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State of the art of lactose-free milk processes and design of a plate heat exchanger for heat treatment

Bibliografia dels processos de llet sense lactosa i disseny d'un bescambiador de calor de plaques per al tractament tèrmic

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Nunca consideres el estudio como una obligación, sino como una oportunidad para penetrar en el bello y maravilloso mundo del saber.

Albert Einstein

REPORT

CONTENTS

1. SUMMARY 5

2. RESUME 7

3. INTRODUCTION 9

4. OBJECTIVES 10

5. MILK 10

5.1. Lactose 11

5.1.1. Kinetic of hydrolysis reaction 11

5.1.2. Lactose concerns 13

5.1.2.1. Lactose intolerance 14

5.1.2.2. Lactose elimination 14

6. INDUSTRIAL PROCESSES FOR LACTOSE HYDROLYSIS 15

6.1. Acid hydrolysis 15

6.2. Lactose ultra-filtration 15

6.3. Enzymatic process 15

6.3.1. Free and soluble enzyme 16

6.3.2. Recuperation of enzyme 16

6.3.3. Injection of sterile enzyme 16

6.3.4. Immobilized enzyme 17

6.3.4.1. Supports 17

7. CHOICE OF THE BEST TECHNOLOGY 18

7.1. Selection of enzyme responsible for lactose hydrolysis 20
7.1.1. pH and temperature influence 21
7.1.2. Optimization of operational conditions 22
7.2. Economy 22
7.3. Social impact 23
8. HEAT TREATMENTS 23
8.1. Low Temperature Pasteurization (VAT) 25
8.2. Conventional pasteurization 25
8.3. Ultra High Temperature (U.H.T) 25
8.4. Uperization or injection 26
8.5. High Temperature Short Time (HTST) 27
8.5.1. Plate heat exchanger 28
8.5.2. Design of the plate heat exchanger 30
8.5.2.1. Numbers of industrial pasteurization 32
8.5.2.2. Mathematic modeling 34
8.5.2.3. Summary of results obtained for reaction 39
8.5.2.4. Pasteurization factor 42
9. SIMULATION 43
10. RESULTS AND DISCUSSION 45
11. CONCLUSIONS 47
12. REFERENCES AND NOTES 48
13. ACRONYMS 51
APPENDICES 55
APPENDIX 1: COMPETITIVE INHIBITION BY PRODUCT 57
APPENDIX 2: LIMIT VALUES OF MILK EMISSIONS 58
APPENDIX 3: COMPARISON OF IMMOBILIZATION METHOD 59
APPENDIX 4: STUDIES OF pH AND TEMPERATURE FOR LACTASE FROM *K.* 60

APPENDIX 5: LACTOSE HYDROLYSIS METHODS IN THE DAIRY INDUSTRY 61
APPENDIX 6: PRODUCT SHEET OF *LACTOSYM PURE* 62
APPENDIX 7: BUDGET OF LACTASE IMMOBILIZATION 66
APPENDIX 8: PROPYLENE GLYCOL 67
APPENDIX 9: GRAPHIC DETERMINATION OF F FACTOR 70
APPENDIX 10: KUMAR CONSTANTS 71
APPENDIX 11: Z AND D VALUES FOR STERILIZATION FACTOR 72
APPENDIX 12: MICROBIOGICAL LIMITS ESTABLISHED FOR COW'S MILK 73
APPENDIX 13: SIMULATION OF REGENERATION SECTION 74
APPENDIX 14: SIMULATION OF WARMING SECTION 75
APPENDIX 15: SIMULATION OF COOLING SECTION I 76
APPENDIX 16: SIMULATION OF COOLING SECTION II 77
APPENDIX 17: PLATE HEAT EXCHANGER 78
APPENDIX 18: PLATE HEAT EXCHANGER LAYOUT 79

1. SUMMARY

Lactose is a disaccharide contained in milk, in a 5% of its volume. The existence of this carbohydrate causes serious crystallization difficulties in the dairy industry, in addition to environmental problems. Moreover, it has to be taken into consideration that a 70% of the population is lactose intolerant.

The present document shows the results of a study carried out in order to determine the current condition of the lactose hydrolysis process to produce free-lactose milk. The study will base on the process variables and the optimal conditions of the enzymatic hydrolysis, always taking into account the extent of reaction. The reaction presents inhibition by product which should have to be minimized in order to reach an efficiency of the process higher than an 80%. Moreover, it will be determined economic and social factors involved in the selection of this kind of process, that make more suitable the use of soluble enzyme instead of the immobilized one.

On the other hand, a literature search has been done to study the different thermal treatments applicable to raw milk in order to deactivate the soluble enzyme that causes the lactose hydrolysis. It will be develop the mathematic modeling of a thermal treatment which will allow inactivating the enzymes and the micro-organisms presents in free-lactose milk for human consumption. In this case, HTST pasteurization (High Temperature Short Time) avoids a meaningful change of the flavor of milk and the loss of its nutritional components as calcium and vitamins source.

The modeling will be done with a plate heat exchanger of four sections to treat a flow of 6.500 L/h and a pasteurization temperature of 84ºC. The model will be validated by software simulation and compared to real data provided by the industry.

Keywords: enzymatic hydrolysis, lactose, lactase, inhibition, pasteurization, plate heat exchanger design

2. RESUM

La lactosa és un disacàrid present en un 5% en volum en la llet. La presència d'aquest carbohidrat provoca greus problemes de cristal·lització en la indústria làctia, mediambientals i d'intolerància que afecten a més del 70% de la població mundial.

En aquest treball es determinarà l'estat actual del processos d'hidròlisi per la producció de llet sense lactosa. S'aprofunditzarà en l'estudi de les variables de procés i condicions òptimes de la hidròlisis enzimàtica tenint en compte el grau d'avanç de la reacció. Una reacció que presenta problemes d'inhibició per producte que hauran de ser minimitzats per tal d'assolir un rendiment del procés superior al 80%. A més, es veuran els factors economicosocials que intervenen en la selecció d'aquest tipus de procés i que fan més viable la utilització de l'enzim soluble front a l'immobilitzat.

D'altra banda, per tal d'arribar al producte final s'estudiaran els diferents tractaments tèrmics aplicables a la llet per l'eliminació de l'enzim soluble responsable de la hidròlisi de la lactosa. Es procedirà a desenvolupar el model matemàtic d'un tractament tèrmic que permeti inactivar tant els enzims com els microorganismes presents en la llet deslactosada amb l'objectiu de fer-la apta per al consum humà. En aquest cas, la pasteurització HTST (High Temperature Short Time) que evita la alteració significativa del sabor de la llet y la pèrdua dels seus components nutricionals com ara la font de calci i de vitamines.

La modelització es durà a terme per un bescanviador de plaques de quatre seccions per tractar un cabal de llet de 6.500 L/h i una temperatura de pasteurització de 84ºC. Es comprovarà la validesa del model respecte a dades reals facilitades per una companyia del sector y una simulació del mateix.

Paraules clau: hidròlisi, lactosa, lactasa, inhibició, pasteurització, bescanviador de plaques, model matemàtic.

