decided to work with two rotary filters in the next conditions:

	RF-01	RF-02
Turning speed [rpm]	0.33	0.33
Pressure difference [Pa]	6,772.76 – 20,318.27	60,954.82 – 84,659.47
Angle submerged [rad]	2.20	2.20

Table 9. Operating conditions of rotary filters

In these conditions, again basing on heuristics, achieving the next filtration speeds is possible: 1221 kg/(h·m^2) for Na_2SO_4 and 305 kg/(h·m^2) for DAF.

4.2.2. CONTROL PARAMETERS

The most important parameter to consider in control is pressure, because suction generated from inside rotary drum is what causes the filtration. As the process progresses, filters are obstructing, so that filtration is increasingly less effective, requiring a regulation of pressure for an increase in suction.

In filtration step of DAF, however, it is important to control temperature of the washing solvent, to minimize product loss by dissolution.

4.3. VESSEL V-02

The mother liquor from the rotary filter RF-01 is fed to vessel V-02, where concentration step and recrystallizing of DAF take place. The V-02 is made of steel AISI 304L and presents the same characteristics, in terms of dimensions, that the vessel V-01

4.3.1. AUXILIARY EQUIPMENT

The stages that are developed inside of the vessel V-02 imply the need for a good agitation system and a system that allows regulation of temperature. They require too the installation of a barometric condenser in which liquefy the vapors from the concentration step and which allows maintaining the low pressure inside the vessel.

Furthermore, since the barometric condenser can maintain low pressure but does not generate it, an ejector will also be necessary. This will be responsible for the launch of stage and removing non-condensable gases capacitor which can enter to the unit. One demister will also be added for retaining dragged liquid droplets by the gases.

Finally, it will be necessary also a tank for storage of the condensed from barometric condenser, which ensures the submersion of lower part of the barometric column.

Jacketed and agitation system

The Vessel V-02 has got the same agitation system, jacketed and insulating of the V-01. The only difference between the vessels will be that blade stirrer will not work while the liquid inside thetank is not enough to cover it, so only the anchor stirrer will provide the agitation. In this case, it is sacrificed the efficiency of agitation in benefit of possibility of using tank for different purposes.

Similarly, the coolant and steam are the same that supply the vessel V-01.

Barometric condenser

In barometric condenser is pretended to recover the vapor of solvent, which cannot be liberated to the atmosphere, and use it for filling the barometric column.

The vapor arrives to condenser in its boiling point at working pressure. It is pretended to condense it at 38ºC for avoid its evaporation. It is decided to use a Cooltrans solution of glycol in water at 60%(14), since it is the coolant which supplies all the installation and it can work at very low temperatures.

It has chosen a condenser of shell and tubes type, since the heat exchange is high and variable, and this type presents bigger exchange area in less volume.

Due to the dirtiest fluid is coolant, it will be circulated through inside of the tubes as they are easier to clean. So, also it is achieved recovering the condensate, which circulates through the shell, and leading it to the barometric column more easily.

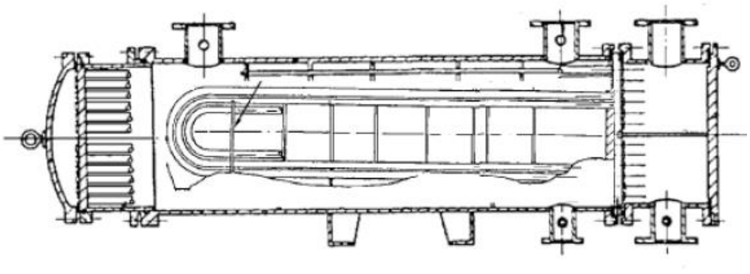

Figure 10. Scheme of a shell and tubes condenser

For the design of condenser has been used the method of Kern(15), which provides a satisfactory prediction of overall heat transfer coefficient (U) as it is based on experimental work in commercial heat exchangers of standard features. However, it cannot expect the same reliability of the calculations concerning pressure drops. The latter is not worrisome, since, usually, in a condenser the pressure loss is small and the process can be considered that occurs at constant pressure(15).

The data obtained from the process of calculation described in Appendix 3 are the following:

Heat exchanges [W]	$1.82 \cdot 10^6$
Exchange area [m²]	44.5
Tube length [m]	2
Number of tubes per pass [m]	76
Internal diameter of the tubes [m]	0.01905
External diameter of the tubes [m]	0.02545
Inner diameter of the shell [m]	0.49
Outer diameter of the shell [m]	0.50
Spacing between tubes [m]	0.032
Number of baffles	9
Baffles diameter [m]	0.43
Spacing between baffles [m]	0.22
Orientation [m]	Vertical cut

Table 10. Characteristics of barometric condenser

It has been decided that condenser will also be of Steel AISI 304L.

Barometric column

Barometric column is coupled to the output of the heat exchanger. Here, condensate is introduced and discharged in a well at room temperature. This temperature difference will cause the liquid to flow by gravity through the column by maintaining the hydrostatic pressure between the internal pressure and atmospheric pressure.

It is considered that the output speed of the acetone-water mixture able to keep the vacuum inside of the unit is 0.98 m/s(16). Through appropriate calculations (Appendix 3) are obtained the needed characteristics of the column: 0,065 m of inner diameter and 6.4m of height.

4.3.2. OPERATING CONDITIONS

As discussed previously, in the vessel V-02 take place numerous steps involving continuous changes in operating conditions.

The vessel V-02 works at atmospheric pressure except during concentration step of DAF, in which a pressure drop is generated to facilitate solvent evaporation.

As for the content of tank and temperature, they are changing during time of occupation of vessel, in the way shown in the following diagrams:

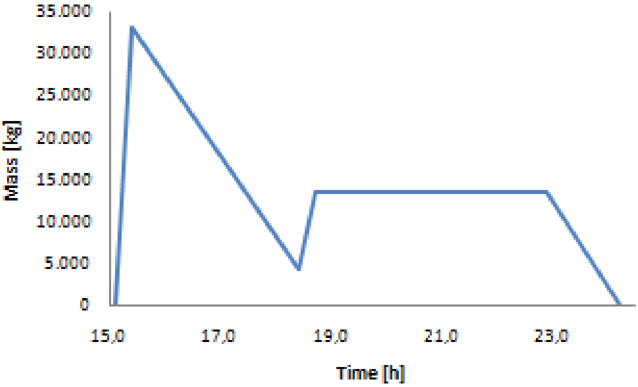

Figure 11. Variations of mass in the vessel V-02

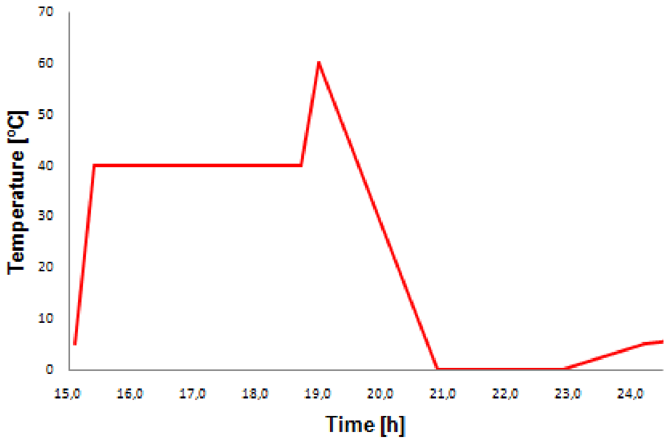

Figure 12. Variations of temperature in vessel V-02

4.3.3. CONTROL PARAMETERS

It will be needed the control of the following parameters:

- Level of liquid inside V-02.
- Temperature in V-02. In case of a decontrol in it, this will be corrected by regulating the flow of coolant or steam through the jacket of the tank.
- Pressure in V-02. Evaporation is produced at 0.56 bar. If the pressure increases, the evaporation will not take place at the expected speed. In addition, it is worked with organic volatile compounds, what can produce an accumulation of gases inside the vessel. Therefore, it will be needed a vent valve for avoid overpressure inside the vessel.
- Temperature in barometric condenser, since it gives needed information to regulate the coolant flow rate.
- Level of liquid in barometric column. Since concentration step is carried out batch wise and steam generation will not be constant, measuring level of liquid in column is required to regulate the output of solvent and maintain adequate liquid height guaranteeing desired pressure.

4.4. ROTARY DRYER RD-01

Once the DAF obtained from filtering passes quality control is fed to the dryer RD-01, which has the following characteristics(17):

Specifications [mm]	Φ1200x120000	**Power [kW]**	11
Rotate Speed [rpm]	3 – 8	**Capacity [t/h]**	2 – 6
Inlet temperature [ºC]	≤ 700	**Weight [t]**	14.8

Table 11. Characteristics of rotary dryer RD-01

4.4.1. OPERATING CONDITIONS

The wet DAF in hexane is introduced into the rotary dryer and completely dry air is blown at a temperature of 40°C to ensure that product does not suffer any damage.

In this case, estimating time of operation is quite complicated, since the drying rate of solids varies according to humidity thereof.

Initially, excess liquid in solid facilitates the evaporation and the drying rate has its highest value. This value depends on the air conditions with which it is dried. However, as the liquid content in the solid decreases, critical humidity is reached and rate of drying decreases substantially. The slope of the line in the period of variable speed drying of solid is characteristic of the solid-solvent system and, therefore, should be determined experimentally.

Unable to perform the necessary experiments, we calculated theoretical speed constant drying period. Due to the dryer will be equipped with baffles to guarantee the cascading solid although the rotation speed is not too high and, therefore, will be a good contact between the air and the surface of the particles of DAF, it has been considered the heat transfer the limiting step. Assuming h_c = 500 W/(m·kg·K)(15) and taking into account the psychrometric properties of air-hexane system, It is calculated an operating time of 3.5 hours.

Given that coefficient value is for coarser solids and for slower rotation speeds, a coefficient higher course transfer is expected. Therefore, it is assumed that with a drying time of 24 hours, the usual for this type of solids, will be more than sufficient to carry out successfully the stage.

4.4.2. CONTROL PARAMETERS

In the case of rotary dryer, the control of temperature of inlet air is necessary to ensure the drying of the solid.

Again, pressure should be controlled by the fact that hexane is evaporated, which can cause overpressures. It should also be controlled if it is decided to work at low pressure to facilitate evaporation.

4.5. CONNECTIVITY AND AUTOMATION

Figure 10 shows the scheme of the necessary connections between equipment, vent valves and valves of flow rate regulation and the necessary pumps for fluids circulation.

Below, a table with basic characteristics of pipes(18) is presented. It is not specified anything about feeding pipes or condenser-ejector connection, due to their characteristics depend of vessels and ejector, respectively.

In reference to valves and pumps, they are shown in the diagram, but it has not specified anything about them in this project.

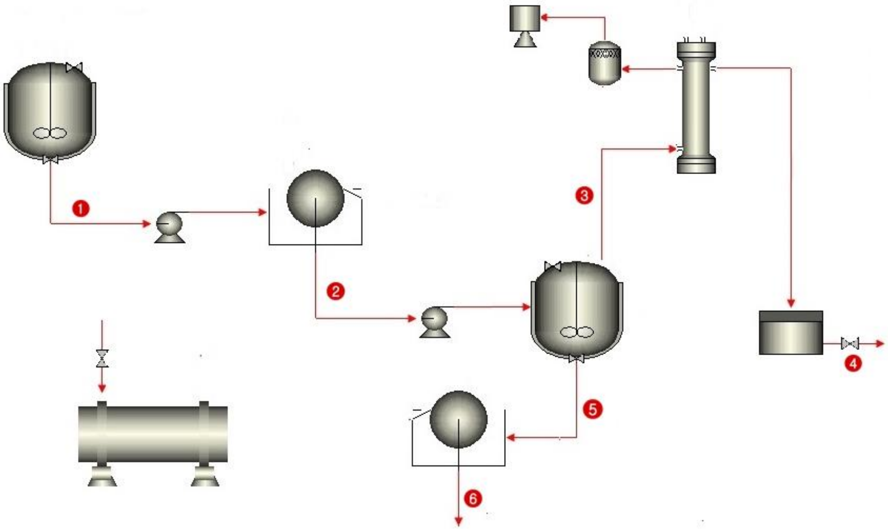

Figure 13. Connectivity and automation

#	Code	Circulating fluid	D_N [mm]	Material
1	203-AWDSR-10101-SS304L	Acetone, water, DAF, sodium sulfate, residues	203.2	AISI 304L
2	76-AWDR-10102-SS304L	Acetone, water, DAF, Residues	76.2	AISI 304L
3	508-AW-10103-SS304L	Acetone, water	508.0	AISI304L
4	65-AW-10104-SS304L	Acetone, water	65.5	AISI304L
5	152-HDWR-10105-SS304L	Hexane, DAF, water, residues	152.4	AISI304L
6	65-HDWR-10106-SS304L	Hexane, DAF, water, residues	65.5	AISI304L

Table 12. Characteristics of pipes

5. RESIDUE MANAGEMENT

Along production process, a series of wastes are generated and they must be treated in the same plant or by an external company. These residues are:

- Sodium sulfate formed during neutralization step, which is removed of the process by filtration.
- Acetone-water mixture. It is obtained during concentration step by evaporation thereof.
- The mother liquor obtained during the second filtering process. Such mother liquors are mostly hexane, but also contain DAF, acetone, water and impurities from reaction step.

Below are listed in the following table the recommended treatments for each type of generated residue and their classification(19).

Waste	Type	Classification	Treatment and final deposition		Recovery methods	
Na_2SO_4	Waste with metals	ES (special)	T14 T13 T33	Deposition in landfills Deposition in special wastes Stabilization	V42	Regeneration of other inorganic materials
Acetone water	Non-halogenated solvents	ES (special)	T21	Non-halogenated waste incineration	V21	Regeneration of solvents
Hexane Impurities	Non-halogenated solvents	ES (special)	T21	Non-halogenated waste incineration	V21	Regeneration of solvents

Table 13. Classification of residues

During the process studied, sodium sulfate is produced in the same amounts as main product. Therefore, it could be considered a byproduct and not a residue. In that case, the best option would subject it to a drying process, on the same floor or in an external company, and market it as anhydrous salt.

In reference to acetone and hexane, because they are obtained in large quantities too, especially acetone and water, the idea would be to subject them to distillation processes for recover and reuse them.

Moreover, also a recovery system of hexane contained in air leaving the dryer is required.

6. SCHEDULING

Once known in depth the process, it has made the sizing of equipments and it has decided which tasks will be carried out in each, it is time to set the pace of production to achieve the annual demand of product to produce.

6.1. GENERAL CONSIDERATIONS

The annual minimum production of DAF to be achieved is one that is able to meet the needs of the annual production of 20,000 kg of Topiramate. Since the production of 1 kg of Topiramate requires approximately 7 kg of DAF, the ultimate goal is to ensure the annual production of 140,000kg DAF. As already mentioned above, the nominal batch size has been chosen is 3500 kg DAF/batch, so the production scheduling has to ensure the production of 40 batches.

To carry out the programming, it is considered that production takes place 24 h/day (3 shifts), 5 days/week and 48 weeks/year. The remaining time corresponds to maintenance shutdowns.

Given that throughout the year there may be various problems, such as delays due to breakdown or delays in the receipt of raw materials, etc., it has been assumed that the real-time production of the plant is about 4500 h/year.

6.2. BATCH TIME

The following table shows the estimated time duration of each stage. It should comment that have been included in it the time leaning equipment.

	Stage	**Equipment**	**Time [h]**
1	Charge	V-01	2,0
2	Refrigeration	V-01	0.5
3	Adding H_2SO_4	V-01	1.4
4	Heating	V-01	0.1
5	Reaction	V-01	2.5
6	Refrigeration	V-01	0.5
7	Adding NaOH	V-01	6.5
8	Filtration	RF-01	1.6
9	Cleaning	V-01	2.0
10	Cleaning	RF-01	1.0
11	Heating	V-02	0.3
12	Concentration	V-02	3.0
13	Charge	V-02	0.3
14	Heating	V-02	0.3
15	Refrigeration	V-02	1.9
16	Recrystallization	V-02	2.0
17	Filtration	RF-02	1.3
18	Cleaning	V-02	2.0
19	Cleaning	RF-02	1.0
20	QC	-	4.0
21	Charge	RD-01	2.0
22	Drying	RD-01	24.0
23	Discharge	RD-01	2.0
24	Cleaning	RD-01	2.0

Table 14. Stages time

From these data, it is estimated occupation time of each team and limiting step of the process is determined.

Equipment	**t'**		**OT$_j$ [h/batch]**
	Start	**End**	
V-01	0	17.1	17.1
RF-01	13.5	16.1	2.6
V-02	13.5	26.2	12.7
RF-02	22.9	25.2	2.3
RD-01	24.2	58.2	34.0

Table 15. Operating time of equipment

The time required for the production of a batch of DAF is therefore of 58.2h and limiting step of the process is the drying step.

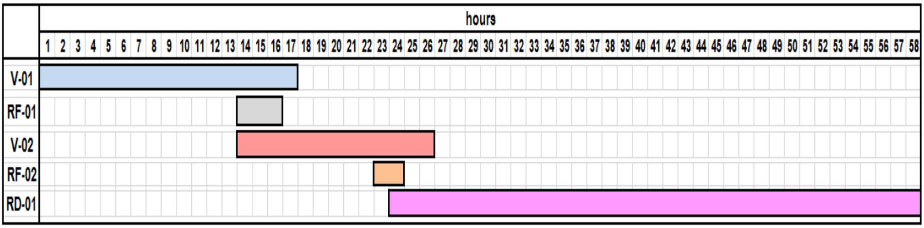

Figure 14. Batch time

6.3. PRODUCTION CAPACITY

It was decided to work in production campaigns. However, even taking this decision, there are two alternatives: to produce in campaigns with or without overlapping.

6.3.1. PRODUCTION IN NON-OVERLAPPING CAMPAIGN

Production in campaigns without overlapping consists to produce a batch after another successively without starting a batch without completing the above.

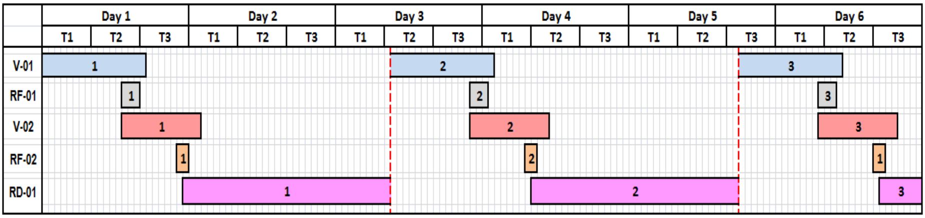

Figure 15. Production in non-overlapping campaign

In this case, production time of a batch of DAF matches the duration of a cycle. In consequence:

$$MS_N = BT + (N-1) \cdot CT = BT + (N-1) \cdot BT = BT \cdot N$$

$$N = \frac{MS_N}{BT} = \frac{4500\ h/year}{58.2\ h/batch} = 77\ batches$$

Due the minimum number of batch to produce is 40, it should be seen the possibility of non-working periods (weekends) involve problems to achieve the desired production.