3. INTRODUCTION

70 % of the world population suffers from lactose intolerance due to a low activity or a deficiency of the enzyme *ß-galactosidase*, which is responsible for the hydrolysis of lactose in glucose and galactose. Hydrolyzing the lactose before avoids these problems of intolerance as well as those related to the crystallization in the production of dairy products and those derived from the high lacto serums contamination. Consequently, the need to manufacture lactose-free dairy products increases.

In spite of the fact that industrial process by means of enzymatic hydrolysis already exists at commercial level, there are many drawbacks that limit its performance. The commercial lactases suffer from inhibition by product preventing, in this way, that the extent of the reaction reaches the 100 %. Though, until now, dairy industries avoid or reduce this problem of inhibition resorting to the immobilization and later recovering the enzyme. Nowadays, it turns out to be more economically profitable to hydrolyze the lactose using a soluble enzyme.

In this sense, dairy companies prefer to use soluble enzymes instead of immobilized ones, for the simple fact it is more appropriate for them to say that the enzyme is not recovered but eliminated of the final product by means of thermal treatment. Customers feel safer knowing that the product they drink is as similar as possible to the one that goes out of the cow and does not contain substances that they consider to be strange.

On the other hand, to inactivate these enzymes and microorganisms a thermal processing is needed. Several pasteurization processes are present in the industry but not all preserved the quality of milk as its vitamins or calcium, producing a final product not suitable for human consumption.

The main aim of the present work is to establish the state of the art of the process of the lactose hydrolysis and to model a plate heat exchanger, which contributes to extend the shelf life of free-lactose milk. This design will be validated by comparison to real data provided by the industry.

4. OBJECTIVES

Considering the aforementioned facts, the present work aims these following objectives:

- To establish the state of the art of the process of the lactose hydrolysis to determine the influence of the process variables on the reaction as well as the by-product minimization.
- To study heat treatments applied to eliminate soluble enzymes to obtain milk completely suitable for human consumption.
- To develop a mathematical modeling of a thermal treatment for free-lactose milk.
- To validate the model by comparing it to a software simulation, the literature and real data from the dairy industry.

5. MILK

Milk is a liquid secreted by the mammary glands of the female mammals after the birth of the calf. Especially that of bovine origin is considered to be the best fresh food by its high nutritional value. The average composition of milk is approximately the described in Table 1.

Compound	Content (vol. %)
Water	87,0
Fats	3,8
Proteins	3,5
Minerals	1,0
Lactose	4,7

Table 1. Chemical composition of milk [1]

The water is the fluid where salts, the vitamins and the lactose are dissolved forming an emulsion with the fats and the proteins. These milk fats are easily digestible and they contain A, D and E vitamins which contribute to the flavor and the physical properties of dairy products.

On the other hand, the proteins of the milk, specially the casein, the albumen and the globulin provide an excellent and healthy source of amino acids which are essential for the development of the muscles. The minerals, basically calcium, phosphorus and magnesium, have an important nourishing contribution in milk as for the growth and the maintenance of the bones.

Lactose is the main sugar of milk being in charge of its sweetness. It will be absorbed by the intestine once hydrolyzed in glucose and galactose.

5.1. LACTOSE

Lactose is the main carbohydrate of milk. It is a disaccharide, a sugar formed by two monosaccharide joined: *D-glucose* and *D-galactose*. Mammal organisms produce an enzyme naturally, the lactase, able to hydrolyze the lactose enabling that these two sugars can be absorbed by the intestine.

5.1.1. Kinetic of lactose hydrolyses

The production of free-lactose milk is based on the natural reaction of transformation the lactose from milk represented in Figure 1.

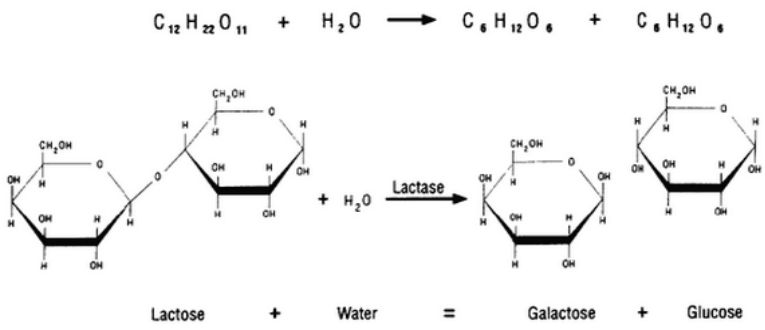

Figure 1. Enzymatic lactose hydrolysis [1].

Several enzymatic models are considered to determinate the kinetic parameters (see Table 2). The model that better fits the experimental data based on the mechanism of reaction suggested by Abuu-Reesh (2000) [2]. It is a Michaelis- Menten type with competitive inhibition for product, for galactose [3]. The inhibitor is fixed on the enzyme taking up the place of the substrat

and competing with this last for the active place (Appendix 1). This mechanism of the reaction is number two of Table 2.

	Kinetic model	Enzymatic mechanism	Ecuation
1	Michaelis-Menten without inhibition	E+S↔ ES → E+P	$V = \frac{Vmax\ Cs}{Km + Cs}$
2	Michaelis-Menten with competitive by product inhibition	E+S↔ ES → E+P E+P↔EP	$V = \frac{Vmax\ Cs}{Km(1 + Cp/Ki) + Cs}$
3	Michaelis-Menten with acompetitive by product inhibition	E+S↔ ES → E+P ES+P↔ESP	$V = \frac{Vmax\ Cs}{Km + Cs(1 + Cp/Ki)}$
4	Michaelis-Menten with no competitive by product inhibition	E+S↔ ES → E+P ES+P↔ESP E+P↔EP	$V = \frac{Vmax\ Cs}{Km(1 + Cp/Ki) + Cs(1 + Cp/Ki)}$

Table 2. Enzymatic models proposed for lactose hydrolysis [2], [4].

Though the comparison of the kinetic parameters obtained in several studies is difficult, due to changes in the experimental conditions established by some authors, in general terms, the values of K_m, K_i and V_{max} found appear in Table 3.

Parameter	*Value*
V_{max}	*0,0186 mol/(mg.min)*
K_m	*0,08 M*
K_i	*6,92 M*

Table 3. Estimated values of the lactose hydrolyses mechanism [2]

With,

K_m: Subtrate concentration when V_0 is a half of V_{max}. It is a measure of the affinity of the enzyme for substrate. As minor this K_m value is, major the affinity of the enzyme for the substrat is.

V_{max}: Maximum theoric velocity reached when all the active centres are occupied by the substrate (it is never really reached).

K_i: inhibitor constant, it is defined as the constant of disociation of the complex enzyme-inhibitor.

C_s: substrate concentration

C_p: product concentration

5.1.2. Lactose concerns

Milk is the nearest food to the nutritional perfection. Nevertheless, one of its components, the lactose causes technological, environmental and health problems for several reasons. Firstly, lactose is characterized for having a low sweetener and to be slightly soluble (19 g/100 mL into water to 20 °C) [5]. In the production of concentrated milk and ice creams, lactose presents problems of crystallization due to the formation of small crystals with a needle shape that give a disagreeable appearance to these products.

The hydrolysis of lactose in glucose and galactose improves the sweetener without increasing its caloric power, avoiding the phenomena of crystallization observed in the concentration or the storage of milk as well as in the production of ice creams. The reason is that the solubility of these sugars is higher than those of lactose. In addition, the high content of lactose in the whey derived from the manufacture of cheeses becomes a pollutant when it is directly spilt to the drainage (Appendix 2), for its high biochemical demand of oxygen (DBO) 5.000 mg O_2/L [5].

From the nourishing point of view, lactose can cause digestive problems in those individuals who suffer from lactase insufficiency. In order that lactose can be correctly assimilated in the digestive system the hydrolysis in glucose and galactose is necessary, these sugars have

sweetener power and readily assimilated. In the hydrolysis, the presence of the enzyme called lactase or *ß-galactosidase* is necessary.

5.1.2.1. Lactose intolerance

The nourishing properties of milk do it an excellent food for all the ages so it plays an important role in the diet, especially cow's milk. Nevertheless, an important part of the world population and about 15 % of the Spanish one (see Table 4), suffer a deficit or low activity of the intestinal lactase that prevents it from assimilating the lactose in different food, among which that of milk. It is due to the fact that lactose which has not been digested in the small intestine goes to the large one where it is fermented by the bacteria of the intestinal flora, producing hydrogen and other gases.

Until recently, the recommendation for the lactose intolerant people was the reduction or elimination of dairy products from their diet. However, it supposed resigning essential nutrients of milk as calcium, vitamin D, riboflavin and proteins, and of course, its flavor. In several countries, the problems of bad absorption of lactose in milk have been counteracted by the manufacture of dairy products with low contents of this disaccharide that assures the contribution of necessary calcium.

Swedish	*English*	*Russian*	***Spanish***	*Arab*	*Eskimo*	*Mexican*	*Center African*	*Thai*
1%	*6%*	*15%*	***15%***	*80%*	*83%*	*83%*	*83%*	*98%*

Table 4. Distribution of lactose intolerant population in the world [6].

5.1.2.2. Lactose elimination

The elimination of lactose can take place for physical methods by precipitation or chemical ones by hydrolysis. The physical route is not the most appropriate way as it alters the flavor and the energetic contribution, such as vitamins and minerals losses. On the other hand, the hydrolysis allows to obtain an equimolar mixture of glucose and galactose that possesses some better functional properties to those of lactose. It can be carried out by chemical methods with strong acids, resins or enzymes, in other words, lactase. The first method spoils the proteins of dairy products whereas the second one offers the inherent advantages of the enzymatic processes, mainly the specificity and it does not need extreme conditions of operation.

6. INDUSTRIAL PROCESSES FOR LACTOSE HYDROLYSIS

As mentioned before, the lactose intolerance problems have been counteracted by the manufacture of dairy products with low content of this disaccharide. There are a great number of reports about these production technologies applied to whey; on the contrary, there is a lack of information for the milk treatment. The processes of hydrolysis can be chemical, physical or microbiological.

6.1. ACID HYDROLYSIS

Lactose hydrolysis by means of acid is complex due to the fact that this sugar shows a great stability to chemical agents. The intervention of acids is necessary to unfold it. This method is not applicable to milk, because sudden pH changes occur, it is only used in whey permeates.

6.2. LACTOSE ULTRA FILTRATION

It is a physical method in which lactose is eliminated using membranes of 0,5 μm with a tangential flow. This technology is not used on a large scale because of the high operation costs [7].

6.3. ENZYMATIC PROCESS

An efficient and economically viable process of lactose hydrolysis depends on the cost of the production of the enzyme, favorable kinetics and the properties of stability. The most important factors that concern the rate of the catalyzed reactions are: the concentration of the enzyme and substrate, the presence of inhibitors, pH, ionic force and temperature. Several authors have carried out the lactose hydrolysis using enzymes coming from different sources. The equations and enzymatic mechanisms for these kinetic models are described in Table 2. Depending on the origin of the enzyme the reaction will be closer to one model or the other. The

enzymes, for the simple fact of being proteins suffer from denaturalization for the effect of temperature (and pH), fact that should take into account later.

The application of enzymes in the production of lactose from hydrolyzed milk is quite common and three main types of process can be found.

6.3.1. Free and soluble enzyme

The employment of free enzyme can be carried out at temperature from 30 to 40°C between 3 and 5 hours; this way, the rate at which pollutant microorganisms of the milk grow is high, in contrast, at low temperatures (3 and 4ºC) a period of time from 16 to 24 h is needed. Under these conditions the extent of reaction obtained is from 70 to 80 % of lactose milk hydrolysis [8].

The enzyme is directly added to the reactor and it is kept up to the desired point of lactose hydrolysis. Small reactors where the enzyme and milk are fed continually and at the same time the hydrolyzed product moves out, are often used to carry out the reaction. The hydrolysis in batch mode is more economic and is the most used process in the dairy industry as for milk and whey. The advantages of the process of free enzyme takes lie in its simplicity and flexibility in conditions of operation and selection of the enzyme source. Its main drawback is the loss of the lactase with the product.

6.3.2. Recuperation of the enzyme

Enzyme recovery systems based on membranes are in use nowadays. The process consists of the ultra-filtering of milk, allowing the hydrolysis in the reactor where a portion retained in the initial filtration is added to the hydrolyzed flow. This process is complex and expensive and thus is not suitable in the industry. A disadvantage of this process is the accumulation of calcium salts in the membranes, which diminishes considerably its efficiency.

6.3.3. Injection of sterile enzyme

In the system of injection by sterile enzyme, a small amount of enzyme will be used to let it act during the time of the product storage ([8], [9]). Its disadvantages are the lack of control in the level of hydrolysis and the presence of proteases that produces disagreeable smell and flavor.

6.3.4. Immobilized enzyme

The immobilization of enzymes is a process where the enzyme is located in a region of the space, to give place to insoluble forms that retain its catalytic activity. They can be re-used repeatedly.

In general, there are two types of reactors to immobilize enzymes, packed bed and fluidized bed. Reactors of packed bed have the advantage of being easy to operate and it can be get faster hydrolysis for liter of enzyme used than in reactors of fluid bed [10]. A disadvantage is the microbial growth on the support. This problem can lead to the contamination of the product, above all, when the substrate is milk [9], [11]. The reactor of fluidized bed avoids this problem thanks to the constant movement of the particles that the enzyme contains. The main drawback consists in its operation complexity.

In regard to the advantages of using immobilized enzymes, it can be emphasized the increase of stability of the enzyme and the possible reutilization of the derivative, which lead to diminish the costs of the process [12]. In addition, reactors with immobilized enzymes allow the employing of high loads of enzyme, which will support its activity during more time. These systems can include recycling, allowing the extraction of products with highest purity. The main disadvantages of the immobilization process are the alteration of the enzyme conformation and the great heterogeneity of the enzyme – support system [11].

6.3.4.1. Supports

The choice of the support and the type of link turns out to be determinant in the later behavior of the biocatalyst. It is necessary to try that the immobilization increases the affinity for the substratum, diminishes the inhibition, extends the ideally interval of pH and reduces the possible microbial contamination [5], [11]. Besides, the support must have mechanical resistance adapted to operation conditions of the reactor and it must be easily separable of the liquid in order to re-used it.

There is a wide variety of materials used as supports for immobilized enzymes. These materials differ in size, density, porosity and form, though generally they are in a cylindrical shape, leaves, fibers and the most common one is in the shape of spheres.