6.3.2. PRODUCTION IN OVERLAPPING CAMPAIGN

Production in overlapping campaigns consists in to optimize production time starting the next batch although not yet been finalized the previous batch, considering that between batch to batch must leave a space of time enough for the limiting step of the process is not an issue.

In this type of production, the cycle time is given by the occupation time of limiting equipment.

In the case of DAF production process, the limiting equipment is the rotary dryer RD-01. This means that the cycle time (CT) is 34 hours.

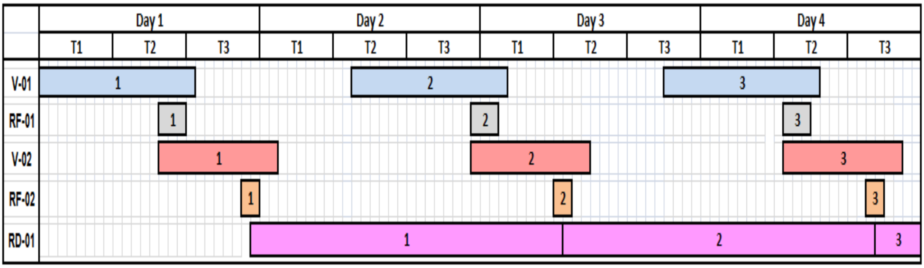

Figure 16. Production in overlapping campaign

In consequence:

$$MS_N = BT + (N-1) \cdot CT$$

$$N = \frac{MS_N - BT}{CT} + 1 = \frac{4500\frac{h}{year} - 58.2\frac{h}{batch}}{34\frac{h}{batch}} + 1 = 131\ batch/year$$

As was logical, if a production campaign without overlap allows producing more lots than necessary, in the case of overlap the desired annual production is guaranteed. In that case, occupancy rate of each of the teams is as follows.

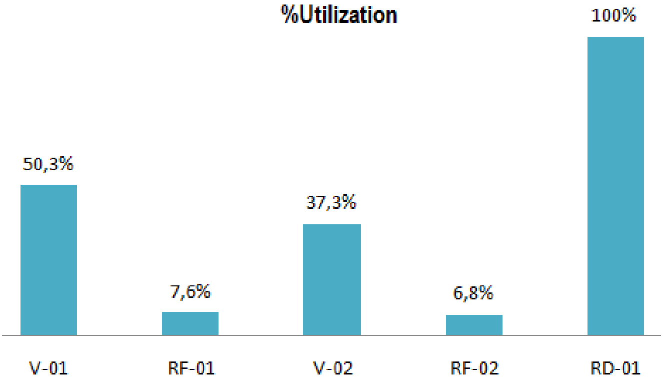

Figure 17. Equipment time utilization

7. PRODUCTION PLANNING

After completion of scheduling, or planning production short term, we proceed to make the long-term programming. To carry it out, it must follow the roadmap outlined in introduction to this work and define the assumptions on which the project has been framed:

PROCESS TOPOLOGY	Network (arbitrary)		
EQUIPMENT ASSIGMENT	Fixed		It has a limited number and type of equipment.
EQUIPMENT CONNECTIVITY	Full		It has been assumed that it is able to interconnect all equipment that require it.
INVENTORY STORAGE POLICIES	Unlimited Intermediate Storage (UIS)		After filtration step of DAF, product can be stored as long as needed before starting drying process.
	Zero Wait (ZW)		The rest of the process steps must occur one after another, with no possibility to stop the process from one stage to another.
MATERIAL TRANSFER	Time consuming	No-resources	Once wet DAF is obtained in the filtration, there are not available vessels to store the product. DAF will be stored in big bags in a conditioned room for its maintenance.
		Pipes	There are available all needed pipes to transfer the product from one step to another.
BATCH SIZE	Fixed		It has been fixed a batch size in 3500 kg DAF. In this project, it has not had in account the possibility of it changes.
BATCH PROCESSING TIME	Fixed	Unit dependent	Batch processing time is fixed and it depends only on the equipment.
DEMAND PATTERNS	Scheduling horizon	Fixed requirements	It has set an annual production target, 140,000 kg DAF, regardless of the demand for the product can be produced at a certain time of the year.
CHANGE OVERS	None		It has not had in account.
RESOURCE CONSTRAINS	None (only equipment)		It has been assumed not to have limitations of raw materials and energy. Only limits the operation of process equipment.
TIME CONSTRAINS	Non-working periods		It has been assumed that production is possible for 24 hours, five days a week, 48 weeks a year. It means that weekends are non-working periods.
COST	None		It has not had in account.
DEGREE OF CERTAINLY	None		It has not had in account.

Table 16. Roadmap project

Having in it counts all these constraints, finally one has concluded that the long-term production would be the following one:

	Starting [h]	Stop [h]	End [h]	Batch time [h]
1	0	0	58.2	58.2
2	34	0	92.2	58.2
3	68	25.8	152	84
4	127	0	185.2	58.2
5	161	0	219.2	58.2
6	195	19	272.2	77.2
7	247	0	305.2	58.2
8	281	0	339.2	58.2
9	315	19	392.2	77.2
10	367	0	425.2	58.2
11	401	0	459.2	58.2
12	435	19	512.2	77.2
13	487	0	545.2	58.2
14	521	0	579.2	58.2
15	555	19	632.2	77.2

Table 17. Long-term production. Example for 15 batches

Since it can be observed, the fact that the stage of dried cannot remain unfinished during the whole weekend involves to stop the production (in the table, yellow color). Provided that the same stage is the bounding of the process, one gives a periodicity in the times of production along the weeks. Definitively, they are needed 14 weeks to carry out the annual demanded production, which is translated in an organization of the flexible enough production. Below, the graph shows the production along few weeks, in order that it appreciates visually what is tried to say.

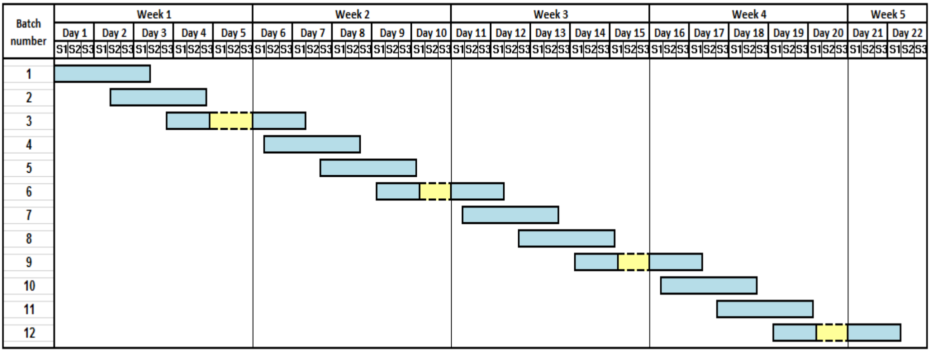

Figure 18. Production planning of the first weeks

8. FINANCIAL VIABILITY

In the present section, there tries to value the economic viability of the project by means of the calculation of Net Present Value (NPV), the Discounted Payback and the Internal Rate of Return (IRR). To be able to determine them is necessary to do an estimation of the initial necessary investment of the project, the income due to the same one and the operating cost. From them will be possible calculate the Profit and Loses (P&L), the Cash Flow and consequently the Discounted Cash Flow (DCF) which are necessary for the calculation of the mentioned indicators.

8.1. ESTIMATION OF THE INITIAL INVESTMENT

Based on the number and type of necessary equipments and resorting to the information facilitated by companies of the sector that work with this type of equipments and by suppliers, the initial investment has been estimated in 4.2 million Euros.

8.2. COST OF GOODS SOLD

First, there are calculated the costs foreseen for the production of 1 lot of finished product. Some of them have referred to the initial realized investment.

Cost of raw materials

The cost of the D-fructose has been obtained of the price of suppliers for the annual necessary quantity. The cost of the rest of raw materials corresponds to the average value of the last four purchases of these products for companies of the sector.

	Quantity [kg/batch]	Price [€/kg]	Cost/Batch [€]
Fructosa	2,555.0	1.82	4,650.10
Acetona	28,049.6	0.75	21,037.20
H2SO4 98%	2,450.0	0.26	637.00
NaOH 50%	3,885.0	0.31	1,204.35
Hexano	9,956.0	0.91	9,059.96
		TOTAL	36,588.61

Table 18. Cost of raw materials for a batch production

Cost of packaging

The costs of the packing have been referred to mass of finished product. Price has fixed 0.20 €/kg of finished product, an estimation based on cost that packing similar quantities supposes to companies of the sector that work with similar products.

The cost of packing for batch is, therefore of:

$$3500\frac{kgDAF}{batch}\cdot\frac{0{,}20€}{kg\ DAF}=700\frac{€}{batch}$$

Cost of waste management

Like already it has been commented in numerous occasions along this document, during the process of production of DAF, residues that must be purified are generated. This fact carries a cost that he must be estimated.

The wet sodium sulfate generated is a residue of not interest in the process. Nevertheless, the residual liquids of the process consist of big volumes that contain high quantities of acetone and hexane, solvents used in big quantities to carry out the process. Due to it, his recovery is important and can suppose a saving.

In calculation of the cost of the raw materials has been considered a price for the acetone and the hexane bigger than the royal one, since there has not been born in mind that these could be re-used. This fact has been compensated in the cost estimated of the waste management.

Finally, one has concluded that this one will be around the 3500 €/batch.

Direct labor cost

It has been carried out an estimation of the hours that an operator is needed in each of the tasks of the productive process:

Equipment	Task	Working hours [h]
V-01	Charge	2.0
	Cooling	0.5
	Adding H_2SO_4	0.7
	Heating	0.1
	Reaction	0.5
	Cooling	0.5
	Adding NaOH	1.0
RF-01	Filtration	3.0
V-02	Heating	0.3
	Concentration	1.0
	Adding Hexane	0.1
	Heating	0.2
	Cooling	0.5
	Recrystallization	1.0
RF-02	Filtration	5.0
RD-01	QC + Drying	7.0
	TOTAL	**23.4**

Table 19. Working hours operator

Direct labor cost has estimated in 30 €/h, average value in companies of the sector that it includes the brute salary more costs of National Health Service and the rest of indirect costs of personnel. Definitively, one concludes that the cost of personnel for every batch of produced DAF is:

$$23.4\frac{h}{batch}\cdot\frac{30€}{h}=702\frac{€}{batch}$$

Energetic cost

Regarding the energetic costs, due to in every unit of the process diverse tasks are carried out, a cost value has been fixed by unit of time of occupation of each equipment during the production of a batch of DAF. Total cost obtained by produced batch has been:

Equipment	Time of occupation [h/batch]	Price [€/h]	Cost [€/batch]
V-01	17.1	20	342
RF-01	2.6	10	26
V-02	12.7	20	254
RF-02	2.3	10	23
RD-01	34	20	680
		TOTAL	**1325**

Table 20. Energetic cost for a batch production

Maintenance cost

It has been considered as 2% of the initial necessary investment, that is to say, of 84,000 €/year. Nevertheless, DAF's production is not realized all the year round and in these periods the equipments will be used for other intentions. Therefore, it is needed to calculate what part from this cost corresponds to DAF production.

Like already it has been commented in a previous paragraph, the production of the annual quantity of wished DAF can be carried out in 14 weeks. However, contemplating the possibility more that probable of that the production will not be realized in only a campaign, it has thought that the process occupies the facilities for 16 weeks to the year of 48 weeks that the facilities are operative.

This period of 16 weeks of occupation corresponds to the most unfavorable case, in which the production it is not carried out in 8 campaigns of 2 weeks. More short campaigns probably would not be viable because changing the process so often would imply cleanliness so exhaustive.

For all that, finally one has determined that the costs of maintenance are approximately:

$$84{,}000\,\frac{€}{year}\cdot\frac{1\,year}{48\,weeks}\cdot\frac{16\,weeks}{40\,batches}=700\,\frac{€}{batch}$$

Cost of amortization

In the chemical industry and in agreement with Spanish Accounting Plan, it considers that the period of useful life of the equipments is 10 years. Supposing a constant amortization and a residual value ten years of zero, the annual costs of amortization of the installation are of 420,000 €/year.

Again, bearing in mind the period of use of the facilities and the number of batches to produce, it is obtained:

$$420{,}000\,\frac{€}{year}\cdot\frac{1\,year}{48\,weeks}\cdot\frac{16\,weeks}{40\,batches}=3500\,\frac{€}{batch}$$

Indirect costs of production

Again, based on the functioning of chemical companies that work with similar products it has thought that the indirect costs of production will be of approximately 500 €/batch.

Once calculated all the costs for produced lot, there is obtained that for an annual production of 40 lots, the total costs ascend to:

COGS	**1,900,624.40 €/year**
– Materials	1.463.544.40 €/year
– Packaging	28,000.00 €/year
– Residues	140,000.00 €/year
– Direct labor	28,080.00 €/year
– Energy	53,000.00 €/year
– Maintenance	28,000.00 €/year
– Amortization	140,000.00 €/year
– Indirects	20,000.00 €/year

Table 21. COGS

8.3. PROFIT & LOSSES STATEMENT (P&L)

To continue, Profit & Loss Statement is shown. It is a summary of the income and the expenses incurred by the operation of the project during the period of one year. First, there will have to calculate the income, which are equivalent to the money that the company saves itself for the fact of not having to buy the DAF to another external company:

$$40\ batch \cdot 3500 \frac{kgDAF}{batch} \cdot 20.50 \frac{€}{kgDAF} = 2{,}870{,}000 \frac{€}{year}$$

PROFIT & LOSSES	
Due to the project	**€**
Income	2,870,000
COGS	1,900,624
Gross Margin	969,376
Fixed Costs	0
EBIT	969,376
Financial expenses	0
EBT	969,376
Taxes	290,813
Net Earnings	678,563

Table 22. Profit & Losses

8.4. NET PRESENT VALUE, DISCOUNTED PAY BACK AND INTERNAL RATE RETURN

In this section, the basic financial indicators are calculated: Discounted Cash Flow (DCF), Net Present Value (NPV), Internal Rate of Return and Payback Period.

For the calculations, it has been chosen a discount rate of 8% and it has been supposed that production is constant in time, that there are not inflationary effects, that the Working Capital is constant and finally that the initial Investment is carried out with own funds of the company.

Discounted Cash Flow (DCF)

Due to the project (k€)	0	1	2	3	4	5	6	7	8	9	10
Income	0	2,870	2,870	2,870	2,870	2,870	2,870	2,870	2,870	2,870	2,870
- COGS	0	1,901	1,901	1,901	1,901	1,901	1,901	1,901	1,901	1,901	1,901
- Fixed Costs	0	0	0	0	0	0	0	0	0	0	0
PBT	0	969	969	969	969	969	969	969	969	969	969
- Taxes	0	291	291	291	291	291	291	291	291	291	291
Net Profit	0	679	679	679	679	679	679	679	679	679	679
+ Amortization	0	140	140	140	140	140	140	140	140	140	140
- Investment in FA	4,200	0	0	0	0	0	0	0	0	0	0
- Investment in CA	0	0	0	0	0	0	0	0	0	0	0
Cash Flow (CF)	-4,200	819	819	819	819	819	819	819	819	819	819

Table 23. Discounted Cash Flow (DCF)

Cash flows that occur uniformly over the project life should use a continuous discount rate. Following equation is a commonly used formula for continuous discounting:

$$DCF_i = \frac{(e^r - 1) \cdot (e^{-rn})}{r}$$

Where DFi is the discount factor for cash flow in year i, and r is the discount (or interest) rate.

For a r value of 8%, DCFi obtained are:

Year	0	1	2	3	4	5	6	7	8	9	10
CF_i	-4,200	819	819	819	819	819	819	819	819	819	819
DCF_i	-4,200	758	702	650	602	557	516	478	442	409	379
DCF_i cumulated	**-4,200**	**-3,442**	**-2,740**	**-2,090**	**-1,489**	**-932**	**-416**	**62**	**504**	**913**	**1,293**

Table 24. DCF_i cumulated

Net Present Value (NPV)

The sum of the discounted cash flows generated in all years that the project is active is called the net present value. The NPV indicates the total cash flow that a project would generate if all revenues and costs associated with the project were reduced to a single instant in time, namely present. NPV is calculated by:

$$NPV_i = \sum_{1}^{i} DCF_i$$

Where *i* is the number of periods of evaluation.

The NPV_{10} obtained for this project is 1,293 k€.

The interpretation of an NPV is relatively simple: If NPV>0, like in this case, the project will return more than the opportunity cost of funds. However, if NPV<0, the project will not return the opportunity cost of funds.

Payback period

The time required for a project to return the initial investment is called the payback period. It is computed by calculating the cumulative return for each year and comparing it to the investment, the time at which this sum exceeds the investment is the payback period.

For this project, the Payback Period value is 7 years. This period of time is a measure of the return of an investment and it can be used to gauge the riskiness of the investments: shorter paybacks enable a business to recover investments with less exposure to risk.

Internal Rate of Return

Conceptually, the NPV is zero if the product breaks even for a given discount rate. This rate is referred to as the internal rate of return (IRR).

The value of IRR obtained has been 14%.

With the values obtained for these financial indicators, it concludes:

- VPN > 0: The project is feasible and the investment will recover.
- Payback Period ≈7 years, which shows that the project has a high Payback for what one comes being requested in companies of the sector (3 to 5 years).

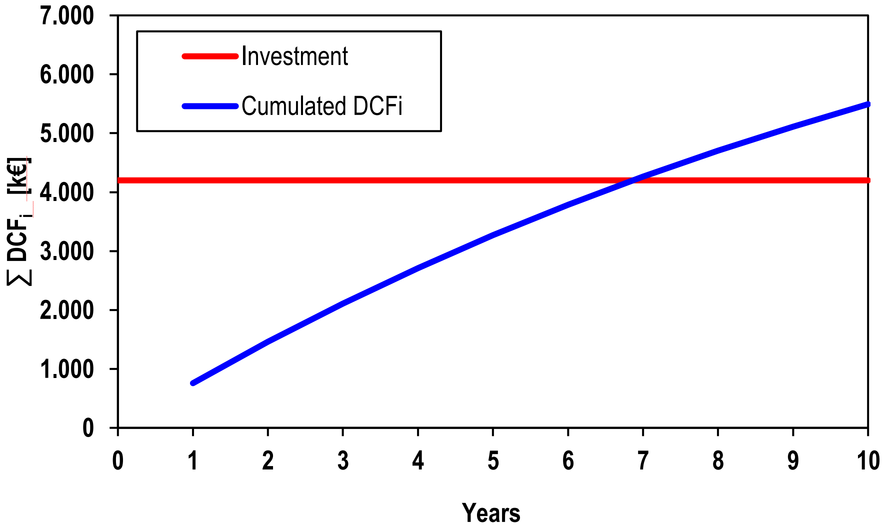

Figure 19. Cumulated DCF_i

From the financial point of view the decision on if to carry out the project is in a not very clear zone. In this case, other not purely financial factors will have to be born in mind, like if it compensates the possibility of avoiding the problems of supply of raw materials or of quality of the product that could be had if the DAF is bought to an external company.