Supports can be classified in two big groups [13]:

- Inorganic supports: Inside this group there are a great variety of supports, which can be natives (clays as the bentonita, pumice, silica, etc.) or manufactured materials (oxides of metals and glass, not porous glass, alumina, ceramics, gel of silica, etc.)

-Organic Supports: They can be classified as natural or synthetic polymers.

The enzymes can join these supports by means of physical adsorption or for covalent union.

In general, methods which are difficult to prepare and whose costs are higher provide stable and lasting biocatalysts. On the other hand, those simple methods as entrapment or adsorption, where the union between the enzyme and the support is weak originate immobilized derivatives that present losses of activity and which must be supplied constantly. Therefore, the best joining method for the support is covalent union. The immobilization of enzymes by this method is based on the formation of covalent bonds between the enzyme and the support. The covalent union is strong and the enzymatic immobilized preparations are therefore stable. Losses of enzyme do not take place to the solution for presence of a substratum or in solve strongly ionic raised. The enzyme will be securely affixed since it would be joined by covalent bonds and the risk of losing is minor [14]. The method of covalent bond is one of the most used to immobilize lactase (Appendix 3).

7. CHOICE OF THE BEST TECHNOLOGY

Nowadays, food processing industries are the widest field of application of the enzymatic processes. This is due to some important factors as the increase of sweetener and digestibility, insolubility for formation of clots, the decrease of crystallization, better bacteriological stability, improvement of texture, etc. This implies low production costs and high rates of reaction in short time. So, the enzymes are catalysts which allow to increase the rate of the chemical reaction.

However, the production and industrial use of enzymes entail a high cost associated with the thermal instability that they present. The use of immobilized enzymes has certain advantages compared to the soluble ones. The development of the technologies of immobilization promotes its applications reducing considerably the costs due to the fact that

after their use they can be recovered by means of centrifugation or filtration. It is able to carry out the isolation and the purification of the products easily. That is why it is suitable to use immobilized enzymes on supports or by means of polymerization (heterogeneous phase). Thus it is possible to re-use the enzyme supposing an economic saving. Moreover, those products can be easily separated and the problems of effluent and raw materials are minimized. The properties of the enzyme like the activity and the stability can be altered favorably.

Immobilized enzymes present different characteristics to the soluble ones due to the fact that their properties are influenced by different factors related to the chemical and structural nature of the support, as well as the joining method used to affix the enzyme. The immobilization of one enzyme on a support can increase its stability against the denaturalization for different agents. This happens especially if this implies conformational changes which diminish the inhibition by product. The number of interactions or links between the enzyme and the support plays an important role.

The immobilization in gels makes that the interactions between the enzyme and the support are purely mechanical and that the enzyme retains the identity of free dissolution preserving the selectivity of the substratum and the majority of its properties. The size of the pore can be larger without the risk of that the enzyme goes out of the gel, so it will diminishes the resistance to the diffusion of substratum and products.

It is quite frequent that the enzyme suffers retroinhibition due to the substrate of the reaction, is to say, that the activity should diminish as the enzyme enters come into contact with a major quantity of substratum. It can be counteracted by using a cyclical operation. The substratum is expelled out of the gel when it contracts, this way it diminishes the concentration and inhibition. For this type of process thermo reversible gels are normally used. These gels work at lower temperatures than those of the thermal denaturalization, so that the enzymatic reaches its maximum activity. Some immobilizations of lactase enzymes are made in this type of gels to reduce the inhibition caused by the product, obtaining conversions of up to 40 % most raised than to the isothermal operations [15].

On the other hand, in the case of covalent union bond, a protection phenomenon to the pH is observed but in minor measure that in case of immobilization for entrapment due to the fact that the network in the first one presents less quantity of monomer and therefore, fewer ionizable groups. By contrast, a protection phenomenon takes place to the temperature for

values of moderated pH due to the fact that when the enzymes joins the counterfoil a denaturalization process occurs, the probability of them re-naturalizing again increases. Nevertheless if temperature and pH raise also the denaturalization becomes irreversible and the possibility of recovery would not exist.

7.1. SELECTION OF ENZYME RESPONSIBLE OF LACTOSE HYDROLYSIS

Nowadays, there are in use enzymes from microbial origin and not animal or vegetable due to the fact that they present better thermo stability and variety as for in conditions of operation depending on the microorganism producer. Legal regulation in health and safety in the production of food products demands that the microorganisms from which the enzymes are obtained are not pathogenic, not toxic, and there is an absence of bacterial pollution as well as the innocuousness of excipients that are added to the enzymatic commercial preparations, or of the reagents and supports used in the immobilization. There is a list of accepted products known as GRAS (Generally recognized as Safe) and particular microorganisms whose safety has been accepted by the regulatory authorities are gathered in the FCC (Food Chemical Codex).

The enzyme responsible of lactose hydrolysis is the lactase or *ß-galactosidase* which properties will depend on its source of origin. Then, the commercial preparation of the enzyme, the method of immobilization used and the type of support selected influence the conditions of temperature and pH that must be used. In spite of having many sources of this enzyme, not all of them are accepted or recognized as innocuous for their industrial application, especially in the food processing industry. Lactase from *Escherichia coli*, though it is a specie studied enough, is not in food processing due to its high cost and it can also cause toxicity problems. It is only used in analytical chemistry [15]. *Aspergillus*'s preparations *Niger*, *Aspergillus oryzae* and *Kluyveromyces* (*lactis* or *fragilis*) are considered to be safe sources of utilization. Generally, the commercial preparations of lactases proceeding from fungi, especially *Aspergillus Niger* and *Aspergillus oryzae*, are of great importance, particularly when the conditions of operation are in a range of acid pH (2,5-4,5), being adapted for the hydrolysis of the acid whey [16].

The *ß-galactosidases* from yeasts *Kluyveromyces fragilis* and *Kluyveromyces lactis* have an ideal pH concentrated in the neutral region, pH between 6 and 7 and between 6,5 and 7,5 respectively, are accepted well for lactose hydrolysis of milk and of sweet whey[[8],[17]].

The above mentioned enzymes are strongly inhibited by high concentration of calcium in the milk and small concentrations of sodium as for the presence of galactose and glucose. They present ideal temperature of activity between 30°C and 40°C, which represents a disadvantage, since it facilitates the microbial pollution, being advisable to include a short period of hydrolysis, from 2 to 3 hours. This way, enzymes coming from fungi are used for lactose hydrolysis of the whey, whereas those of yeast and bacteria are used for the hydrolysis of the sugar in milk (pH = 6,6) and in syrups of whey (pH = 6,1). *ß -galactosidases* from *Saccharomyces*, especially of S. lactis, is present in the majority of dairy preparations, due to the fact that its ideal conditions (35-40ºC, pH 6,6-6,8) are near the native temperature and pH of milk and the majority of dairy preparations . In addition, they present a high activity, despite their very low temperatures (minors of 40ºC). The conditions of temperature and pH of maximum activity of enzymes *ß-galactosidase* of different microorganisms are presented in Table.5.

Microorganism	T(ºC)	pH
Escherichia coli.	37	7,0-7,3
Aspergillus niger.	40-60	3,6
Kluyveromyces fragilis.	37-43	7,0
Kluyveromices lactis.	34-45	6,5-7,5

Table 5. Temperature and optimum pH of lactase from different micro-organisms [11], [17], [18], [19].