9. CONCLUSIONS

Once concluded this project, there are exposed the obtained conclusions in reference with the initial aims of the project:

- Bearing in mind that it is wanted to carry out the production with the minimal number of equipments, one has concluded that are necessary: 2 vessels (reactors), 2 rotating filters and a rotating dryer, each one with its respective auxiliary necessary equipments, automation and control.
    - The two vessels are necessary because on having had to leak big volumes, it has been chosen for filtrations in continuous, so minimum is needed two vessels, the vessel in use and a second where to be leading the volume of already leaked liquid.
    - As for the rotary filters, it could have been decided to use an only filter. Nevertheless, the fact that first the solid crystalline is filtered and then the solid porous organic, it involves that the mesh has to be replaced in each occasion. In addition, in the second filtration the wished product is obtained and it is tried to be obtained with a very high purity, for what the use of an only one filter would force to carry out too careful processes of cleanliness.
- According to the chapter 3.2, it has concluded that batches of 3500 kg of DAF will be produced, the half of the necessary to produce one batch of Topiramate.

- The sizing of the equipments has been realized bearing in mind the way and the conditions of operation, as well as the fact that they are the same equipments those who limit the development of process. Finally, one has concluded that the tanks will be of the same size, of approximately 44.2 m3, whereas both filters will be different between them. The first one will be of 3.80x2.05X1.70 m, whereas the second one will be low, of 4.30x2.30x2.00 m. To finish, the rotating dryer will be of 1.20x1.20 m.

–

- From the analysis of the functioning of the equipments in each stage, one has concluded that the time of batch, including the times of cleanliness of the equipments, is of 58.2 h. The bounding stage of the process is the stage of dried, which lasts 34 hours and fixes the time of a cycle. From the accomplishment of the scheduling, one has concluded that, in campaigns with overlapping, the most feasible form of production for the saving in time of occupation of the equipments, the wished production could be carry out, at best, in only 14 weeks. However, foreseeing the worst of the cases in which the production was realized in campaigns of two weeks, 16 weeks would be sufficient, which means that the process presents flexibility in the distribution of the production throughout the year.

- By means of the calculation of the financial basic indicators, one has concluded that from the financial point of view, the viability of the starting up of the project is not clear. The initial estimated investment is of 4,200,000 € and the obtained Payback Period has been of approximately 7 years, a bit high for what one comes asking in the industries of the sector (from 3 to 5 years), by what to take the decision other factors will have to be born in mind, in addition to the purely financial ones, like it can be the possibility of save the problems related with the supply of the raw materials or with the quality of the received product.

RECOMMENDATIONS

Of all the information extracted along the accomplishment of this project, they propose some recommendations for those that are interested in looking to beyond into this topic:

- One of the longest stages of the process is the stage of neutralization. His exothermic character forces to carry out the stage of slow form and with a very exhaustive control of the temperature. It would propose to realize studies in laboratory on how to improve the selectivity of the reaction without need to need a pH so acid, that way the duration of the stage of neutralization would be shorter

- The most important losses of product are caused by the dissolution of the DAF in the solvents that are withdrawn from the principal line of the process. It would be interesting to try of taking the reaction to higher concentrations, with what the quantities of solvents to use you would be minor.

- The sodium sulfate is a by-product of the process that is produced practically in the same quantities that the principal product. It would be advisable to realize a study to see what can be done to save the expenses that it produces as residue.

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11. ACRONYMS

CA: Current Assets

CF: Cash Flow

COGS: Cost of Goods Sold

CQ: Control Quality

DAF: Diacetone-β-fructose

DCF: Discounted Cash Flow

EBIT: Earnings Before Interests and Taxes

EBT: Earnings Before Taxes

FA: Fixed Assets

FIS: Finite Intermediate Storage

HE: Heat Exchanger

IRR: Internal Rate of Return

NIS: No intermediate Storage

NPV: Net Present Value

P&L: Profit and Losses

PBT: Profit Before Taxes

RD: Rotary dryer

RF: Rotary Filter

V: Vessel

VIS: Unlimited Intermediate Storage

ZW: Zero wait

12. NOMENCLATURE

A_s: Cross flow area [m^2]
A_{TUBE}: Area of a tube [m]

BT: Batch time [h]

c: Thickness [mm]

Cp: Calorific capacity [J/(kg·K)]

CT: Cycle time [h]

Db: Diameter of tubular bundle [mm]

DCF_i: Discount factor for cash flow in year *i*

D_d: Diameter of the baffle [m]

D_{eq}: Equivalent diameter [m]

$D_{ext,c}$: External diameter of the shell [m]

$D_{ext,t}$: External diameter of tubes [m]

D_i: Impellier diameter [m]

$D_{int,c}$: Internal diameter of the shell [m]

$D_{int,t}$: Internal diameter of tubes [m]

D_N: Nominal diameter [m]

D_t: Tank diameter [m]

E_d: Spread between baffles [m]

g: Gravity [m/s^2]

G_s: Linear velocity of vapor [kg/s]

h_c: Individual coefficient of heat transfer [$W/(m^2 \cdot K)$]

j_h: Factor of heat transfer [-]

k_r: Coefficient of material transfer [J/(s·m·K)]

L: Length [m]

l_B: Leugth of the baffle [m]

M: Molecular mass [g/mol]

m_i: Mass of *i* [kg]

MS_n: Makespan [h]

N: Number of batches

N: Turn speed [rpm]

N_B: Number of baffles [-]

Np: Power number

$N_{T,pass}$: Number of tubes by pass [tubes]

NT: Number of tubes [tubes]

Nu: Nusselt [-]

OT_j: Occupation time of *j* [h]

P: Pressure [Pa]

Pr: Prandlt [-]

P_t: Tube pitch [mm]

Q: Exchanged heat [W]

q: Volumetric flow rate [m^3/s]

r: Discount rate [-]

Re: Reynolds [-]

S_{col}: Column section [m^2]

S_T: Section of a tube [m^2]

S_{TOTAL}: Total section [m^2]

T: Temperature [ºC]

t: Time

t_i: Inlet temperature of coolant [ºC]

t_o: Outlet temperature of coolant [ºC]

V: Volume [m^3]

V_r: Linear speed of coolant [m/s]

W_i: Impellier width [m]

W_r: Coolant flow rate [kg/s]

W_v: Vapor flow rate [kg/s]

z_i: Height of *i* [m]

Δh_{diss}: Enthalpy of dissolution [J/mol]

Δh_r: Enthalpy of reaction [J/mol]

ΔT: Difference of temperature [K]

λ: Latent heat [J/kg]

μ_i: viscosity of *i* [Pa·s]

ρ: Density [kg/m3]

σ_{LE}: Elastic yield [Pa]

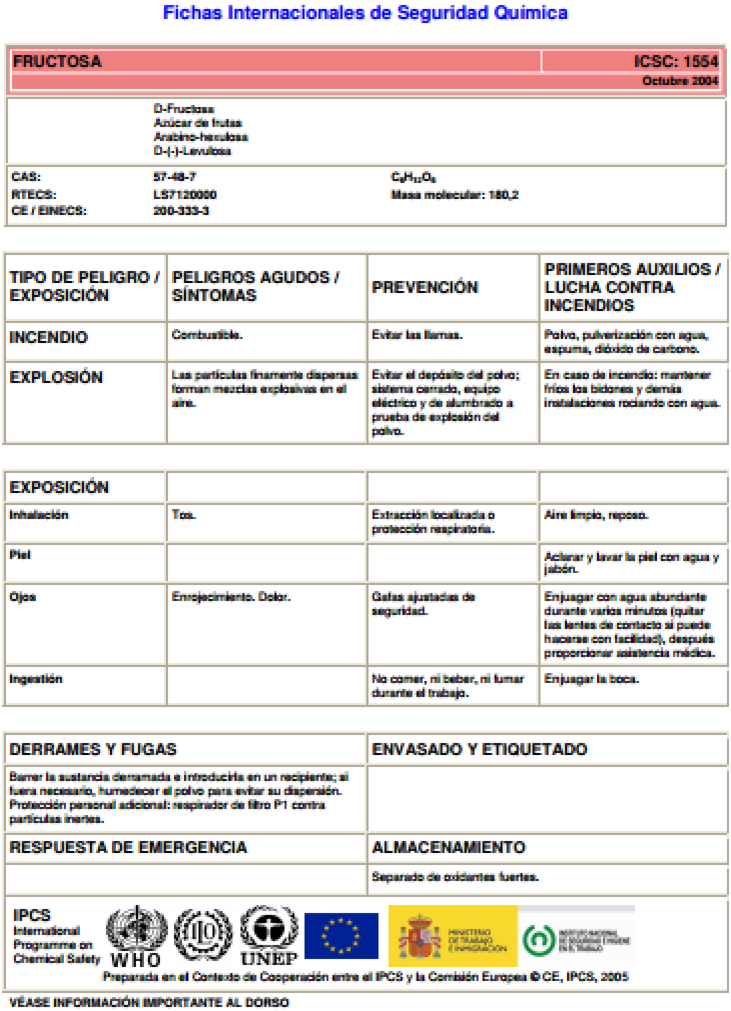
13. INDEX OF FIGURES AND TABLES

FIGURES

TABLES

APPENDICES

APPENDIX 1: SAFETY DATA SHEETS



Fichas Internacionales de Seguridad Química

FRUCTOSA	**ICSC: 1554** **Octubre 2004**

D-Fructosa
Azúcar de frutas
Arabino-hexulosa
D-(-)-Levulosa

CAS:	**57-48-7**	**$C_6H_{12}O_6$**
RTECS:	**LS7120000**	**Masa molecular: 180,2**
CE / EINECS:	**200-333-3**	

TIPO DE PELIGRO / EXPOSICIÓN	PELIGROS AGUDOS / SÍNTOMAS	PREVENCIÓN	PRIMEROS AUXILIOS / LUCHA CONTRA INCENDIOS
INCENDIO	Combustible.	Evitar las llamas.	Polvo, pulverización con agua, espuma, dióxido de carbono.
EXPLOSIÓN	Las partículas finamente dispersas forman mezclas explosivas en el aire.	Evitar el depósito del polvo; sistema cerrado, equipo eléctrico y de alumbrado a prueba de explosión del polvo.	En caso de incendio: mantener fríos los bidones y demás instalaciones rociando con agua.

EXPOSICIÓN			
Inhalación	Tos.	Extracción localizada o protección respiratoria.	Aire limpio, reposo.
Piel			Aclarar y lavar la piel con agua y jabón.
Ojos	Enrojecimiento. Dolor.	Gafas ajustadas de seguridad.	Enjuagar con agua abundante durante varios minutos (quitar las lentes de contacto si puede hacerse con facilidad), después proporcionar asistencia médica.
Ingestión		No comer, ni beber, ni fumar durante el trabajo.	Enjuagar la boca.

DERRAMES Y FUGAS	ENVASADO Y ETIQUETADO
Barrer la sustancia derramada e introducirla en un recipiente; si fuera necesario, humedecer el polvo para evitar su dispersión. Protección personal adicional: respirador de filtro P1 contra partículas inertes.	
RESPUESTA DE EMERGENCIA	**ALMACENAMIENTO**
	Separado de oxidantes fuertes.

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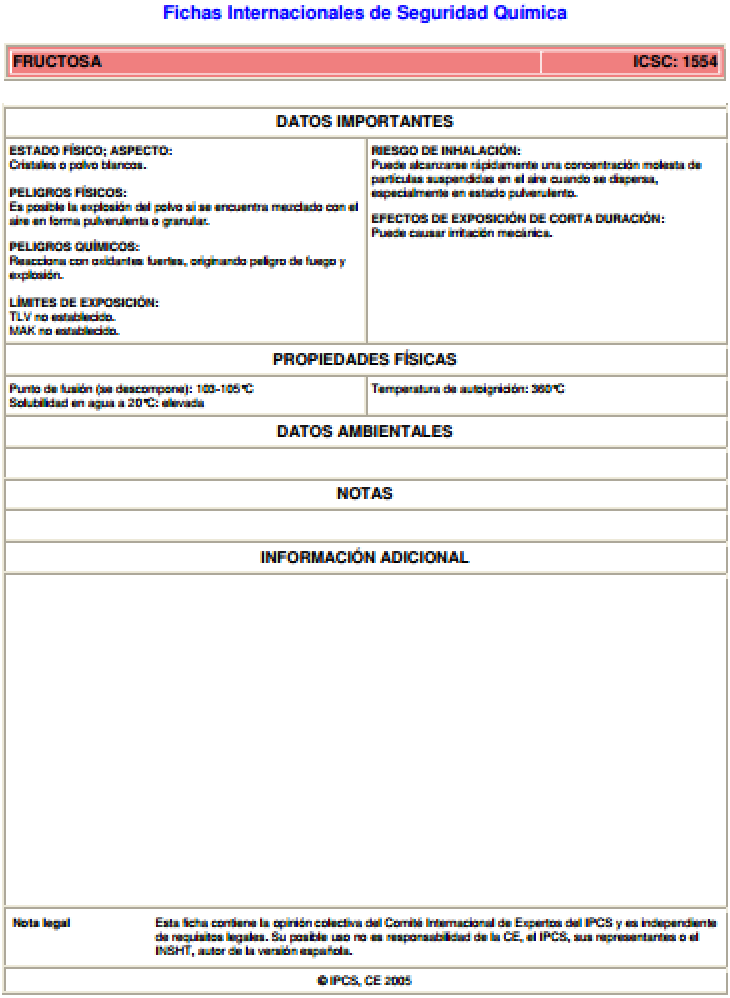
Chemical Safety

WHO UNEP

Preparada en el Contexto de Cooperación entre el IPCS y la Comisión Europea © CE, IPCS, 2005

VÉASE INFORMACIÓN IMPORTANTE AL DORSO



Fichas Internacionales de Seguridad Quimica

FRUCTOSA	**ICSC: 1554**

DATOS IMPORTANTES

ESTADO FÍSICO; ASPECTO: Cristales o polvo blancos. **PELIGROS FÍSICOS:** Es posible la explosión del polvo si se encuentra mezclado con el aire en forma pulverulenta o granular. **PELIGROS QUÍMICOS:** Reacciona con oxidantes fuertes, originando peligro de fuego y explosión. **LÍMITES DE EXPOSICIÓN:** TLV no establecido. MAK no establecido.	**RIESGO DE INHALACIÓN:** Puede alcanzarse rápidamente una concentración molesta de partículas suspendidas en el aire cuando se dispersa, especialmente en estado pulverulento. **EFECTOS DE EXPOSICIÓN DE CORTA DURACIÓN:** Puede causar irritación mecánica.

PROPIEDADES FÍSICAS

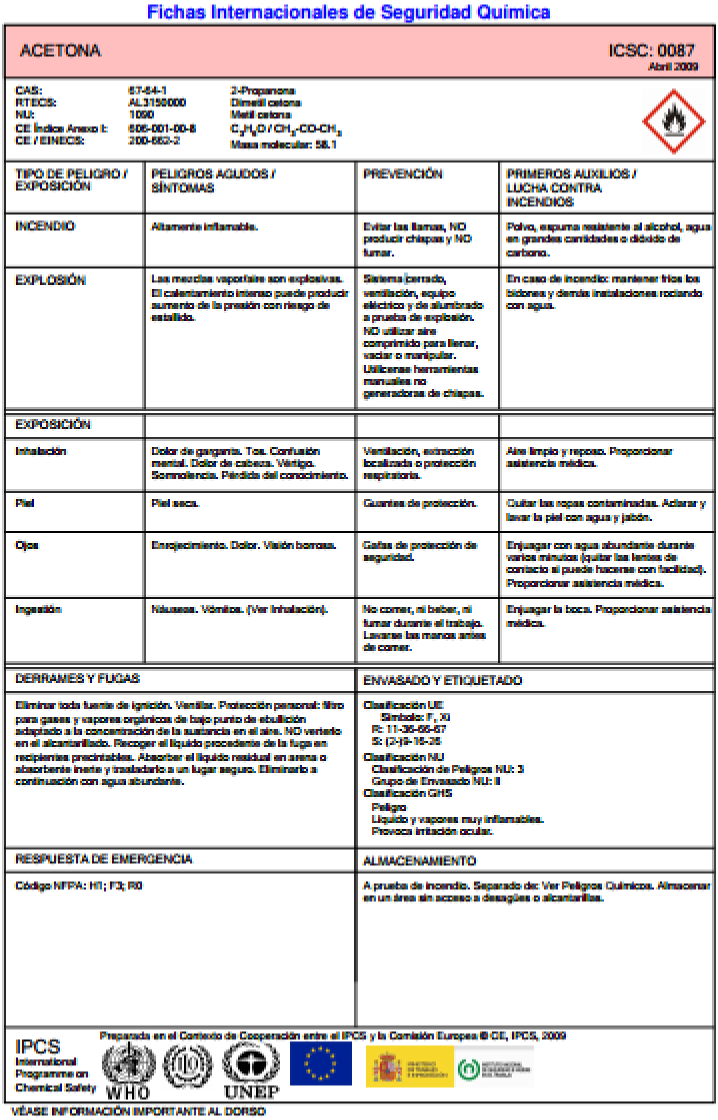
Punto de fusión (se descompone): 103-105°C Solubilidad en agua a 20°C: elevada	Temperatura de autoignición: 360°C

DATOS AMBIENTALES

NOTAS

INFORMACIÓN ADICIONAL

Nota legal	Esta ficha contiene la opinión colectiva del Comité Internacional de Expertos del IPCS y es independiente de requisitos legales. Su posible uso no es responsabilidad de la CE, el IPCS, sus representantes o el INSHT, autor de la versión española.



Fichas Internacionales de Seguridad Química

ACETONA — **ICSC: 0087**

Abril 2009

CAS:	67-64-1	2-Propanona
RTECS:	AL3150000	Dimetil cetona
NU:	1090	Metil cetona
CE Índice Anexo I:	606-001-00-8	C_3H_6O / CH_3-CO-CH_3
CE / EINECS:	200-662-2	Masa molecular: 58.1

TIPO DE PELIGRO / EXPOSICIÓN	PELIGROS AGUDOS / SÍNTOMAS	PREVENCIÓN	PRIMEROS AUXILIOS / LUCHA CONTRA INCENDIOS
INCENDIO	Altamente inflamable.	Evitar las llamas, NO producir chispas y NO fumar.	Polvo, espuma resistente al alcohol, agua en grandes cantidades o dióxido de carbono.
EXPLOSIÓN	Las mezclas vapor/aire son explosivas. El calentamiento intenso puede producir aumento de la presión con riesgo de estallido.	Sistema cerrado, ventilación, equipo eléctrico y de alumbrado a prueba de explosión. NO utilizar aire comprimido para llenar, vaciar o manipular. Utilícense herramientas manuales no generadoras de chispas.	En caso de incendio: mantener fríos los bidones y demás instalaciones rociando con agua.
EXPOSICIÓN			
Inhalación	Dolor de garganta. Tos. Confusión mental. Dolor de cabeza. Vértigo. Somnolencia. Pérdida del conocimiento.	Ventilación, extracción localizada o protección respiratoria.	Aire limpio y reposo. Proporcionar asistencia médica.
Piel	Piel seca.	Guantes de protección.	Quitar las ropas contaminadas. Aclarar y lavar la piel con agua y jabón.
Ojos	Enrojecimiento. Dolor. Visión borrosa.	Gafas de protección de seguridad.	Enjuagar con agua abundante durante varios minutos (quitar las lentes de contacto si puede hacerse con facilidad). Proporcionar asistencia médica.
Ingestión	Náuseas. Vómitos. (Ver Inhalación).	No comer, ni beber, ni fumar durante el trabajo. Lavarse las manos antes de comer.	Enjuagar la boca. Proporcionar asistencia médica.