7.1.1. pH and temperature influence

pH and temperature can be fixed in 6,5 and 45°C respectively (Appendix 4), because they were the best evaluated conditions in hydrolysis, under which the major activity of enzyme is obtained [11],[18],[19,[20]. Nevertheless, enzyme can continue hydrolyzing successfully to higher temperatures, up to about 65°C but with a lower activity.

With regard to the pH, lactase presents great sensibility to changes in this condition, as it was demonstrated that on increasing or diminishing this value just in only one unit, the enzyme loses significantly great part of its activity. At the end of pH range the activity is almost nie. It is possible to obtain 100 % of hydrolysis in about an hour, using only 0,1 g/L of enzyme [12].

Adding more enzymes the same percentage will be obtained in the same time of hydrolysis, though the rate will be lightly increased. The rate of reaction decreases due to the galactose inhibition, as it has been shown in the literature.

7.1.2. Optimization of conditions

According to the state of the art established, the best conditions to develop lactose hydrolysis are the following ones: temperature of 45ºC, pH of 6.5, 0,1 g/L of enzyme *ß-galactosidase* from *kluyveromices lactis* immobilized on support of gel by covalent union.

There are several commercial methods of lactose hydrolysis in use (see Appendix 5). Due to the high quantities of product that implies the process with soluble enzyme the most used method is that of immobilized enzyme [10], [21]. However, nowadays, and due to the decrease of enzymes prices, it is more profitable to use soluble enzyme which then will be eliminated by thermal processes [22]. These thermal processes are the same that those of pasteurization of common milk, which the plant already takes it into account so that there are no extra costs. Moreover the social impact supports this preference. To explain this change of mind of dairy industries it is necessary to add a small economic detail later.

7.2. ECONOMY

To support this idea, the price of soluble enzyme, *lactosym-Pure 6.500 L* (Appendix 6) is fixed on 45 €/kg [23]. On the other hand, the price of immobilize lactase from *K.lactis* joined by covalent union to glioxil-agarosa, cost 847,00 € [24] for only 100 mg of enzyme (Appendix 7). That means almost 200. 0000 times more.

Moreover, bearing in mind that the process of enzyme recovery, is usually done by ultra-filtration which is relatively expensive, nowadays it is most profitable to use soluble enzyme methods to hydrolyse the lactose of milk than immobilized methods, especially for pilot plants. To have a quick overview of the increase in the cost that free-lactose milk could suppose, “Central Lechera Asturiana” milk sells its skimmed milk at 0,79 € /l and its milk without lactose to 1,15 € /l [25]. Therefore, it is important that the costs of the process are as low as possible in view of consumers.

7.3. SOCIAL IMPACT

It is common that the intervention of the biotechnology sciences in the food processing industry scares the society. Prejudices are often discussed on the nutrition established in individuals due to the fact that it is thought that they can be a risk for health.

Society is still traditional in the aspect of the food, though it is known that food that is always in the fridge as yogurt or cheese is obtained from the fermentation of milk or that these biotechnologies included are used for the manufacture of alcoholic drinks. Despite this, society proves to be reticent. Consumers of free lactose milk prefer buying the product knowing that the biological agent was been eliminated from milk and does not contain substances that they consider to be strange [22]. All these facts justifie the employment of soluble enzyme.

8. HEAT TREATMENTS

The manufacturing process of free lactose milk consists of the following stages. As soon as milk has been subjected to a thermal soft treatment, it is added to a tank together with the enzyme. The temperature and the pH are controlled. The extent of the reaction obtained is 70-80 % and it is establish by the temperature, the time of reaction and the quantity of enzyme added. The milk is pasteurized later in order to eliminate enzymes or bacteria as it is describe in Figure 2.

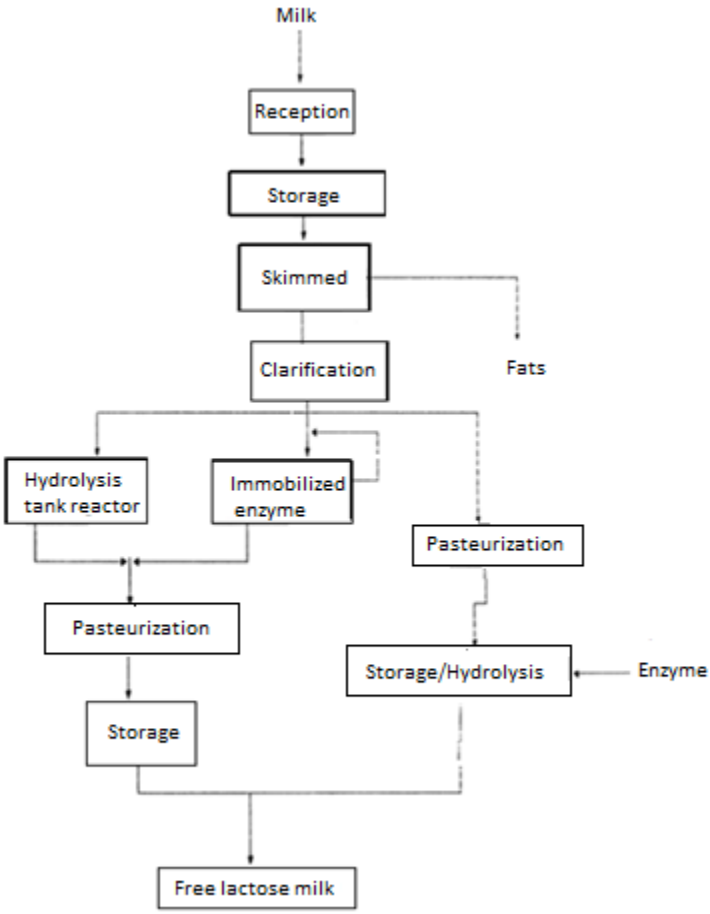

Figure 2. Diagram of hydrolysis lactose process.

Once the lactose hydrolysis by soluble lactase takes place in the reactor, it is necessary to eliminate the enzyme and consequently, the pathogenic bacteria present in milk. In accordance with some studies, the thermal intense treatment to which milk is subjected can result in caramelized lactose and the liberation of sulfuryl groups. It is detected by a coffee color and a change in flavor due to the destruction of 30 % of vitamins and to the precipitation of up to 60 % of the proteins of the whey. There are three types of well differentiated processes: slow or VAT

(Low Temperature Pasteurization), pasteurization at high temperatures during a brief period (HTST - High Temperature / Short Time) and the process at ultra-high temperatures (U.H.T - Ultra - High Temperature) [26], [27].

8.1. LOW TEMPERATURE PASTEURIZATION (VAT)

The pasteurization of milk is a thermal process that in a certain time achieves the destruction of all the pathogenic organisms that it could contain without considerably altering its composition, either flavor or nutritional value. So between 90 and 99% of microorganism are eliminated and enzymes are deactivated. Moreover is a form to prolong the life of the product.