DERRAMES Y FUGAS	ENVASADO Y ETIQUETADO
Eliminar toda fuente de ignición. Ventilar. Protección personal: filtro para gases y vapores orgánicos de bajo punto de ebullición adaptado a la concentración de la sustancia en el aire. NO verterlo en el alcantarillado. Recoger el líquido procedente de la fuga en recipientes precintables. Absorber el líquido residual en arena o absorbente inerte y trasladarlo a un lugar seguro. Eliminarlo a continuación con agua abundante.	Clasificación UE Símbolo: F, Xi R: 11-36-66-67 S: (2-)9-16-26 Clasificación NU Clasificación de Peligros NU: 3 Grupo de Envasado NU: II Clasificación GHS Peligro Líquido y vapores muy inflamables. Provoca irritación ocular.
RESPUESTA DE EMERGENCIA	**ALMACENAMIENTO**
Código NFPA: H1; F3; R0	A prueba de incendio. Separado de: Ver Peligros Químicos. Almacenar en un área sin acceso a desagües o alcantarillas.

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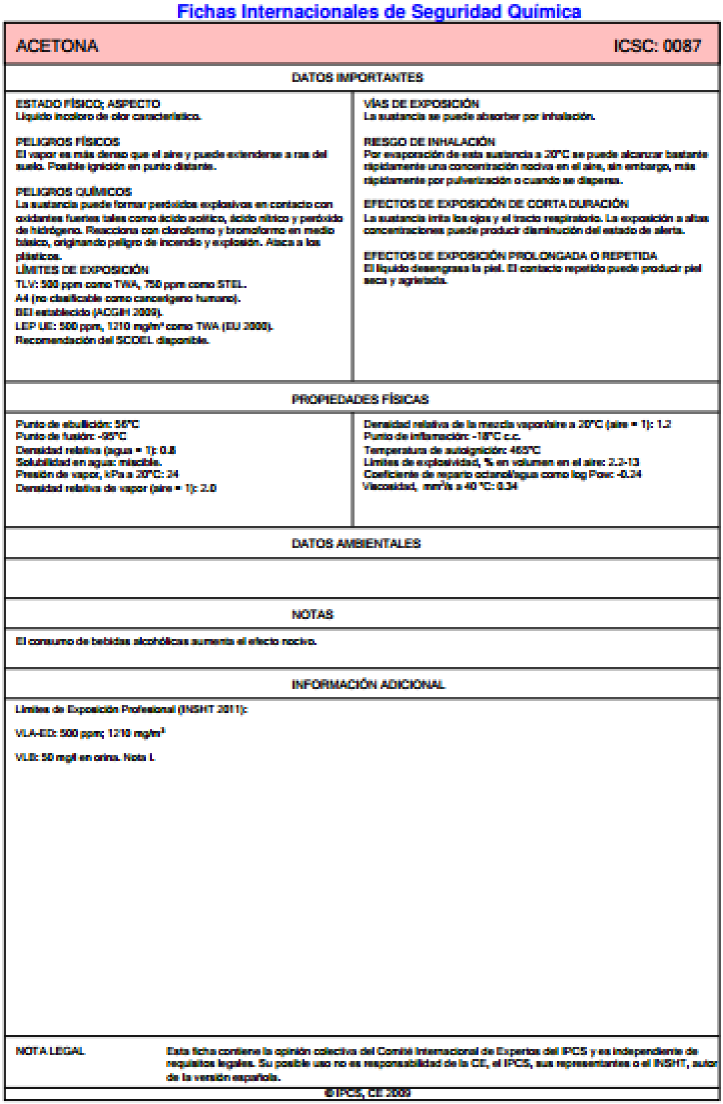
VÉASE INFORMACIÓN IMPORTANTE AL DORSO



Fichas Internacionales de Seguridad Química

ACETONA **ICSC: 0087**

DATOS IMPORTANTES

ESTADO FÍSICO; ASPECTO
Líquido incoloro de olor característico.

PELIGROS FÍSICOS
El vapor es más denso que el aire y puede extenderse a ras del suelo. Posible ignición en punto distante.

PELIGROS QUÍMICOS
La sustancia puede formar peróxidos explosivos en contacto con oxidantes fuertes tales como ácido acético, ácido nítrico y peróxido de hidrógeno. Reacciona con cloroformo y bromoformo en medio básico, originando peligro de incendio y explosión. Ataca a los plásticos.

LÍMITES DE EXPOSICIÓN
TLV: 500 ppm como TWA, 750 ppm como STEL.
A4 (no clasificable como cancerígeno humano).
BEI establecido (ACGIH 2009).
LEP UE: 500 ppm, 1210 mg/m³ como TWA (EU 2000).
Recomendación del SCOEL disponible.

VÍAS DE EXPOSICIÓN
La sustancia se puede absorber por inhalación.

RIESGO DE INHALACIÓN
Por evaporación de esta sustancia a 20°C se puede alcanzar bastante rápidamente una concentración nociva en el aire, sin embargo, más rápidamente por pulverización o cuando se dispersa.

EFECTOS DE EXPOSICIÓN DE CORTA DURACIÓN
La sustancia irrita los ojos y el tracto respiratorio. La exposición a altas concentraciones puede producir disminución del estado de alerta.

EFECTOS DE EXPOSICIÓN PROLONGADA O REPETIDA
El líquido desengrasa la piel. El contacto repetido puede producir piel seca y agrietada.

PROPIEDADES FÍSICAS

Punto de ebullición: 56°C
Punto de fusión: -95°C
Densidad relativa (agua = 1): 0.8
Solubilidad en agua: miscible.
Presión de vapor, kPa a 20°C: 24
Densidad relativa de vapor (aire = 1): 2.0

Densidad relativa de la mezcla vapor/aire a 20°C (aire = 1): 1.2
Punto de inflamación: -18°C c.c.
Temperatura de autoignición: 465°C
Límites de explosividad, % en volumen en el aire: 2.2-13
Coeficiente de reparto octanol/agua como log Pow: -0.24
Viscosidad, mm²/s a 40 °C: 0.34

DATOS AMBIENTALES

NOTAS

El consumo de bebidas alcohólicas aumenta el efecto nocivo.

INFORMACIÓN ADICIONAL

Límites de Exposición Profesional (INSHT 2011):

VLA-ED: 500 ppm; 1210 mg/m³

VLB: 50 mg/l en orina. Nota I.

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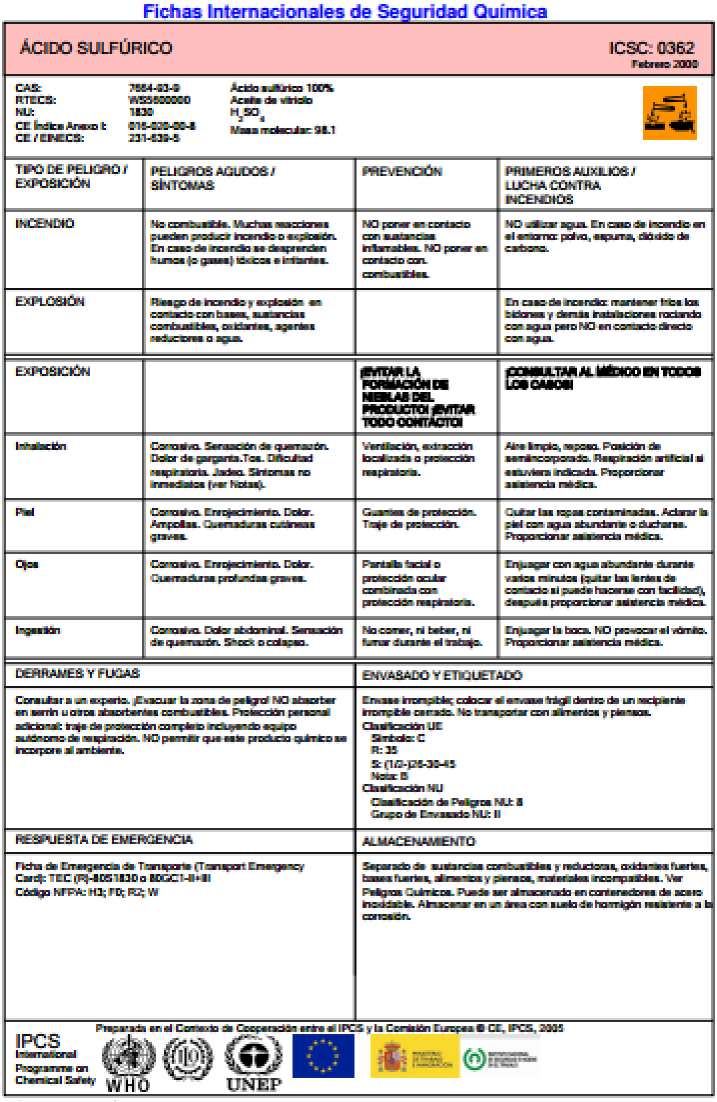

Fichas Internacionales de Seguridad Química

ÁCIDO SULFÚRICO ICSC: 0362

Febrero 2000

CAS:	7664-93-9	Ácido sulfúrico 100%
RTECS:	WS5600000	Aceite de vitriolo
NU:	1830	H_2SO_4
CE Índice Anexo I:	016-020-00-8	Masa molecular: 98.1
CE / EINECS:	231-639-5	

TIPO DE PELIGRO / EXPOSICIÓN	PELIGROS AGUDOS / SÍNTOMAS	PREVENCIÓN	PRIMEROS AUXILIOS / LUCHA CONTRA INCENDIOS
INCENDIO	No combustible. Muchas reacciones pueden producir incendio o explosión. En caso de incendio se desprenden humos (o gases) tóxicos e irritantes.	NO poner en contacto con sustancias inflamables. NO poner en contacto con combustibles.	NO utilizar agua. En caso de incendio en el entorno: polvo, espuma, dióxido de carbono.
EXPLOSIÓN	Riesgo de incendio y explosión en contacto con bases, sustancias combustibles, oxidantes, agentes reductores o agua.		En caso de incendio: mantener fríos los bidones y demás instalaciones rociando con agua pero NO en contacto directo con agua.
EXPOSICIÓN		**¡EVITAR LA FORMACIÓN DE NIEBLAS DEL PRODUCTO! ¡EVITAR TODO CONTACTO!**	**¡CONSULTAR AL MÉDICO EN TODOS LOS CASOS!**
Inhalación	Corrosivo. Sensación de quemazón. Dolor de garganta.Tos. Dificultad respiratoria. Jadeo. Síntomas no inmediatos (ver Notas).	Ventilación, extracción localizada o protección respiratoria.	Aire limpio, reposo. Posición de semiincorporado. Respiración artificial si estuviera indicada. Proporcionar asistencia médica.
Piel	Corrosivo. Enrojecimiento. Dolor. Ampollas. Quemaduras cutáneas graves.	Guantes de protección. Traje de protección.	Quitar las ropas contaminadas. Aclarar la piel con agua abundante o ducharse. Proporcionar asistencia médica.
Ojos	Corrosivo. Enrojecimiento. Dolor. Quemaduras profundas graves.	Pantalla facial o protección ocular combinada con protección respiratoria.	Enjuagar con agua abundante durante varios minutos (quitar las lentes de contacto si puede hacerse con facilidad), después proporcionar asistencia médica.
Ingestión	Corrosivo. Dolor abdominal. Sensación de quemazón. Shock o colapso.	No comer, ni beber, ni fumar durante el trabajo.	Enjuagar la boca. NO provocar el vómito. Proporcionar asistencia médica.

DERRAMES Y FUGAS	ENVASADO Y ETIQUETADO
Consultar a un experto. ¡Evacuar la zona de peligro! NO absorber en serrín u otros absorbentes combustibles. Protección personal adicional: traje de protección completo incluyendo equipo autónomo de respiración. NO permitir que este producto químico se incorpore al ambiente.	Envase irrompible; colocar el envase frágil dentro de un recipiente irrompible cerrado. No transportar con alimentos y piensos. Clasificación UE Símbolo: C R: 35 S: (1/2-)26-30-45 Nota: B Clasificación NU Clasificación de Peligros NU: 8 Grupo de Envasado NU: II

RESPUESTA DE EMERGENCIA	ALMACENAMIENTO
Ficha de Emergencia de Transporte (Transport Emergency Card): TEC (R)-80S1830 o 80GC1-II+III Código NFPA: H3; F0; R2; W	Separado de sustancias combustibles y reductoras, oxidantes fuertes, bases fuertes, alimentos y piensos, materiales incompatibles. Ver Peligros Químicos. Puede ser almacenado en contenedores de acero inoxidable. Almacenar en un área con suelo de hormigón resistente a la corrosión.

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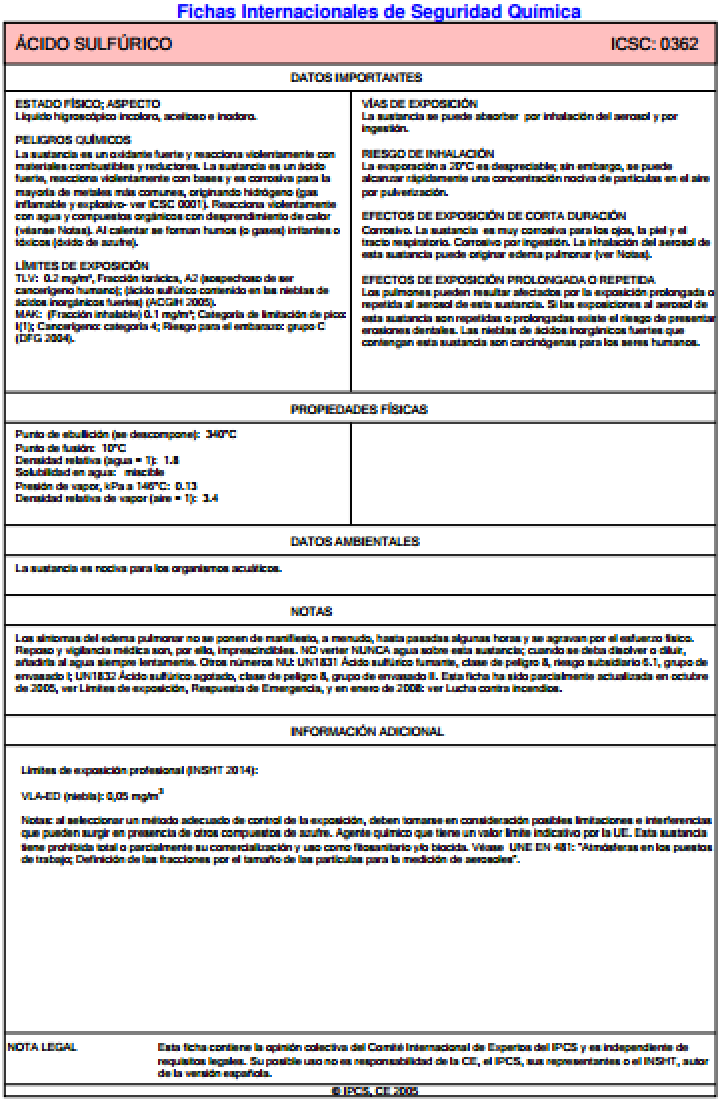

Fichas Internacionales de Seguridad Química

ÁCIDO SULFÚRICO **ICSC: 0362**

DATOS IMPORTANTES

ESTADO FÍSICO; ASPECTO
Líquido higroscópico incoloro, aceitoso e inodoro.

PELIGROS QUÍMICOS
La sustancia es un oxidante fuerte y reacciona violentamente con materiales combustibles y reductores. La sustancia es un ácido fuerte, reacciona violentamente con bases y es corrosiva para la mayoría de metales más comunes, originando hidrógeno (gas inflamable y explosivo- ver ICSC 0001). Reacciona violentamente con agua y compuestos orgánicos con desprendimiento de calor (véanse Notas). Al calentar se forman humos (o gases) irritantes o tóxicos (óxido de azufre).

LÍMITES DE EXPOSICIÓN
TLV: 0.2 mg/m^3, Fracción torácica, A2 (sospechoso de ser cancerígeno humano); (ácido sulfúrico contenido en las nieblas de ácidos inorgánicos fuertes) (ACGIH 2005).
MAK: (Fracción inhalable) 0.1 mg/m^3; Categoría de limitación de pico: I(1); Cancerígeno: categoría 4; Riesgo para el embarazo: grupo C (DFG 2004).

VÍAS DE EXPOSICIÓN
La sustancia se puede absorber por inhalación del aerosol y por ingestión.

RIESGO DE INHALACIÓN
La evaporación a 20°C es despreciable; sin embargo, se puede alcanzar rápidamente una concentración nociva de partículas en el aire por pulverización.

EFECTOS DE EXPOSICIÓN DE CORTA DURACIÓN
Corrosivo. La sustancia es muy corrosiva para los ojos, la piel y el tracto respiratorio. Corrosivo por ingestión. La inhalación del aerosol de esta sustancia puede originar edema pulmonar (ver Notas).

EFECTOS DE EXPOSICIÓN PROLONGADA O REPETIDA
Los pulmones pueden resultar afectados por la exposición prolongada o repetida al aerosol de esta sustancia. Si las exposiciones al aerosol de esta sustancia son repetidas o prolongadas existe el riesgo de presentar erosiones dentales. Las nieblas de ácidos inorgánicos fuertes que contengan esta sustancia son carcinógenas para los seres humanos.

PROPIEDADES FÍSICAS

Punto de ebullición (se descompone): 340°C
Punto de fusión: 10°C
Densidad relativa (agua = 1): 1.8
Solubilidad en agua: miscible
Presión de vapor, kPa a 146°C: 0.13
Densidad relativa de vapor (aire = 1): 3.4

DATOS AMBIENTALES

La sustancia es nociva para los organismos acuáticos.

NOTAS

Los síntomas del edema pulmonar no se ponen de manifiesto, a menudo, hasta pasadas algunas horas y se agravan por el esfuerzo físico. Reposo y vigilancia médica son, por ello, imprescindibles. NO verter NUNCA agua sobre esta sustancia; cuando se deba disolver o diluir, añadirla al agua siempre lentamente. Otros números NU: UN1831 Ácido sulfúrico fumante, clase de peligro 8, riesgo subsidiario 6.1, grupo de envasado I; UN1832 Ácido sulfúrico agotado, clase de peligro 8, grupo de envasado II. Esta ficha ha sido parcialmente actualizada en octubre de 2005, ver Límites de exposición, Respuesta de Emergencia, y en enero de 2008: ver Lucha contra incendios.

INFORMACIÓN ADICIONAL

Límites de exposición profesional (INSHT 2014):

VLA-ED (niebla): 0,05 mg/m^3

Notas: al seleccionar un método adecuado de control de la exposición, deben tomarse en consideración posibles limitaciones e interferencias que pueden surgir en presencia de otros compuestos de azufre. Agente químico que tiene un valor límite indicativo por la UE. Esta sustancia tiene prohibida total o parcialmente su comercialización y uso como fitosanitario y/o biocida. Véase UNE EN 481: "Atmósferas en los puestos de trabajo; Definición de las fracciones por el tamaño de las partículas para la medición de aerosoles".

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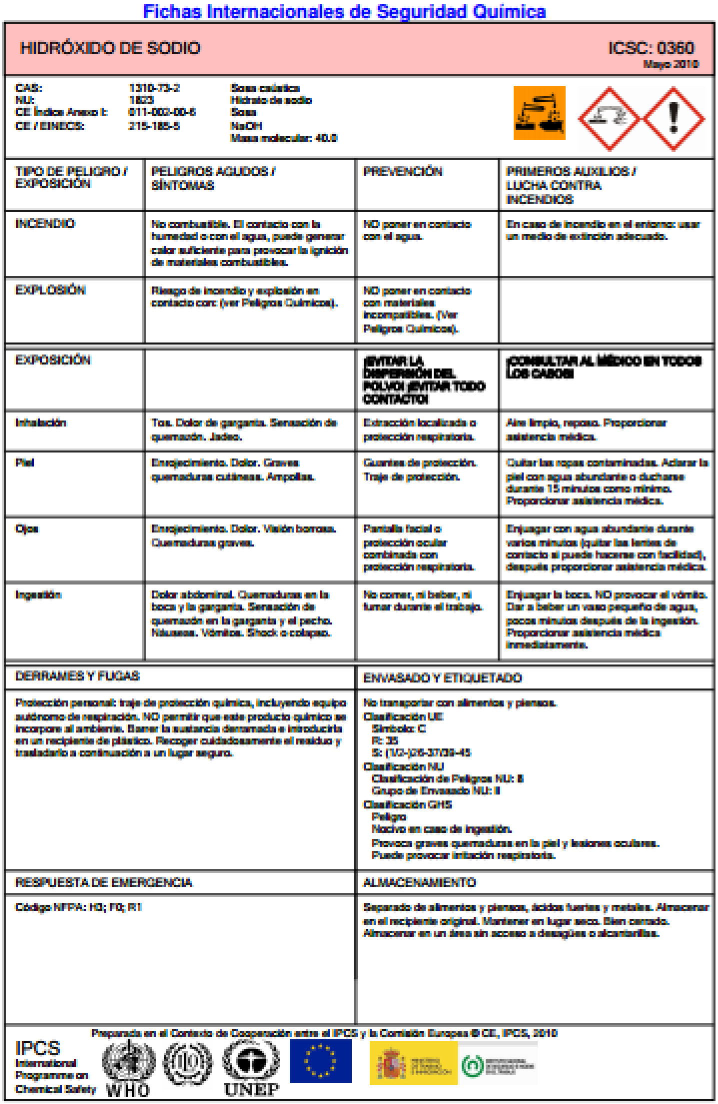

Fichas Internacionales de Seguridad Química

HIDRÓXIDO DE SODIO | **ICSC: 0360**
Mayo 2010

CAS:	1310-73-2	Sosa cáustica
NU:	1823	Hidrato de sodio
CE Índice Anexo I:	011-002-00-6	Sosa
CE / EINECS:	215-185-5	NaOH
		Masa molecular: 40.0

TIPO DE PELIGRO / EXPOSICIÓN	PELIGROS AGUDOS / SÍNTOMAS	PREVENCIÓN	PRIMEROS AUXILIOS / LUCHA CONTRA INCENDIOS
INCENDIO	No combustible. El contacto con la humedad o con el agua, puede generar calor suficiente para provocar la ignición de materiales combustibles.	NO poner en contacto con el agua.	En caso de incendio en el entorno: usar un medio de extinción adecuado.
EXPLOSIÓN	Riesgo de incendio y explosión en contacto con: (ver Peligros Químicos).	NO poner en contacto con materiales incompatibles. (Ver Peligros Químicos).	
EXPOSICIÓN		**¡EVITAR LA DISPERSIÓN DEL POLVO! ¡EVITAR TODO CONTACTO!**	**¡CONSULTAR AL MÉDICO EN TODOS LOS CASOS!**
Inhalación	Tos. Dolor de garganta. Sensación de quemazón. Jadeo.	Extracción localizada o protección respiratoria.	Aire limpio, reposo. Proporcionar asistencia médica.
Piel	Enrojecimiento. Dolor. Graves quemaduras cutáneas. Ampollas.	Guantes de protección. Traje de protección.	Quitar las ropas contaminadas. Aclarar la piel con agua abundante o ducharse durante 15 minutos como mínimo. Proporcionar asistencia médica.
Ojos	Enrojecimiento. Dolor. Visión borrosa. Quemaduras graves.	Pantalla facial o protección ocular combinada con protección respiratoria.	Enjuagar con agua abundante durante varios minutos (quitar las lentes de contacto si puede hacerse con facilidad), después proporcionar asistencia médica.
Ingestión	Dolor abdominal. Quemaduras en la boca y la garganta. Sensación de quemazón en la garganta y el pecho. Náuseas. Vómitos. Shock o colapso.	No comer, ni beber, ni fumar durante el trabajo.	Enjuagar la boca. NO provocar el vómito. Dar a beber un vaso pequeño de agua, pocos minutos después de la ingestión. Proporcionar asistencia médica inmediatamente.

DERRAMES Y FUGAS	ENVASADO Y ETIQUETADO
Protección personal: traje de protección química, incluyendo equipo autónomo de respiración. NO permitir que este producto químico se incorpore al ambiente. Barrer la sustancia derramada e introducirla en un recipiente de plástico. Recoger cuidadosamente el residuo y trasladarlo a continuación a un lugar seguro.	No transportar con alimentos y piensos. Clasificación UE Símbolo: C R: 35 S: (1/2-)26-37/39-45 Clasificación NU Clasificación de Peligros NU: 8 Grupo de Envasado NU: II Clasificación GHS Peligro Nocivo en caso de ingestión. Provoca graves quemaduras en la piel y lesiones oculares. Puede provocar irritación respiratoria.

RESPUESTA DE EMERGENCIA	ALMACENAMIENTO
Código NFPA: H3; F0; R1	Separado de alimentos y piensos, ácidos fuertes y metales. Almacenar en el recipiente original. Mantener en lugar seco. Bien cerrado. Almacenar en un área sin acceso a desagües o alcantarillas.

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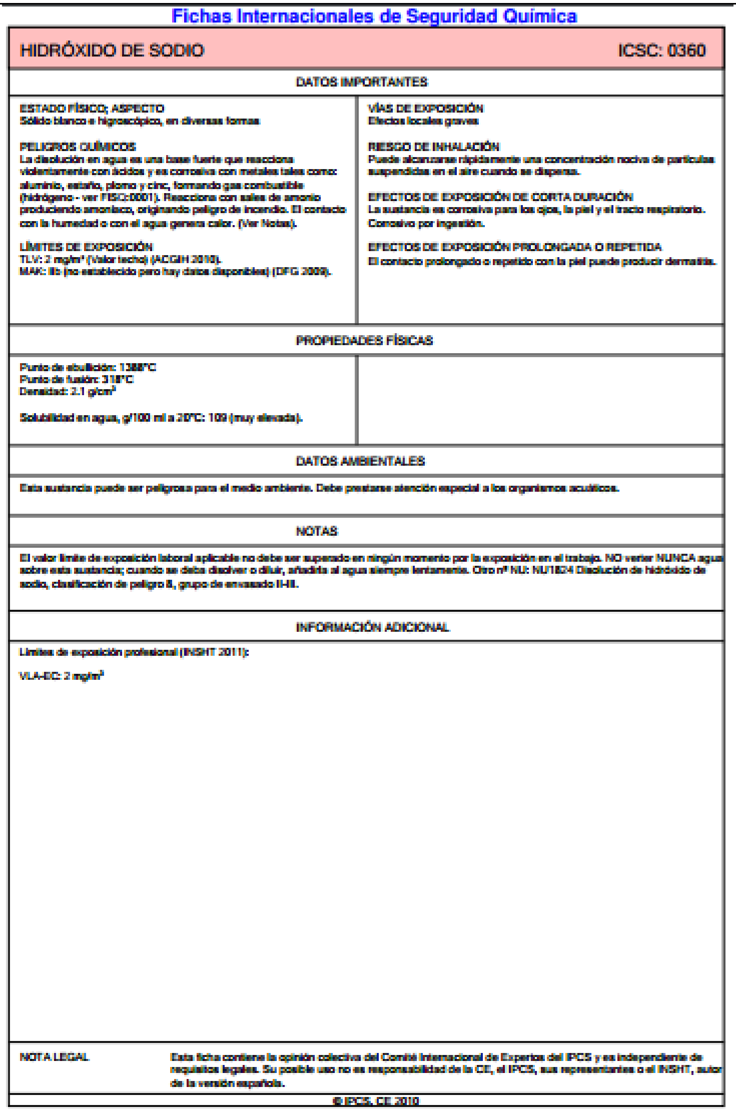
IPCS
International
Programme on
Chemical Safety



Fichas Internacionales de Seguridad Química

HIDRÓXIDO DE SODIO	ICSC: 0360

DATOS IMPORTANTES

ESTADO FÍSICO; ASPECTO Sólido blanco e higroscópico, en diversas formas. **PELIGROS QUÍMICOS** La disolución en agua es una base fuerte que reacciona violentamente con ácidos y es corrosiva con metales tales como: aluminio, estaño, plomo y cinc, formando gas combustible (hidrógeno - ver FISQ:0001). Reacciona con sales de amonio produciendo amoniaco, originando peligro de incendio. El contacto con la humedad o con el agua genera calor. (Ver Notas). **LÍMITES DE EXPOSICIÓN** TLV: 2 mg/m³ (Valor techo) (ACGIH 2010). MAK: IIb (no establecido pero hay datos disponibles) (DFG 2009).	**VÍAS DE EXPOSICIÓN** Efectos locales graves. **RIESGO DE INHALACIÓN** Puede alcanzarse rápidamente una concentración nociva de partículas suspendidas en el aire cuando se dispersa. **EFECTOS DE EXPOSICIÓN DE CORTA DURACIÓN** La sustancia es corrosiva para los ojos, la piel y el tracto respiratorio. Corrosivo por ingestión. **EFECTOS DE EXPOSICIÓN PROLONGADA O REPETIDA** El contacto prolongado o repetido con la piel puede producir dermatitis.

PROPIEDADES FÍSICAS

Punto de ebullición: 1388°C
Punto de fusión: 318°C
Densidad: 2.1 g/cm³

Solubilidad en agua, g/100 ml a 20°C: 109 (muy elevada).

DATOS AMBIENTALES

Esta sustancia puede ser peligrosa para el medio ambiente. Debe prestarse atención especial a los organismos acuáticos.

NOTAS

El valor límite de exposición laboral aplicable no debe ser superado en ningún momento por la exposición en el trabajo. NO verter NUNCA agua sobre esta sustancia; cuando se deba disolver o diluir, añadirla al agua siempre lentamente. Otro nº NU: NU1824 Disolución de hidróxido de sodio, clasificación de peligro 8, grupo de envasado II-III.

INFORMACIÓN ADICIONAL

Límites de exposición profesional (INSHT 2011):

VLA-EC: 2 mg/m³

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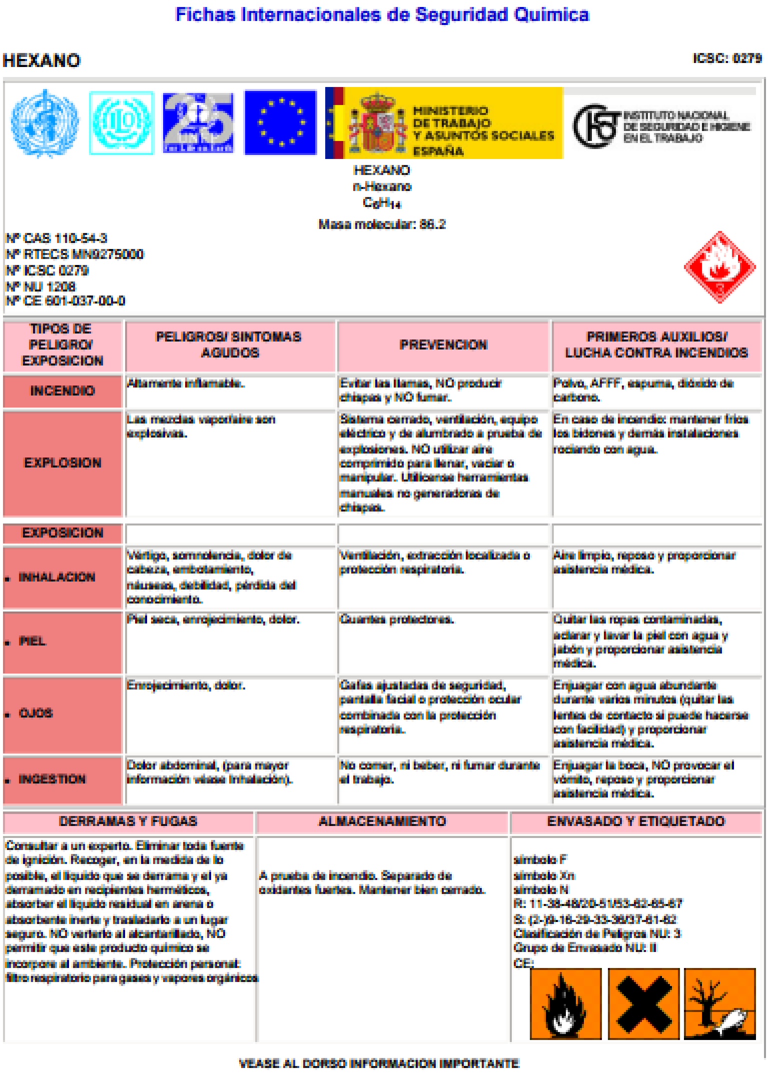


Fichas Internacionales de Seguridad Quimica

HEXANO **ICSC: 0279**

HEXANO
n-Hexano
C_6H_{14}

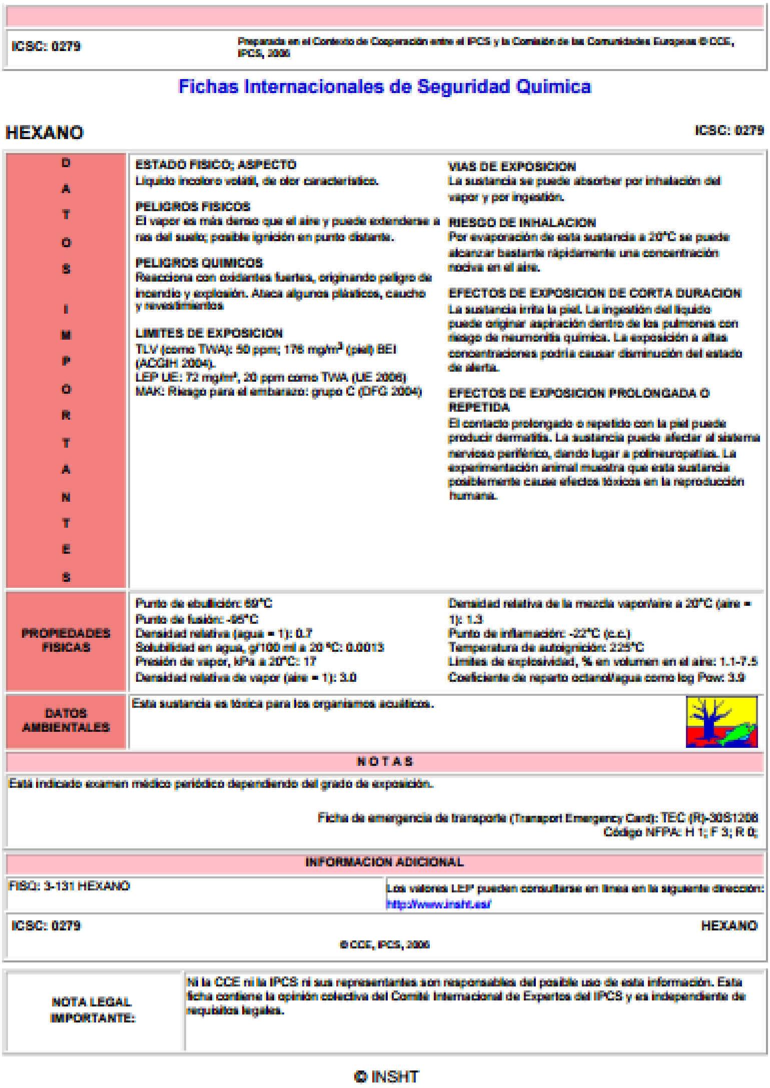
Masa molecular: 86.2

Nº CAS 110-54-3
Nº RTECS MN9275000
Nº ICSC 0279
Nº NU 1208
Nº CE 601-037-00-0

TIPOS DE PELIGRO/ EXPOSICION	PELIGROS/ SINTOMAS AGUDOS	PREVENCION	PRIMEROS AUXILIOS/ LUCHA CONTRA INCENDIOS
INCENDIO	Altamente inflamable.	Evitar las llamas, NO producir chispas y NO fumar.	Polvo, AFFF, espuma, dióxido de carbono.
EXPLOSION	Las mezclas vapor/aire son explosivas.	Sistema cerrado, ventilación, equipo eléctrico y de alumbrado a prueba de explosiones. NO utilizar aire comprimido para llenar, vaciar o manipular. Utilícense herramientas manuales no generadoras de chispas.	En caso de incendio: mantener fríos los bidones y demás instalaciones rociando con agua.
EXPOSICION			
▪ **INHALACION**	Vértigo, somnolencia, dolor de cabeza, embotamiento, náuseas, debilidad, pérdida del conocimiento.	Ventilación, extracción localizada o protección respiratoria.	Aire limpio, reposo y proporcionar asistencia médica.
▪ **PIEL**	Piel seca, enrojecimiento, dolor.	Guantes protectores.	Quitar las ropas contaminadas, aclarar y lavar la piel con agua y jabón y proporcionar asistencia médica.
▪ **OJOS**	Enrojecimiento, dolor.	Gafas ajustadas de seguridad, pantalla facial o protección ocular combinada con la protección respiratoria.	Enjuagar con agua abundante durante varios minutos (quitar las lentes de contacto si puede hacerse con facilidad) y proporcionar asistencia médica.
▪ **INGESTION**	Dolor abdominal, (para mayor información véase Inhalación).	No comer, ni beber, ni fumar durante el trabajo.	Enjuagar la boca, NO provocar el vómito, reposo y proporcionar asistencia médica.