VAT was the first pasteurization method, though it has been improved by more effective systems. This process consists of heating big volumes of milk in a container at 63 ° C during 30 minutes, and then the milk is cooled to temperatures between 4 and 10ºC. This step is repeated several times to continue with the packaging process of the product, sometimes more than 24 hours. The use of slow pasteurization is adapted to process small quantities of milk up to approximately 2.000 liters daily, otherwise it is not advisable. It avoids the proliferation of the organisms but milk has to be cooled slowly [28], [27].

8.2. CONVENTIONAL PASTEURIZATION

It takes place at temperatures from 72 to 75ºC for 15 to 20 seconds and then milk is cooled at temperatures of 4 to 5ºC. During this thermal process all the pathogenic bacteria are eliminated as yeasts and moulds, even though not the toxins and others. Milk contains enzymes, which are being inactivated when the thermal process overcomes the 78ºC. When having it treated with a thermal soft process, there are no changes on the characteristics and the nutritional value of the food is scanty. The useful life of the pasteurized food is minor than that of the sterilized ones since the temperatures and the time to which it is subjected to the thermal process is minor than in the case of the sterilized food ([28],[29], [15]).

8.3. ULTRA HIGH TEMPERATURE (U.H.T)

U.H.T consists of a thermal process of constant flow, in which the milk is subjected to temperatures from 135 to 140ºC for 2 to 4 seconds. Immediately followed by a cooling at room temperature and then it is kept in sterile containers closed hermetically, for its later storage. It assures the commercial sterility keeping the properties of milk intact and especially its

nourishing quality, which can be commercialized to temperature set. Doing so, the destruction of all the live micro-organisms is reached, including spores. On the other hand, the heating in the process U.H.T can be directly affected by indirect steam injection or through a heat exchanger. In both cases milk free of pathogenic microorganisms is obtained. This process is carried out in a sterilized closed system which avoids the contamination of milk ([28],[29], [15]).

The product comes directly into contact with the heating way (steam) and later it is later cooled for sudden expansion by means of vacuum. In direct systems the water is added to milk, so the water steam condensed is liberated by expansion to the vacuum and this way the product recovers its original composition. This system could cause the interaction between proteins and/or fatty acid which leads to stability problems in milk (floccules). That is the reason why the homogenization is done after the treatment. The direct systems are divided in two categories [30]:

- System of steam injection: the water steam is injected in the product.

- System of steam infusion: the product gets in an equipment container full of steam.

In the indirect systems, the heat is transferred from the heating way to the product through an exchanging surface. The product never comes into contact with the heating fluid.

Different ways can be used like heat exchanger of plates, an exchange of tubular heat or a heat exchanger of scraped surface. It is possible to combine the types of heat exchangers in the indirect systems, in accordance with the product and the process needs [30]. Few pumps are required to flow the liquid along the pipelines in turbulent regime in order to heat it uniformly for what it is necessary to use high pressures. It works at high temperatures above 132°C.

One of the advantages of this method is the high quality reached and longer life in shelf. It lasts for a useful life of 6 months, without refrigeration. Moreover, there are not needed refreshed vehicles for its transport which decrease the transportation cost. But not all are advantages. Complex equipment is needed for aseptic packaging, more experienced operatives and support sterility in the aseptic packing is required. Moreover, lipase which are thermo resistant or protease can lead to a deterioration of the flavor and aging milk.

8.4. UPERIZATION OR INJECTION

It is the abbreviation of ultra pasteurization. In this process the bacteria are completely eliminated. Its lethal process takes place during 1,5-2 seconds. The uperization, is a treatment

in which milk lasts shorter. It consists of an injection of direct steam at 148ºC during only 2 seconds and 4 tenths. This way the vitamins are kept, as well as proteins and minerals of milk, its flavor and natural color, too. It is the only method that avoids the oxidation of milk because during the process the oxygen is extracted. It keeps the whole own smell, flavor and color of just fresh milked milk [15].

8.5. HIGH TEMPERATURE SHORT TIME (HTST)

This method is the most used nowadays in liquids, like milk, fruit juices or beer. As a general rule it is the most suitable since it exposes the food to high temperatures during a brief period of time and a little industrial equipment is only necessary to realize this process, as a valuable degradation of flavor does not produce. Moreover, it has determined the survival rate of the vine-stocks of different microorganisms during the pasteurization of milk and there has been detected that the U.H.T pasteurization under certain conditions destroys the vitamin A and vitamin B [31].

The resultant pasteurized milk in HTST treatment is not sterile, so that it is necessary to cool it rapidly after the pasteurization in order to anticipate the multiplication of the surviving bacteria. There are two different methods under the category of HTST pasteurization:

- "Batch" process: a great quantity of milk is warmed up in an autoclave reactor. It is a method used nowadays, especially by the small producers due to the fact that it is a simple process.

- Process of “constant flow ": the food is kept between a plate heat exchanger and a tubular heat exchanger. This method is most applied by the food processing industries to a major scale, since the method allows to carry out the pasteurization of large food quantities in a short time like in the case of dairy industry.

This method presents a lot of advantages. It can process large volumes of milk and it exposes the food to high temperatures, below 100ºC, during a brief period. The industrial equipment needed to carry out the process is rather low, reducing hereby maintenances costs. The automation of the process assures a better pasteurization. As it is a closed system, the contamination is avoided. The main disadvantage is that it cannot be adapted to process small quantities of milk and it requires highly qualified staff. The rubbers gaskets that connect the plates are too fragile and the drainage is difficult. There is a limit of temperature. Standard

rubber gasket admits a maximum operating temperature of 150ºC, depending on the nature of the rubber gasket used ([32], [33]). Table 6 shows a summary of the thermal treatments aforementioned.

TEMPERATURE (ºC)	TIME	TYPE OF PASTEURIZATION
63	30 MIN	VAT
72	15 S	HTST
89	1,0 S	ULTRA PASTEURIZATION
90	0,5 S	ULTRA PASTEURIZATION
100	0,01 S	ULTRA PASTEURIZATION
138	2,0 S	U.H.T

Table 6. Average temperature and time of pasteurization milk for different thermal treatments [34].

8.5. 1. PLATE HEAT EXCHANGER

Plate exchanger was first used for the treatment and the pasteurization of milk to satisfy the need to possess an equipment of easy cleanliness, without irregularities where they could shelter bacteria and that its development was not even promoted. In addition, the production of milk needs high coefficients of heat transfer in order that the time of residence, especially at high temperatures, is minimum. HTST systems need devices able to heat faster, as the changer of plates [35].

The plate exchangers are from the type recovery and compact. In them, heat transference takes place between two fluid currents which do not have contact between them. The stream involved currents are separated between them by a thermo-conductor wall from which the heat is transmitted by convection and conduction from the heat liquid way to the cold. In many industrial applications the plate heat exchanger has displaced that of tubular type, for two main reasons. The coefficient of heat transfer is higher, which allows to construct more compact equipments and with minor residence time of the fluids and they are easily detachable. Some models of plate exchangers cannot be disassemble due to the fact that the plates are welded. That is why the interchanger of gaskets is advisable.

Cold and warm fluids go into the connection orifices and circulate along the channels that are formed between plates without being able to be mixed. A fluid is led by the odd channels whereas the other one is led by the couples. The distribution of the fluids by their corresponding channels is done by means of a series of gaskets in the odd channels that do not allow the entry of the fluid that has to circulate along the couples, and in the couples that the entry does not allow of that of the odd ones. Generally, though multiple configurations exist, the flow of both fluids is done in cross-current and in one step. Thus the sense of traffic of a fluid is the contrary of the other one. The heat transfer in this exchanger is more effective than the parallel one.