DERRAMAS Y FUGAS	ALMACENAMIENTO	ENVASADO Y ETIQUETADO
Consultar a un experto. Eliminar toda fuente de ignición. Recoger, en la medida de lo posible, el líquido que se derrama y el ya derramado en recipientes herméticos, absorber el líquido residual en arena o absorbente inerte y trasladarlo a un lugar seguro. NO verterlo al alcantarillado, NO permitir que este producto químico se incorpore al ambiente. Protección personal: filtro respiratorio para gases y vapores orgánicos.	A prueba de incendio. Separado de oxidantes fuertes. Mantener bien cerrado.	símbolo F símbolo Xn símbolo N R: 11-38-48/20-51/53-62-65-67 S: (2-)9-16-29-33-36/37-61-62 Clasificación de Peligros NU: 3 Grupo de Envasado NU: II CE:

VEASE AL DORSO INFORMACION IMPORTANTE



ICSC: 0279	Preparada en el Contexto de Cooperación entre el IPCS y la Comisión de las Comunidades Europeas © CCE, IPCS, 2006

Fichas Internacionales de Seguridad Quimica

HEXANO **ICSC: 0279**

DATOS IMPORTANTES	**ESTADO FISICO; ASPECTO** Líquido incoloro volátil, de olor característico. **PELIGROS FISICOS** El vapor es más denso que el aire y puede extenderse a ras del suelo; posible ignición en punto distante. **PELIGROS QUIMICOS** Reacciona con oxidantes fuertes, originando peligro de incendio y explosión. Ataca algunos plásticos, caucho y revestimientos **LIMITES DE EXPOSICION** TLV (como TWA): 50 ppm; 176 mg/m^3 (piel) BEI (ACGIH 2004). LEP UE: 72 mg/m^3, 20 ppm como TWA (UE 2006) MAK: Riesgo para el embarazo: grupo C (DFG 2004)	**VIAS DE EXPOSICION** La sustancia se puede absorber por inhalación del vapor y por ingestión. **RIESGO DE INHALACION** Por evaporación de esta sustancia a 20°C se puede alcanzar bastante rápidamente una concentración nociva en el aire. **EFECTOS DE EXPOSICION DE CORTA DURACION** La sustancia irrita la piel. La ingestión del líquido puede originar aspiración dentro de los pulmones con riesgo de neumonitis química. La exposición a altas concentraciones podría causar disminución del estado de alerta. **EFECTOS DE EXPOSICION PROLONGADA O REPETIDA** El contacto prolongado o repetido con la piel puede producir dermatitis. La sustancia puede afectar al sistema nervioso periférico, dando lugar a polineuropatías. La experimentación animal muestra que esta sustancia posiblemente cause efectos tóxicos en la reproducción humana.
PROPIEDADES FISICAS	Punto de ebullición: 69°C Punto de fusión: -95°C Densidad relativa (agua = 1): 0.7 Solubilidad en agua, g/100 ml a 20 °C: 0.0013 Presión de vapor, kPa a 20°C: 17 Densidad relativa de vapor (aire = 1): 3.0	Densidad relativa de la mezcla vapor/aire a 20°C (aire = 1): 1.3 Punto de inflamación: -22°C (c.c.) Temperatura de autoignición: 225°C Límites de explosividad, % en volumen en el aire: 1.1-7.5 Coeficiente de reparto octanol/agua como log Pow: 3.9
DATOS AMBIENTALES	Esta sustancia es tóxica para los organismos acuáticos.	

NOTAS

Está indicado examen médico periódico dependiendo del grado de exposición.

Ficha de emergencia de transporte (Transport Emergency Card): TEC (R)-30S1208
Código NFPA: H 1; F 3; R 0;

INFORMACION ADICIONAL

FISQ: 3-131 HEXANO	Los valores LEP pueden consultarse en línea en la siguiente dirección: http://www.insht.es/

ICSC: 0279 **HEXANO**

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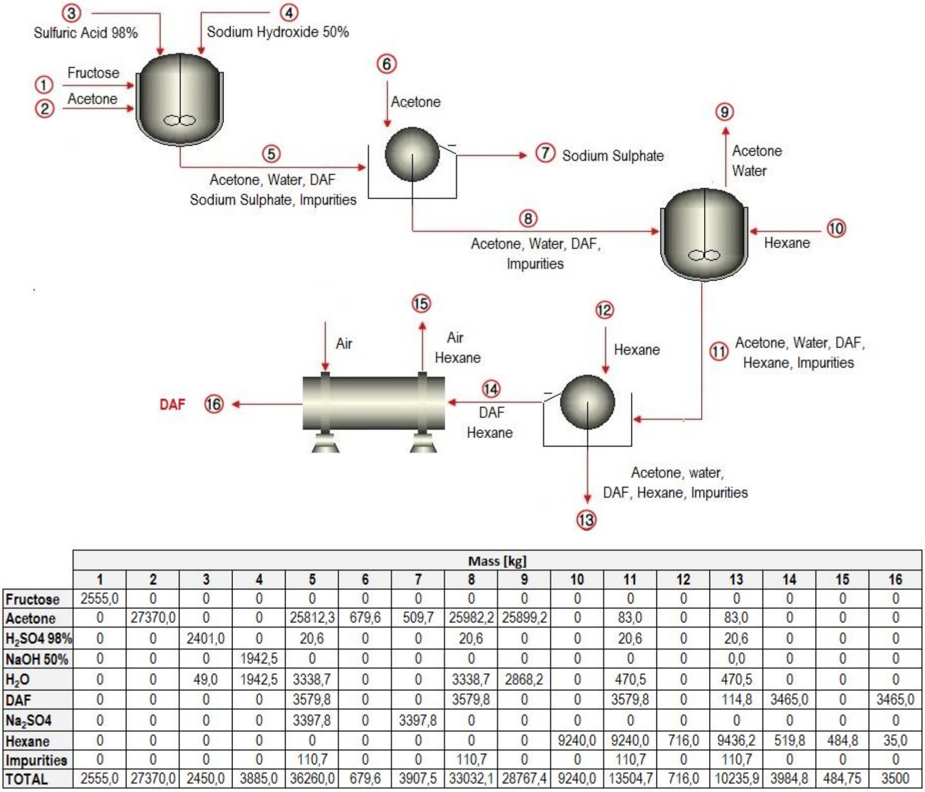
APPENDIX 2: MATERIAL BALANCE



	Mass [kg]															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Fructose	2555,0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acetone	0	27370,0	0	0	25812,3	679,6	509,7	25982,2	25899,2	0	83,0	0	83,0	0	0	0
H_2SO4 98%	0	0	2401,0	0	20,6	0	0	20,6	0	0	20,6	0	20,6	0	0	0
NaOH 50%	0	0	0	1942,5	0	0	0	0	0	0	0	0	0,0	0	0	0
H_2O	0	0	49,0	1942,5	3338,7	0	0	3338,7	2868,2	0	470,5	0	470,5	0	0	0
DAF	0	0	0	0	3579,8	0	0	3579,8	0	0	3579,8	0	114,8	3465,0	0	3465,0
Na_2SO4	0	0	0	0	3397,8	0	3397,8	0	0	0	0	0	0	0	0	0
Hexane	0	0	0	0	0	0	0	0	0	9240,0	9240,0	716,0	9436,2	519,8	484,8	35,0
Impurities	0	0	0	0	110,7	0	0	110,7	0	0	110,7	0	110,7	0	0	0
TOTAL	2555,0	27370,0	2450,0	3885,0	36260,0	679,6	3907,5	33032,1	28767,4	9240,0	13504,7	716,0	10235,9	3984,8	484,75	3500

Figure 20. Global material balances

APPENDIX 2: MANUAL OF CALCULUS

SIZING OF THE EQUIPMENTS

Calculus has been realized for to know the approximate size that the vessels, the agitation systems and the barometric condenser will have to have. For what it concerns to the coils of the container V-01, the rotating filters RF-01 and RF-02 and to the dryer, an already existing model in the market has been selected.

V-01 and V-02

The maximum contained of the vessel V-01 will be:

	Mass [kg]	Volume [m^3]
Fructose	27370	-
Acetone	2555	34.6
H_2SO_4 98%	2450	1.3
NaOH 50%	3885	2.9

Table 25. Contained of Vessel V-01

Supposing that the volumes are additives, in the worst of the cases, the volumetric maximum content of the vessel will be of 38.9 m^3.

Knowing that inside of the tank they will find also the system of agitation and two coils and that this one has to present between 15 and one 20 % of volume free by the fact of working with volatile compounds as the acetone, following dimensions have been attributed to it.

Diameter [m]	3.20
Section [m2]	8.00
Height [m]	5.50
Wall thickness [m]	0.01
Capacity [m3]	44.20

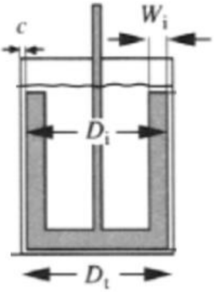
Table 26: Specifications of V-01

Agitation system

Since already it has been commented in the section of description of the equipments, two types of agitator have been selected for each of the tanks that are needed (V-01 and V-02).

The dimensions of the impellers are directly related to the size of the vessel, for what the dimensions needed for every type of agitator will be common in both vessels, since these also are equal.

In case of the paddle agitator, the length of the same ones is equivalent to 1/3 of the diameter of the container. For the agitator of anchor, the dimensions come given by the following relations:



Dt/Di	c/Di	Wi/Di
1.02	0.001	0.01

Table 27. Characteristics of an anchor stirrer

Definitely, it is concluded:

Anchor stirrer	**Impeller diameter [m]**	3.10
	Height [m]	3.10
	Thickness [m]	0.32
	Agitation speed [rpm]	12
	Agitation power [kW]	3.7
Blades stirrer	**Impeller diameter [m]**	2.2
	Paddle length [m]	1.10
	Agitation speed [rpm]	60
	Agitation power [kW]	2.3

Table 28. Characteristics of agitation system

The power of agitation will depend on the fluid to waving and of the turn speed of the impeller. Since the anchors agitators turn to very low speeds, maximum up to 2m/s, and in both containers the fluid to waving is different, it is necessary to calculate the power of agitation for each of the agitators.

First it is necessary to calculate the number of Reynolds. It is expressed like:

$$Re = \frac{\rho\, D^2\, N}{\mu}$$

Below, the number of power (Np) will be determined. For definition, it is directly related to the Reynolds number. The parameters b and x will depend on the type of regime of circulation:

$$Np = b\, Re^x$$

Regime	B	x
Laminar	35	-1
Turbulent	2	0

Table 29. Parameters of agitation dependents of the regime

Finally, the power of the agitator is determined from the following empirical correlation:

$$P = Np\, \rho\, N^3 D^5$$

With all this, the following values are obtained:

	POWER [kW]	
	V-01	**V-02**
Anchor	3,7	3,1
Paddles	2,3	2,2

Table 30. Power of agitation

Barometric condenser

To be able to initiate the design of the heat interchanger is necessary to know first the heat quantity exchanged and the necessary area of exchange.

It is calculated the heat necessary for to condense a certain flow rate of vapor by means of the latent heat:

$$Q = w_v \cdot \lambda$$

$$Q = \frac{28087{,}8 kg}{3h} \cdot 6{,}98 \cdot 10^5 \frac{J}{kg} = 6{,}54 \cdot 10^9 \frac{J}{h}$$

Now already it is possible to calculate the needed flow of coolant. It has been selected as coolant a mixture of water and glycol to 60%, the properties physicist - chemistry of which are collected in the Appendix B.

$$Q = w_r \cdot C_{p,r} \cdot \Delta T = w_r \cdot C_{p,r} \cdot (t_s - t_e)$$

Therefore:

$$w_r = \frac{Q}{C_{p,r} \cdot (t_s - t_e)} = \frac{6{,}54 \cdot 10^9 \frac{J}{h}}{2900 \frac{J}{kg \cdot K} \cdot \big(0 - (-35)\big)K} = 64{,}4 \cdot 10^3 \frac{kg}{h}$$

It is important to comment that this value corresponds to the flow of coolant necessary minimum, nevertheless, it will work with a flow rate that allows to keep a linear speed of the fluid of 1.4 m /s. This way, it is improved the heat transfer and it is made sure that some change in the current of steam supply should not carry not condensed steam.

Like it has been commented in the description of the process, the heat interchanger has been designed by means of the method Kern. This method consists of an iterative process that it begins supposing a value of the global coefficient of heat transfer and by means of the resolution of the mathematical model ending up with the calculation of a new value of the coefficient. If the supposed value and the calculated one look alike, the hypothesis can give valid. If it is not, a new iteration is realized where the calculated coefficient happens to be the supposed coefficient.

Below, the calculations corresponding to the last iteration of the process are presented.

1. A value for the global coefficient of heat transfer is supposed.

$$U_{suspuesto} = 710 \frac{W}{m^2 \cdot K}$$

2. The necessary area of exchange is calculated:

$$\Delta T_1 = T_s - t_e = 40℃ - (-35℃) = 75℃$$

$$\Delta T_2 = T_e - t_s = 40℃ - 0℃ = 40℃$$

$$Q = U \cdot A \cdot \Delta T_{ml} = U \cdot A \cdot \frac{\Delta T_2 - \Delta T_1}{ln\frac{\Delta T_2}{\Delta T_1}} \rightarrow A = \frac{Q}{U \cdot \frac{\Delta T_2 - \Delta T_1}{ln\frac{\Delta T_2}{\Delta T_1}}} = \frac{6{,}54 \cdot 10^9 \frac{J}{h} \cdot \frac{1h}{3600s}}{733 \frac{W}{m^2 \cdot K} \cdot \frac{(75-40)K}{ln\frac{75℃}{40℃}}}$$

$$A = 44{,}5\, m^2$$

3. Commercial length, radius and thickness for pipes in interchangers are chosen and it is calculated the area of every pipe. That way, by means of the total area and the tubular area, it is possible to obtain the number of pipes that the interchanger has to contain:

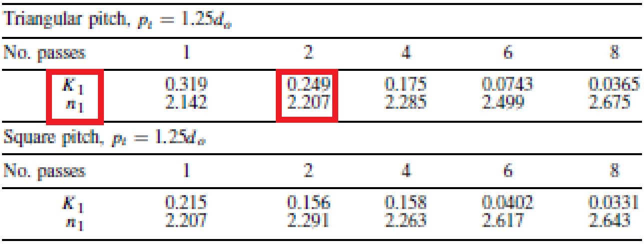
- $L = 1{,}83m$
- $D_{int,t} = ¾\text{ in} = 0{,}01905\text{ m}$
- $e = 0{,}0032m$

$$A_{TUBE} = \pi \cdot D_{ext,t} \cdot L = 2\pi \cdot (0{,}01905 + 0{,}0032 \cdot 2)m \cdot 1{,}83m = 0{,}29m^2$$

$$N_T = \frac{A}{A_{TUBE}} = \frac{44{,}5\, m^2}{0{,}29m^2} = 152\ tubes$$

4. Below, it is calculated the diameter of the tubular bundle for a few tubes placed with triangular arrangement and for two passes by tube:

$$D_b[mm] = D_{ext}[mm] \cdot \left(\frac{N_T}{K_1}\right)^{\frac{1}{n1}}$$



Triangular pitch, $p_t = 1.25d_o$					
No. passes	1	2	4	6	8
K_1 n_1	0.319 2.142	0.249 2.207	0.175 2.285	0.0743 2.499	0.0365 2.675
Square pitch, $p_t = 1.25d_o$					
No. passes	1	2	4	6	8
K_1 n_1	0.215 2.207	0.156 2.291	0.158 2.263	0.0402 2.617	0.0331 2.643

Table 31. Parameters for tubular bundle design

$$D_b = (0{,}01905 + 2 \cdot 0{,}0032)mm \cdot \left(\frac{152}{0{,}249}\right)^{\frac{1}{2{,}207}} = 466\ mm$$

5. From the diameter of the tubular bundle it can be found the difference between this one and the internal diameter of the shell.

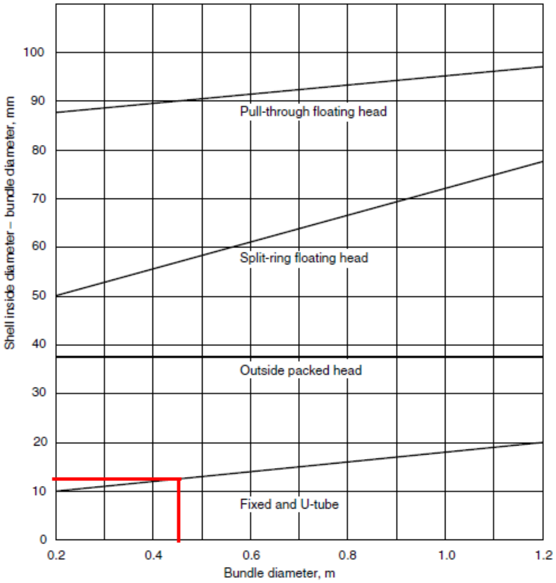


Table 32. Relation tubular bundle - size of shell

The internal diameter of the shell is obtained this way:

$$D_{int,c} - D_b = 12mm \rightarrow D_{int,c} = 12\ mm + D_b = 12\ mm + 466mm = 478\ mm$$

6. With the choice of a typical thickness of shell like it can be 4,8mm, an external diameter of shell is obtained of:

$$D_{ext,c} = D_{int,c} + 2 \cdot e = 478mm + 2 \cdot 4{,}8mm = 487mm = 4{,}9\ m$$

7. To continue, the total section of step for two pass of tubes is calculated. Since it has been said previously, the linear speed of the cooling one is fixed inside the pipes in 1.4 m/s.

$$S_t = \pi \cdot \frac{D_{ext,t}^2}{4} = \pi \cdot \frac{(0{,}01905 + 0{,}0032 \cdot 2)^2 m^2}{4} = 5{,}1 \cdot 10^{-4} m^2$$

$$N_{T,pass} = \frac{N_T}{2} = \frac{152\ tubes}{2} = 76\ tubes\ by\ pass$$

$$S_{TOTAL} = N_{T,pass} \cdot S_t = 76\ tubes \cdot 5{,}1 \cdot 10^{-4} m^2 = 0{,}039 m^2$$

$$v_r = \frac{w_r}{S_{TOTAL} \cdot \rho} \rightarrow w_r = v_r \cdot S_{TOTAL} \cdot \rho = 1{,}4\ \frac{m}{s} \cdot 0{,}039 m^2 \cdot 1115 \frac{kg}{m^3} = 60{,}4\ \frac{kg}{s}$$

It is appreciated as the flow rate of coolant obtained is quite superior to the necessary minimum. Since the range of temperatures to which the coolant works might carry problems of freezing in the exterior part of the tubes, it has tried to modify the temperature of entry of the same one to the interchanger. Nevertheless, this involves a major area of exchange and, in consequence, a major number of pipes, for what finally it should return to increase the flow of cooling to obtain a speed of the fluid that favors the heat exchange. For all this and not having been possible to find a balance that compensates these differences, finally the values have been adopted proposed like the most suitable.