The most used material for the sheets is the stainless steel, resistant to the corrosion and low thermo-resistance. The thickness of the plates is comprised between 0,4 mm and 1 mm. In order to increase the surface to heat transfer, plates present a corrugated relief that help to induce a high level of turbulence even for average relatively low rates (0,25 m/s to 1 m/s) [34]. Due to the corrugation of the plates and the increase of the turbulence a better transfer of the heat is obtained. Two big groups of corrugation systems can be differentiated: "intermating" type and " Chevron"' type that is the most used. The Figure 3 shows the channels where the cold fluid and the warm circulate. The number of plates is decided depending on program of temperatures and on the flows, physical properties of the fluids, losses of admissible load.

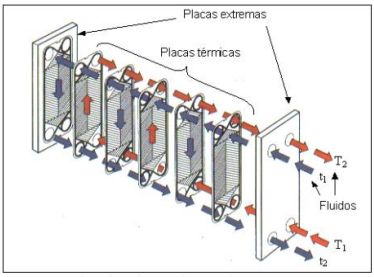

Figure 3. Flows and temperatures in the plate heat exchanger [36].

Plate heat exchangers present several advantages compared to the tubular ones. On the one hand, they are easily disassembled. All the surfaces can be cleaned easily either by manual or chemical methods. They diminish the dead times and a special equipment of cleanliness is not required. The costs of maintenance are minor. This advantage is particular of

those of type joins since the interchangers of welded plates cannot be dismantled and they need from more complex methods of cleanliness.

Moreover, they present a major global coefficient of transfer; up to five times higher to those obtained for the units of pipe and framework. This implies a minor area needed for heat transfer and therefore less installation weight and volume cost reduction up to 90 % is achieved as a consequence of less area of heat transfer ([33], [35]).

In addition, it allows the application of flows in cross-current in the majority of the applications. It is possible to work even with differences of temperature of up to 1ºC, maximizing the possibility of heat recovery. The symmetry of the channels eliminates the need to decide which of the fluids will circulate along the pipes and which along the shell, provided that the sides of the plate are equivalent.

One of the most important advantages is they are adaptable and their design is modularly. The capacity can be increased or diminished in spite of only setting or removing plates. The change of the disposition of the plates allows modifying the program of operating temperatures easily and even its utilization in different processes. Heat-sealed do not present this characteristic since its disassembly and extension are not possible. In case of those of shell and pipe it is not easy to adapt them to the changes of the thermal demand.

Plate heat exchangers present three main limitations. Firstly, the metal sheet, should be wavy or not, is not an element adapted to support high pressures, so that the maximum pressures for the most common models are from 10 to 15 bar, though there are models capable of supporting slightly major pressures. This is due to the risk of the break of the union ([33], [35]).

Then, there are several types of materials of the union that have a maximum limit of operating temperature from 140 to 150ºC. Due to the narrow channels between plates, the drop of pressure across a plate interchanger is relatively big, for what it is necessary to bear in mind the investment and the costs of operation and maintenance of the system of pumping when comparing it with other types of exchangers ([33], [35]).

8.5.2. Design of the plate heat exhanger

A complete process of HTST pasteurization is composed by several equipments namely a tank of entry, a pump to flow the mixture, a four section plate heat exchanger, a recirculation

valve, a heating system, control elements, pipes and union accessories ([15],[36]). Flowsheet of this process is showed in Figure 4.

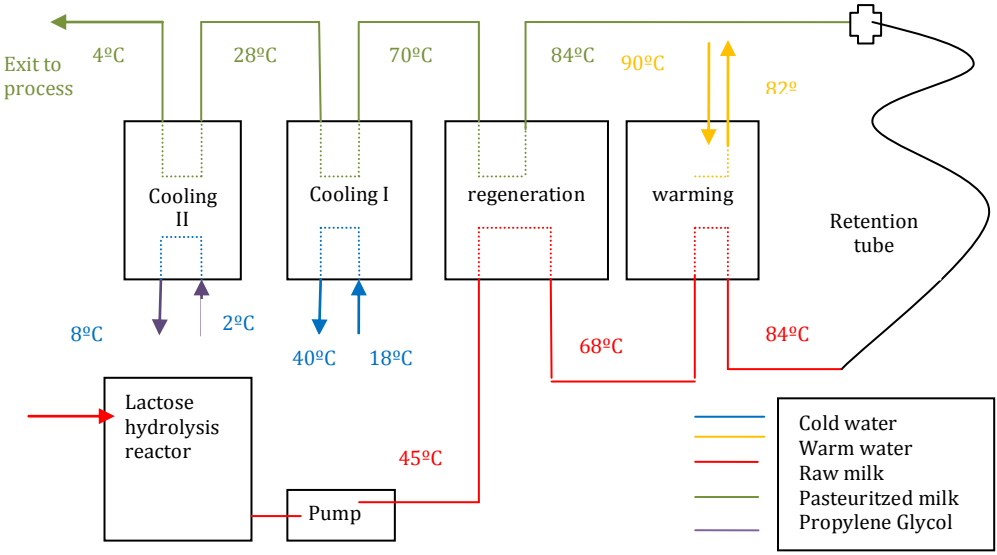

Figure 4. HTST process with a plate heat exchanger of four sections [37].

Milk reaches the equipment exchanger at 45°C approximately; from a tank and the pump flows it to the first section. It warms up for regeneration. In this section of regeneration, the raw milk is warmed up to 68°C approximately, in cross-current, by means of the already pasteurized mixture, which temperature takes advantage in this zone of regeneration. On having gone out of the section of regeneration, the milk passes thought a filter that eliminates impurities that it could have obtained. Then, this milk goes on to the heat changers of the zone where one warms it up to the temperature of pasteurization, this one is 84°C by means of water at 90ºC, in cross-current also. Warm water is in continuous circulation by a pump which takes it from a boiler. Since the water is cooled, a steam injection is needed. This action is done through a regulatory valve controlled to fix the temperature mixture at 84ºC. When this temperature is reached milk goes on to the section of temperature retention; this section can be constituted by an external pipe or a retardant included in the own interchanger; the most common is the pipe of retention; where the time that milk is retained is of 15 to 20 seconds. This time is enough to eliminate microorganisms. To the exit of the retention zone, milk passes to a valve of diversion;

in this valve, if milk does not reach the temperature of 83-84°C, it is automatically returned to the regulatory tank to be re-processed, but if milk reaches this temperature, it goes on to the zone of regeneration in order that it yields heat to the inlet, where it is cooled by raw milk up to 70°C. From here milk goes on to the section of cooling where two zones are distinguished: one where the mixture is cooled until 28ºC by cold water at 18ºC in cross-current and another one where propylene glycol (Appendix 8) at 2ºC circulates. The tour finishes here going out from the exchanger at a temperature of 4°C. So as not to spend great tour to decrease its temperature and be able to reuse it, it is possible to install cooling water.

The scheme represented in Figure 4 will be used to design the plate heat exchanger for HTST process by calculation and then the simulation to validate it.