8. Below, it tries to calculate the individual coefficient of heat transfer of the cooling one. For it, the value of the number of Reynolds, the factor of heat transfer and the number of Prandlt are needed.

$$Re = \frac{\rho \cdot v_r \cdot D_{int,t}}{\mu_r} = \frac{1115\frac{kg}{m^3} \cdot 1{,}4\ \frac{m}{s} \cdot 0{,}01905m}{0{,}009\frac{kg}{s \cdot m}} = 3304$$

Is observed that there is not obtained a value of Reynolds that corresponds to a turbulent regime of circulation. Though that a laminar regime is not the one that more favors the heat transfer, there is obtained that on having tried to force this type of regime playing with sections and lengths of tubes and with flow rate of coolant, the speed of the coolant increases too much producing the same presented previously problems.

$$Pr = \frac{C_{p,r} \cdot \mu_r}{k_r} = \frac{2900\ \frac{J}{kg \cdot K} \cdot 0{,}009\frac{kg}{s \cdot m}}{0{,}45\frac{J}{s \cdot m \cdot K}} = 58$$

$$\frac{L}{D_{int,t}} = \frac{1{,}83m}{0{,}01905m} = 96$$

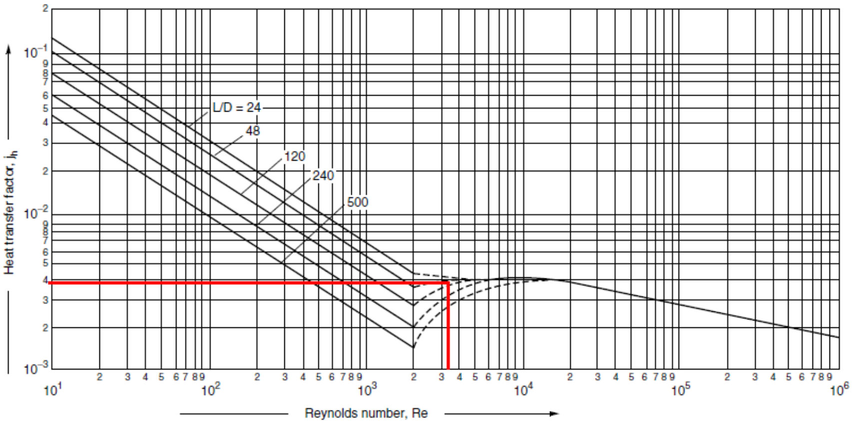


Figure 21. Factor of heat transfer depending on the Reynolds

$$j_h = 3{,}9 \cdot 10^{-3}$$

$$Nu = \frac{h_i \cdot D_{int,t}}{k_r} = j_h \cdot Re \cdot Pr^{\frac{1}{3}} \cdot \left(\frac{\mu_r}{\mu_w}\right)^{0,14} \rightarrow h_i = \frac{j_h \cdot Re \cdot Pr^{\frac{1}{3}} \cdot \left(\frac{\mu_r}{\mu_w}\right)^{0,14} \cdot k_r}{D_{int,t}}$$

$$h_i = \frac{3,9 \cdot 10^{-3} \cdot 3304 \cdot 58^{\frac{1}{3}} \cdot \left(\frac{0,009\frac{kg}{s \cdot m}}{0,001\frac{kg}{s \cdot m}}\right)^{0,14} \cdot 0,45\frac{J}{s \cdot m \cdot K}}{0,018m} = 1602\frac{J}{s \cdot m^2 \cdot K}$$

9. For triangular arrangements, it is recommended that the tube pitch (Pt) should be 1,25 times the external diameter of the tubes. It is advised also that the distance between baffles should be 45 % of the inside diameter of the shell. With it, it is calculated the cross area, the linear speed of the steam and the equivalent diameter.

$$A_s = \frac{\left(p_t - D_{ext,t}\right) \cdot D_{int,c} \cdot l_B}{p_t} = \frac{(0,03181 - 0,02545)m \cdot 0,48m \cdot 0,45 \cdot 0,48m}{0,03183m} = 0,92m^2$$

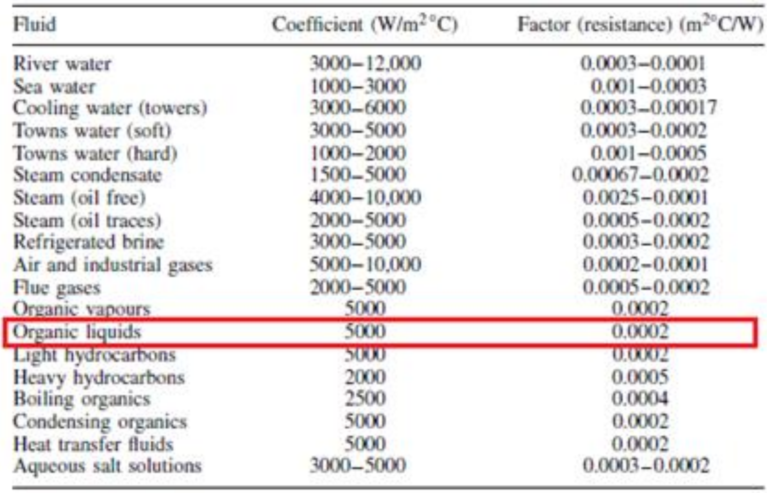
$$G_s = \frac{w_v}{A_s} = \frac{28087,8\frac{kg}{h} \cdot \frac{3h}{3600s}}{0,92m^2} = 25,5\frac{kg}{s \cdot m^2}$$

$$D_{eq} = \frac{4 \cdot \left(\frac{p_t}{2} \cdot 0,87 \cdot p_t - \frac{1}{2}\pi\frac{D_{ext,t}^2}{4}\right)}{\frac{\pi \cdot D_{ext,t}}{2}} = \frac{4 \cdot \left(\frac{0,03181m}{2} \cdot 0,87 \cdot 0,03181m - \frac{1}{2}\pi\frac{0,02545^2m^2}{4}\right)}{\frac{\pi \cdot 0,02545m}{2}}$$

$$D_{eq} = 0,037m$$

10. Finally, considering despicable the resistance to the heat transfer in the steam phase due to his high speed, it is calculated the global coefficient of heat transfer:

$$\frac{1}{U_{calculated}} = \frac{D_{ext,t} ln\left(\frac{D_{ext,t}}{D_{int,t}}\right)}{2 \cdot k_w} + \frac{D_{ext,t}}{D_{int,t}} \cdot \frac{1}{h_{id}} + \frac{D_{ext,t}}{D_{int,t}} \cdot \frac{1}{h_i}$$



Fluid	Coefficient (W/m^2°C)	Factor (resistance) (m^{2}°C/W)
River water	3000–12,000	0.0003–0.0001
Sea water	1000–3000	0.001–0.0003
Cooling water (towers)	3000–6000	0.0003–0.00017
Towns water (soft)	3000–5000	0.0003–0.0002
Towns water (hard)	1000–2000	0.001–0.0005
Steam condensate	1500–5000	0.00067–0.0002
Steam (oil free)	4000–10,000	0.0025–0.0001
Steam (oil traces)	2000–5000	0.0005–0.0002
Refrigerated brine	3000–5000	0.0003–0.0002
Air and industrial gases	5000–10,000	0.0002–0.0001
Flue gases	2000–5000	0.0005–0.0002
Organic vapours	5000	0.0002
Organic liquids	5000	0.0002
Light hydrocarbons	5000	0.0002
Heavy hydrocarbons	2000	0.0005
Boiling organics	2500	0.0004
Condensing organics	5000	0.0002
Heat transfer fluids	5000	0.0002
Aqueous salt solutions	3000–5000	0.0003–0.0002

Figure 22. Table Individual coefficients of heat transfer

$$\frac{1}{U_{calculated}} = \frac{0{,}02545m \cdot ln\left(\frac{0{,}02545m}{0{,}01905m}\right)}{2 \cdot 14\frac{W}{m \cdot K}} + \frac{0{,}02545m}{0{,}01905m} \cdot \left(\frac{1}{5000\frac{W}{m^2 \cdot K}} + \frac{1}{1602\frac{W}{m^2 \cdot K}}\right)$$

$$\frac{1}{U_{calculated}} = 0{,}001706\frac{m^2 \cdot K}{W}$$

$$U_{calculated} = 733\frac{W}{m^2 \cdot K}$$

Due to $\mathrm{U_{calculated}} \approx \mathrm{U_{supposed}}$

It has given the values calculated for valid. Due to in these conditions, theoretically, the heat exchange should be sufficient, it is decided to lengthen the length of the tubes to 2m for more safety.

As for the baffles that the interchanger must contain:

$$E_d = 0{,}45 \cdot D_{int,c} = 0{,}45 \cdot 0{,}48m = 0{,}22m$$

$$D_d = D_{int,c} - \frac{1}{16} = 0{,}42m$$

$$N_B = \frac{L}{E_d} = \frac{2\ m}{0{,}22} = 9\ baffles$$

Barometric column design

For the design of the barometric column, it has been born in mind that it is recommended that in internal side it is kept a speed of the fluid of approximately 0.98 m/s.

Therefore, knowing the flow rate of liquid that must be removed of the column for to keep constant the height of liquid, it is calculed its diameter:

$$q = \frac{w}{\rho} = \frac{2{,}6\ kg/s}{0{,}9 \cdot 790 \frac{kg\ Ac.}{m^3} + 0{,}1 \cdot 1000\ \frac{kg\ H_2O}{m^3}} = 3{,}2 \cdot 10^{-3} \frac{m^3}{s}$$

$$q = v_{H_2O} \cdot S_{col} = v_{H_2O} \cdot \frac{\pi \cdot {D_{col}}^2}{4} \rightarrow D_{col} = \sqrt{\frac{q \cdot 4}{v_{H_2O} \cdot \pi}} = \sqrt{\frac{3{,}2 \cdot 10^{-3} \frac{m^3}{s} \cdot 4}{0{,}98 \frac{m}{s} \cdot \pi}} = 0{,}065m$$

As for the height of the column, following equation of Bernoulli:

$$z_1 + \frac{P_1}{\rho \cdot g} + \frac{{v_1}^2}{2 \cdot g} = z_2 + \frac{P_2}{\rho \cdot g} + \frac{{v_2}^2}{2 \cdot g}$$

Considering despicable the term of kinetic energy:

$$z_1 + \frac{P_1}{\rho \cdot g} = z_2 + \frac{P_2}{\rho \cdot g}$$

$$\Delta z = \frac{P_2 - P_1}{\rho \cdot g} = \frac{44572Pa}{\left(0{,}9 \cdot 790 \frac{kg\ Ac.}{m^3} + 0{,}1 \cdot 1000\ \frac{kg\ H_2O}{m^3}\right) \cdot 9{,}8 \frac{m}{s^2}} = 5{,}6m$$

It is recommended to add an excess of height to the column of approximately 2,5ft (0,8m) to assure that its low part is always plunged and that the air inlet is impossible. Therefore, a final height of column is obtained of:

$$z_{col} = 5{,}6m + 0{,}8m = 6{,}4m$$

CALCULATION OF THE TIMES OF OPERATION

Coolings

For the calculation of the necessary time to carry out the stages of cooling the following procedure has followed:

1. To suppose a value of the global coefficient of heat transfer.
2. To calculate the area of contact that is had in every case. Due to that the coolant circulates along the jacketed of the vessels, the area of contact has been calculated as the lateral area of the tank that corresponds with the height of the liquid that exists in his interior.
3. To calculate the total heat to extracting of the system.
4. To fix a temperature of entry of the coolant.
5. Since one works in discontinuously and the driving force of the heat exchange, the difference of temperature between liquid and coolant, is decreasing, the calculations are realized with an intermediate temperature of liquid between the initial and the wished final.
6. Having in tells the section of step of the cooling fluid across the jacketed (0,05m2) and that the speed of this one has to be of between 1,5-2 m/s, there is calculated the flow of coolant maximum.
7. By means of the maximum flow rate, the final temperature of the coolant is calculated.
8. Finally, the heat flow that the coolant is capable of extracting can be calculated and, in consequence, the total time needed to extract the wished heat.

Then, there appear the results obtained for each of the stages of cooling that are carried out along the process:

	COOLING 1	**COOLING 2**	**COOLING 3**
Mass [kg]	29925,0	32375,0	13504,7
Q [J]	$9{,}6\cdot10^{8}$	$1{,}0\cdot10^{9}$	$1{,}8\cdot10^{9}$
A [m²]	43,3	44,9	17,8
U [W/(m²·K)	300	300	300
te [ºC]	-35	-35	-35
T [ºC]	12,5	12,5	30
W_{ref} [kg/s]	22	22	22
Ts [ºC]	-26	-26	-30
t [h]	0,5	0,5	1,5

Table 33. Calculus of coolings

Heatings

For the stages of heating, it has been decided to use as heating fluid water steam of half a pressure to a temperature of entry of 143ºC. To calculate the necessary time to carry out the heating of the liquid, the balance sheet of energy has been realized in not stationary condition of the system.

$$\rho \cdot C_p \cdot V \cdot \frac{dT}{dt} = U \cdot A \cdot (T_c - T) \xrightarrow[\rho \cdot V = M]{} M \cdot C_p \cdot \frac{dT}{dt} = U \cdot A \cdot (T_c - T)$$

$$\frac{dT}{T_c - T} = \frac{U \cdot A}{M \cdot C_p} \cdot dt$$

$$\int_{T_0}^{T} \frac{dT}{T_c - T} = \frac{U \cdot A}{M \cdot C_p} \cdot \int_0^t dt \rightarrow ln \frac{T_c - T}{T_c - T_0} = -\frac{U \cdot A}{M \cdot C_p} \cdot t$$

$$t = -\frac{ln \frac{T_c - T}{T_c - T_0}}{\frac{U \cdot A}{M \cdot C_p}}$$

The obtained results are:

	HEATING 1	HEATING 2	HEATING 3
M [kg]	32375,0	33032,1	13504,7
T_0 [ºC]	5	5	40
T [ºC]	20	40	60
T_c [ºC]	143	143	143
A [m^2]	43,3	48,7	18
U [W/(m^2·K)	375	375	375
C_p [J/(kg·K)]	2141,8	2141,8	2387,6
t [h]	0,1	0,3	0,3
Q [W]	$2{,}1\cdot10^6$	$2{,}2\cdot10^6$	$6{,}25\cdot10^5$
λ [J/kg]	$2{,}26\cdot10^6$	$2{,}26\cdot10^6$	$2{,}26\cdot10^6$
W_v [kg/s]	0,9	1,0	0,3

Table 34. Calculus of heatings

Adding stages

For the calculation of the minimal time necessary for the addition of the sulfuric acid and the hydroxide of sodium, it has followed the same procedure that for the stages of cooling. Nevertheless, in these cases, the heat to withdrawing has to be calculated in agreement by the enthalpies of dissolution and of reaction.

On having added the sulfuric acid, this one dissolves in the acetone. His dissolution is an exothermic process. By means of the circulation of coolant, it has to be able to extracting the heat quantity produced by the dissolution of the acid to be able like that to keep the constant temperature. The total heat to extracting is:

$$Q_{H2SO4} = \frac{0{,}98 \cdot m_{H2SO4}}{M_{H2SO4}} \cdot \Delta H_{diss} = \frac{2450kg}{98\,\frac{kg}{kmol}} \cdot 96000\,\frac{kJ}{kmol} = 2{,}4 \cdot 10^6 kJ$$

On having added the sodium hydroxide, two things happen: this one dissolves exothermically and, in addition, it reacts exothermically also with the sulfuric already present acid in the medium.

$$H_2SO_4 + 2\ NaOH \rightarrow Na_2SO_4 + H_2O$$

Therefore, the total heat to extracting by means of the circulation of coolant is:

$$Q_{NaOH} = \frac{0{,}5 \cdot m_{NaOH}}{M_{NaOH}} \cdot \left(\Delta H_{diss} + \frac{1\ mol\ Na_2SO_4}{2\ mol\ NaOH} \cdot \frac{\Delta H_r}{1\ mol\ Na_2SO_4}\right)$$

$$Q_{NaOH} = \frac{0{,}5 \cdot 3885kg}{40\frac{kg}{kmol}} \cdot \left(43000\frac{kJ}{kmol} + \frac{1\ kmol\ Na_2SO_4}{2\ kmol\ NaOH} \cdot \frac{692250\ kJ}{1\ kmol\ Na_2SO_4}\right) = 1{,}9 \cdot 10^7 kJ$$

In the next table the obtained results appear. It is necessary to remember that in case of the addition of the hydroxide of sodium, the circulation of coolant across the coils is activated and, therefore, is had a bigger area of contact.

	Addition of H2SO4	**Addition of NaOH**
Q [J]	$2{,}4 \cdot 10^9$	$1{,}9 \cdot 10^{10}$
A [m²]	43,3	44,9
U [W/(m²·K)	300	300
te [ºC]	-35	-35
T [ºC]	5	5
W_{ref} [kg/s]	22	100
Ts [ºC]	-28	-22
t [h]	1,4	6,5

Table 35. Adding stages

Concentration stage

The total mass of liquid that it is tried to evaporate is of 28767,4kg, of which 90% corresponds to acetone and the rest to water. An approximation of the latent heat of the evaporated mixture is estimated in:

$$\left.\begin{aligned} \lambda_{Acetone} &= 5{,}24 \cdot 10^5 \frac{J}{kg} \\ \lambda_{Water} &= 2{,}26 \cdot 10^6 \frac{J}{kg} \end{aligned}\right\} \lambda_{Mix} = 0{,}9 \cdot 5{,}24 \cdot 10^5 \frac{J}{kg} + 0{,}1 \cdot 2{,}26 \cdot 10^6 \frac{J}{kg} = 6{,}98 \cdot 10^5 \frac{J}{kg}$$

Therefore, the total necessary heat to carry out the evaporation is equivalent to:

$$Q_T = m \cdot \lambda_{Mix} = 28767{,}4kg \cdot 6{,}98 \cdot 10^5 \frac{J}{kg} = 2 \cdot 10^{10} J$$

If, again, the heat transfer is considered to be like bounding:

$$Q = U \cdot A \cdot (T_c - T) = 300\frac{W}{m^2 \cdot K} \cdot 48{,}7\, m^2 \cdot (143 - 40)K = 1{,}9 \cdot 10^6 \frac{J}{s}$$

$$t = \frac{Q_T}{Q} = \frac{2 \cdot 10^{10} J}{1{,}9 \cdot 10^6 \frac{J}{s}} \cdot \frac{1\, h}{3600\, s} = 3h$$

The needed flow rate of steam is:

$$w_v = \frac{Q_T}{\lambda_v} = \frac{1{,}9 \cdot 10^6 \frac{J}{s}}{2{,}26 \cdot 10^6 \frac{J}{kg}} = 0{,}84\frac{kg}{s}$$

Filtration stages

To determine the time of duration of the stages of filtration, it has taken like references the following heuristic ones:

For crystalline solids, like Na2SO4, it is recommended:

-Rotary speed: 0,33rpm

Difference from pressure of between 2-6 inches of mercury

In these conditions a speed of filtration of approximately 1220,7 kg / (m2 · h) is obtained. For softer and porous solids, like the DAF, speeds of filtration about 305,2 kg / (m2 · h) are obtained if it works at the following conditions:

-Rotary speed: 0,33rpm

Difference from pressure of between 18-25 inches of mercury

Taking this information as a reference, times of filtration of 1,3h for the filtration of DAF and of 0,6h for the filtration of the Na2SO4 are obtained. However, it has fixed the necessary time to the first filtration in 1,6h, to avoid thickness of cake too high.

Drying stage

The dried consists of the elimination of present liquid in a wet solid by evaporation by means of the contact of the solidwith a warm gas that provides the energy necessary for the evaporation. It is therefore a stage of transfer of material and energy simultaneously.

The driving force of the process is the saturation humidity of the air in the conditions of operation of the solvent to evaporating.

Since already it has been commented along the document, the speed of dried of the solid presents two periods: a speed period of dried constant, where it limits the heat transfer, and a period of variable speed, dependent on the solid - solvent system, where it limits the transfer of material.

Due to:

The necessary information to determine the speed of dried of the DAF in the variable period should decide experimentally.

The dryer turns and provokes the fall in waterfall of the wet solid, favoring the contact between the phases and the transfer of material.

It has been decided to determine only the initial speed of dried of the solid to obtain an estimation of the necessary time to carry out the stage.

In the period of constant speed, it is possible to calculate the speed of dried like:

By means of the use of the psychrometric diagram, the saturation temperature of the air in hexane in the conditions of work and the speed of dried are decided.

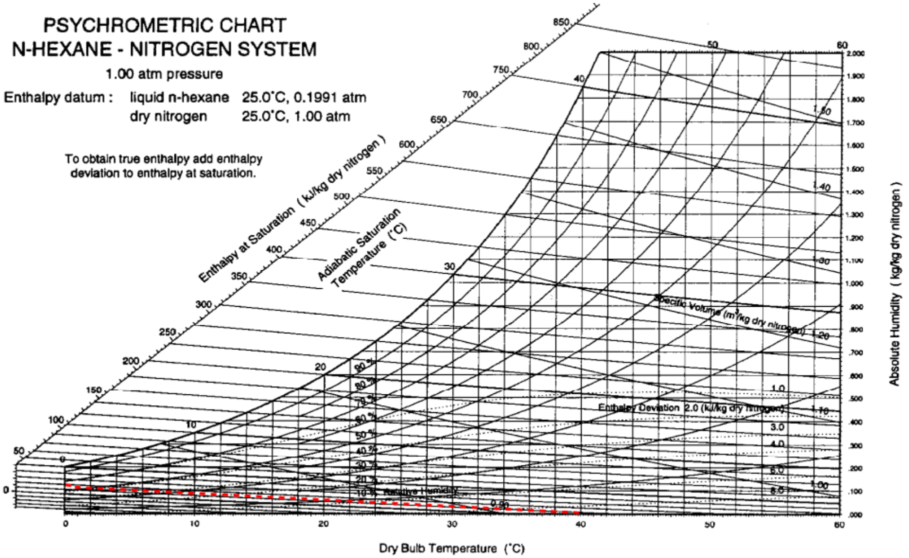


Figure 23. Psychrometric diagram hexane-air

$$n = 500\frac{W}{kg \cdot m \cdot K} \cdot 1.2m \cdot \frac{\left(40-(-5)\right)K}{334870\frac{J}{kg}} = 0.08\frac{kg}{s}$$

It is tried to evaporate 484,8 kg of hexane, therefore:

$$\mathrm{t} = \frac{484{,}8\ \mathrm{kg}}{0.08\frac{\mathrm{kg}}{\mathrm{s}}} \cdot \frac{1\ \mathrm{h}}{3600\ \mathrm{s}} = 2\mathrm{h}$$

Evidently, it is only an estimation and, provided that the speed of dried in case of being a constant would be raised, it thinks that with 24 hours the dried one would be completed.

Pipes design

There is calculated the minimal diameter of conduction of the pipelines according to the equation:

$$D = \sqrt{\frac{4 \cdot q}{\pi \cdot s}}$$

Speeds recommended for fluids in pipelines are used: for liquids for lines of conduction 1,5 m/s, for flows for gravity m/s and, both for air and for steam, 15 m/s.

Once obtained a value of diameter chooses as normalized diameter immediately top to the calculated one.

As for the calculation of the minimal thickness, one resorts to the expression:

$$e = \frac{P \cdot r}{\sigma_{LE}}$$

All the calculated thicknesses are lower than the catalogued, so it will be chosen most adapted according to the offer of the manufacturer.

APPENDIX 3: SPECIFICATION SHEETS

PROJECT: PRODUCTION OF DIACETONE-β-FRUCTOSE	**NUMBER OF EQUIPMENT:** V-01
	FUNCTION: Reactor

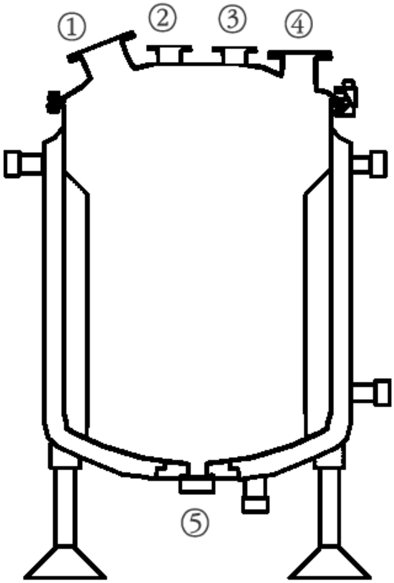
Functioning of the unit		
Feed [kg]	36260	
Temperature of operation [°C]	5-25	
Pressure of operation [bar]	1.013	
Design specifications		
Volume [m³]	44.2	
Wall thickness [mm]	10	
Diameter 1 [mm]	**	
Diameter 2 [mm]	**	
Diameter 3 [mm]	**	
Diameter 4 [mm]	**	
Diameter 5 [mm]	203.2	
Time of occupation [h]	17.1	
Painting	-	
Number of legs	4	
Supports	*	
Cylinder		
Height [m]	5.50	
Diameter [m]	3.20	
Materials		
Tank	Steel AISI 304L	
Flanges	*	
Tubes	*	
Screws	*	
Joints	*	
Inputs and outputs		
Number	**Function**	
1,2,3,4	Input	* To be specified by the manufacturer
5	Output	** Dependent of another equipments

Table 35. V-01 specifications sheet

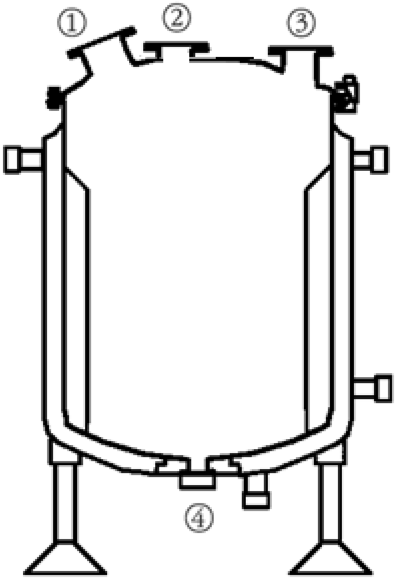
<table>
<tr><td colspan="2" rowspan="2">PROJECT: PRODUCTION OF DIACETONE-β-FRUCTOSE</td><td>NUMBER OF EQUIPMENT: V-02</td></tr>
<tr><td>FUNCTION: Crystallizer</td></tr>
<tr><td colspan="2">Functioning of the unit</td><td rowspan="26"> </td></tr>
<tr><td>Feed [kg]</td><td>33032.1</td></tr>
<tr><td>Temperature of operation [°C]</td><td>0-60</td></tr>
<tr><td>Pressure of operation [bar]</td><td>0.56-1.013</td></tr>
<tr><td colspan="2">Design specifications</td></tr>
<tr><td>Volume [m³]</td><td>44.2</td></tr>
<tr><td>Wall thickness [mm]</td><td>10</td></tr>
<tr><td>Diameter 1 [mm]</td><td>76.2</td></tr>
<tr><td>Diameter 2 [mm]</td><td>**</td></tr>
<tr><td>Diameter 3 [mm]</td><td>508.0</td></tr>
<tr><td>Diameter 4 [mm]</td><td>65.5</td></tr>
<tr><td>Time of occupation [h]</td><td>17.1</td></tr>
<tr><td>Painting</td><td>-</td></tr>
<tr><td>Number of legs</td><td>4</td></tr>
<tr><td>Supports</td><td>*</td></tr>
<tr><td colspan="2">Cylinder</td></tr>
<tr><td>Height [m]</td><td>5.50</td></tr>
<tr><td>Diameter [m]</td><td>3.20</td></tr>
<tr><td colspan="2">Materials</td></tr>
<tr><td>Tank</td><td>Steel AISI 304L</td></tr>
<tr><td>Flanges</td><td>*</td></tr>
<tr><td>Tubes</td><td>*</td></tr>
<tr><td>Screws</td><td>*</td></tr>
<tr><td>Joints</td><td>*</td></tr>
<tr><td colspan="2">Inputs and outputs</td></tr>
<tr><td>Number</td><td>Function</td></tr>
<tr><td>1,2</td><td>Input</td><td>* To be specified by the manufacturer</td></tr>
<tr><td>3,4</td><td>Output</td><td>** Dependent of another equipments</td></tr>
</table>

Table 36. V-02 specifications sheet

PROJECT: PRODUCTION OF DIACETONE-β-FRUCTOSE		**NUMBER OF EQUIPMENT: -**	
FUNCTION: To shake			
TYPE: Mechanical agitator			
Viscosity of the mixture [Pa·s] 0,0005		**Temperature of the mixture [°C]** 5-25	**Type of solid** Crystalls
Vessel, number of equipment V-01			
DESIGN DATA		**SPECIFICATIONS**	
Impeller, type	Anchor	**MATERIALS**	
Impeller diameter [m]	3.10	Vessel Steel AISI 304L	
Height [m]	3.10	Impeller Steel AISI 304L coated with polyester resine	
Thickness [m]	0.32		
Rotation speed [rpm]	12		
Power [kW]	3.7	**Rings gasket**	*
Location of the impeller in the vessel	Centered	**Other wet parts**	*
* To be specified by the manufacturer			
		Supports	*
		Cushions	*
		Gasket lubrication	*
		Engine	
		Type	*
		Nominal power [kW]	*

Table 37. Anchor agitator V-01 specifications sheet

PROJECT: PRODUCTION OF DIACETONE-β-FRUCTOSE		**NUMBER OF EQUIPMENT: -**	
FUNCTION: To shake			
TYPE: Mechanical agitator			
Viscosity of the mixture [Pa·s] 0,118 **Temperature of the mixture [°C]** 0-60 **Type of solid** Porous solid			
Vessel, number of equipment V-02			
DESIGN DATA		**SPECIFICATIONS**	
Impeller, type	Anchor	**MATERIALS**	
Impeller diameter [m]	3.10	Vessel Steel AISI 304L	
Height [m]	3.10	Impeller Steel AISI 304L coated with polyester resine	
Thickness [m]	0.32		
Rotation speed [rpm]	12		
Powder [kW]	3.1	**Rings gasket**	*
Location of the impeller in the vessel	Centered	**Other wet parts**	*
* To be specified by the manufacturer			
		Supports	*
		Cushions	*
		Gasket lubrication	*
		Engine	
		Type	*
		Nominal powder [kW]	*

Table 38. Anchor agitator V-02 specifications sheet

PROJECT: PRODUCTION OF DIACETONE-β-FRUCTOSE		**NUMBER OF EQUIPMENT: -**	
FUNCTION: To shake			
TYPE: Mechanical agitator			
Viscosity of the mixture [Pa·s] 0,0005 **Temperature of the mixture [°C]** 5-25 **Type of solid** Crystalls			
Vessel, number of equipment V-01			
DESIGN DATA		**SPECIFICATIONS**	
Impeller, type	Paddles	**MATERIALS**	
Impeller diameter [m]	2.20	Vessel	Steel AISI 304L
Rotation speed [rpm]	60	Impeller	Steel AISI 304L coated with polyester resin
Powder [kW]	2.3		
Location of the impeller in the vessel	Centered	**Rings gasket**	*
		Other wet parts	*
* To be specified by the manufacturer			
		Supports	*
		Cushions	*
		Gasket lubrication	*
		Engine	
		Type	*
		Nominal powder [kW]	*

Table 39. Paddle agitator V-01 specifications sheet

PROJECT: PRODUCTION OF DIACETONE-β-FRUCTOSE		**NUMBER OF EQUIPMENT: -**	
FUNCTION: To shake			
TYPE: Mechanical agitator			
Viscosity of the mixture [Pa·s] 0,118 **Temperature of the mixture [°C]** 0-60 **Type of solid** Porous solid			
Vessel, number of equipment V-02			
DESIGN DATA		**SPECIFICATIONS**	
Impeller, type	Paddle	**MATERIALS**	
Impeller diameter [m]	2.20	Vessel Steel AISI 304L	
Rotation speed [rpm]	60	Impeller Steel AISI 304L coated with polyester resin	
Powder [kW]	2.1		
Location of the impeller in the vessel	Centered	**Rings gasket**	*
		Other wet parts	*
* To be specified by the manufacturer			
		Supports	*
		Cushions	*
		Gasket lubrication	*
		Engine	
		Type	*
		Nominal powder [kW]	*

Table 40. Paddle agitator V-02 specifications sheet

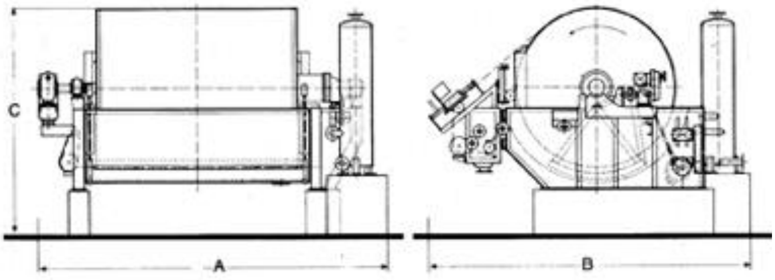
PROJECT: PRODUCTION OF DIACETONE-β-FRUCTOSE		**NUMBER OF EQUIPMENT:** RF-01	
		* To be specified by the manufacturer	
FUNCTION: To fíltrate the sodium sulfate			
TYPE: Rotatory			
SPECIFICATIONS		**OPERATION CONDITIONS**	
Model	TSF 9,2/20	**Temperature of the mixture [°C]**	5-25
Filter area [m^2]	5.8	**Type of solid:**	Crystalls
Drum diameter [mm]	920		
Drum width [mm]	2000		
Number of cells	14	**MATERIALS**	*
A [m]	3.80		
B [m]	2.05		
C [m]	1.70		
Operating weight [Tm]	4.1		
Energy consumption [kW]	1.5		
Turning [rpm]	0.33		
Pressure difference [Pa]	6,772.76 – 20,318.27		
Angle submerged [rad]	2.20		

Table 41. RF-01 specifications sheet

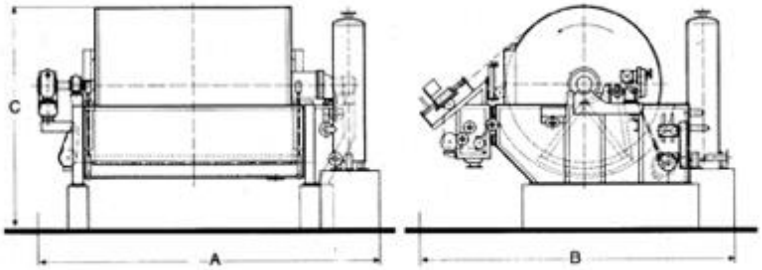
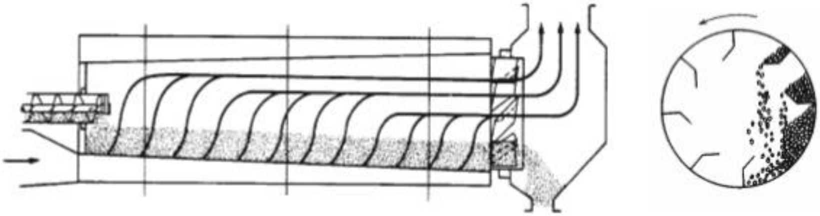
PROJECT: PRODUCTION OF DIACETONE-β-FRUCTOSE		**NUMBER OF EQUIPMENT:** RF-02	
FUNCTION: To fíltrate the DAF		* To be specified by the manufacturer	
TYPE: Rotatory			
SPECIFICATIONS		**OPERATION CONDITIONS**	
Model	TSF 13,1/25	**Temperature of the mixture [°C]**	0-25
Filter area [m^2]	10.0	**Type of solid:**	Porous solid
Drum diameter [mm]	1310		
Drum width [mm]	2500		
Number of cells	14	**MATERIALS**	*
A [m]	4.30		
B [m]	2.05		
C [m]	1.70		
Operating weight [Tm]	4.1		
Energy consumption [kW]	1.5		
Turning [rpm]	0.33		
Pressure difference [Pa]	60,954.82 – 84,659.47		
Angle submerged [rad]	2.20		

Table 42. RF-02 specifications sheet

PROJECT: PRODUCTION OF DIACETONE-β-FRUCTOSE

NUMBER OF EQUIPMENT: RD-01

FUNCTION: To dry



TYPE: Rotary

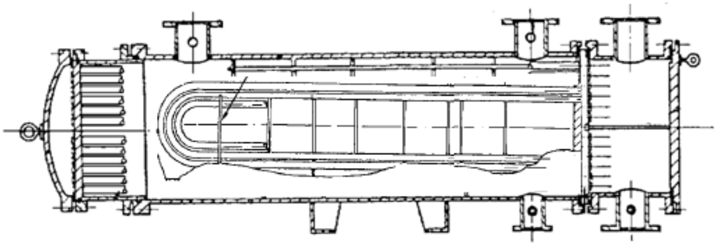
SPECIFICATIONS		OPERATION CONDITIONS	
Specifications [mm]	Φ1200x120000	**Temperature [°C]**	40
Ritate speed [rpm]	3- 8	**Pressure [bar]**	Until 1.013
Capacity [t/h]	2 - 6	**Type of solid**	Porous solid
Weight [t]	14.8		
Powder [kW]	11	**MATERIALS**	*

* To be specified by the manufacturer

Table 43. RD-01 specifications sheet

PROJECT	**PRODUCTION OF DIACETONE-β-FRUCTOSE**			
NUMBER OF EQUIPMENT	HE-01			
SERVICE	Total condenser			
TYPE	X	HORIZONTAL		VERTICAL
Functioning of the unit				
	TUBES SIDE		**SHELL SIDE**	
Circulating fluid	Mixture of glycol in water 60% (*COOLTRANS*)		Acetone and water	
	INPUT	**OUTPUT**	**INPUT**	**OUTPUT**
Steam [kg/h]	-	-	Variable	-
Coolant [kg/h]	193,200	193,200	-	-
Condensed [kg/h]	-	-	-	Variable
Condensed fluid [kg/h]	Acetone and wáter			
Molecular weight [kg/kmol]	18-58			
Latent heat [kJ/kg]	698			
Temperature [ºC]	38			
Pressure [bar]	0.56			
Exchanged heat [kW]	1900			
Global coefficient of heat transfer $[W/(m^2 \cdot K)]$	733			
Exchange area [m^2]	44.5			
SPECIFICATIONS				

	TUBES SIDE	**SHELL SIDE**
Pressure [bar]	0.56	0.56
Temperature [ºC]	38	38
Lenght [m]	2.00	*
Internal diameter [m]	0.019 (3/4 in)	0.48 (19.2 in)
External diameter [m]	0.025 (1 in)	0.49 (19.6 (in)
Number os passes	2	1
Number of tubes by pass	76	
Pass	TRIANGULAR	
Tubular bundle	X FIXED	Floating
	BAFFLES	
Type	Cross segmented	
Number	9	
Diameter [m]	0.42	
Spread between baffles [m]	0.22	
	INSULATING	
Thickness [mm]	70	



MATERIALS	
SHELL	Steel AISI 304L
TUBES	Steel AISI 304L
BAFFLES	Steel AISI 304L
INSULATING	Glass wool
NOTES:	
* To be specified by the manufacturer	

Table 44. HE-01 specifications sheet