8.5.2.1. Numbers of the pasteurization in the industry

The parameters of which it arranges [24] are the following :

- Flow of product to treating, m_F and temperatures of entry and exit of the product, T_e and T_s.

- Flow of the service fluid, it is water, propylene glycol or sterile milk according to the section, m_w and temperatures of entry and exit of the product, t_e and t_s.

- Range of usual values of plate heat exchangers properties (Table 7)

- Plates properties and standard lengths used in the calculation [24] (Table 8)

- Thermo-physic properties of the fluids in the plate heat exchanger (Table 9)

-The capacity of production used will be performed according to real data. In this case, in Catalonia the consumption of milk turns out to be 11.826.100 Liters per year [38]. Bearing in mind that the production of milk without lactose to regional level is 30 % it will take 6.500 L/h as a flow of production of the pasteurizer.

Thickness (mm)	0,5 -1.2
Velocities (m/s)	0,1-1
Exchanger area per plate (m^2)	0,032-3,4
Exchanger area per unit (m^2)	0,1-2200
Distance between 2 plates (mm)	1-5,5
Wide of plate (m)	0,2-1,5
Length of plate (m)	0,5-3
Maximum drop of pressure (bar)	0,7
Corrugating angle (º)	30-65
U ($W/(m^2.K)$)	1.500-3.000

Table 7. Range of values allowed for plate pasteurizer [39],[40],[41],[42].

L(mm)	*E_p(mm)*	*a_p(mm)*	*e (mm)*	*Material*
894	1,6	243	0,4	AISI 316

Table 8. Dimensions of the plates used for the calculation [24].

	Pasteurized milk	Raw milk	Warm water	Propylene Glycol	Cold water
density kg/m³	990,59	1.006,44	967,99	1.031,71	995,51
viscosity kg/(m.s)	$7{,}10E^{-04}$	$6{,}10E^{-04}$	$6{,}20E^{-04}$	$6{,}35E^{-03}$	$8{,}20E^{-04}$
Calorific Capacity J/(kg.ºC)	3.950	3.970	4.200	4.180	4.180
Conductivity W/(m.K)	$5{,}20E^{-01}$	$5{,}40E^{-01}$	$5{,}40E^{-01}$	$4{,}60E^{-01}$	$6{,}1E^{-01}$

Table 9. Physical properties of the fluids implied in the pasteurization process [24].

This information will be sufficient to establish and to resolve a mathematical model based on several hypotheses which are described in the following paragraphs.

8.5.2.3. Mathematical modeling

The HTST pasteurizer consists of four sections. For it there will be designed a single plate heat exchanger assembled in an alone body where the sections are separated by plates of connection. In the following lines, the design of each section will be detailed: warming, regeneration and two of cooling. It will allow to determine the areas of heat transmission necessary for each of the renowned sections as well as the number of plates to be used. The iterative method of coefficients of heat transfer will be used to determine the validity of the above mentioned calculations [43]. The method consists of supposing a value of the coefficient of global heat transfer. It will be considered to be a flow in cross-current since that obtains a transfer of major heat than in case of the flow in parallel.

In order to apply the selected method and simplify the calculation the following considerations were taken:

- It will be supposed that there is not phase change for any of the fluids.
- The heat exchanger operates in stationary conditions.
- The heat losses towards the exterior are insignificant.
- The global coefficient of heat transfer is constant along the whole interchanger.

- The specific heats and the densities were considered to be constants in the range of temperature.

- It will be supposed that the flows of fluid are equally distributed between the different surfaces.

- Flow and temperatures of the fluids will be supposed to be uniform in the whole surface. Provided that this is not rigorously true and one lacks information it will be think that the fluids are to an average temperature determined between the entry and the exit.

Later, there are exposed the steps followed to model the plate heat exchanger.

Firstly, it is necessary to make an energy balance to be able to evaluate the heat needed to pasteurize the product. It is important to remember that the thermal losses are negligible. Therefore:

$$Q = \Delta H \quad (8.1)$$

$$Q = m_f.(H_2 - H_1) = m_s.(h_1 - h_2) \quad (8.2)$$

$$Q = m_f.Cp_f.(T_s - T_e) = m_s.Cp_s.(t_e - t_s) \quad (8.3)$$

$$m_s = Q/(Cp_s.(t_e - t_s)) \quad (8.4)$$

So, the Fourrier design equation established:

$$Q = U.A.\Delta T_m \quad (8.5)$$

Where the logarithmic average temperature, ΔT_m is defined the following way:

$$\Delta t_1 = t_s - T_e \quad (8.6)$$

$$\Delta t_2 = t_e - T_s \quad (8.7)$$

$$\Delta T_m = (\Delta t_2 - \Delta t_1)/(\ln \Delta t_2/\Delta t_1) \quad (8.8)$$

Normally, the canals on the ends of the interchanger consist of the half of surface of the interior canals and, therefore, they transfer less heat. The efficiency of the interchanger diminishes. For this reason it is necessary to introduce the correction factor, F, graphically determined by means of R and P factors (Appendix 9):

$$R = (t_e - t_s)/(T_s - T_e) \quad (8.9)$$

$$P = (T_s - T_e)/(t_e - T_e) \quad (8.10)$$

This way, the heat transferred along the interchanger will be:

$$Q = F.U.A.\Delta T_m \quad (8.11)$$

And the heat transfer area, A:

$$A = Q/(U.F.\Delta T_m) \quad (8.12)$$

In this point the value of U will be supposed according to literature. It takes 2.000 W/(m^2.K) (Table 6). Now it is possible to calculate the number of plates, N_p, using :

$$N_p = A/A_p \quad (8.13)$$

Where A_p refers to the heat transfer area of each plate. The number of plates has to be uneven as the number of total channels, N_{ct}, trying adding one to the number of plates, dividing it by two gives the number of channels, N_c, for the fluid of service and the product. If the number of plates, N_p, is bigger than 700, the design is considered incorrect. That is to say, the dimensions of the plates have to be verified.

$$N_c = \frac{N_p+1}{2} = \frac{N_{ct}}{2} \quad (8.14)$$

To be able to determine the convective heat transfer coefficients, it will be done from dimensionless numbers. For them it is necessary to calculate the area of total flow (A_f) of fluids first.

$$A_f = a_p.E_p.N_c \quad (8.15)$$

Where a_p is the effective width of every plate and E_p represents the distance between plates. On the other hand, the hydraulic diameter, D_e, is:

$$D_e = (4.a_p.E_p)/(a_p + E_p) \quad (8.16)$$

Consequently, mass velocities of each fluid are:

$$G_f = m_f/A_f \quad (8.17)$$

$$G_w = m_s/A_f \quad (8.18)$$

Now the dimensionless numbers will be calculated for each fluid, Reynolds, Nusselt and Prandtl , following the relations:

$$Re = \frac{D_e.G}{\mu} \quad (8.19)$$

$$Pr = \frac{Cp.\mu}{k} \quad (8.20)$$

$$Nu = Ch.(Re)^{y}(Pr)^{\frac{1}{3}}\left(\frac{\mu}{\mu_w}\right)^{0.17} \quad (8.21)$$

Where C_h and y are Kumar's coefficients (Appendix 10). They depend on the angles of inclination of the plate and on the regime of flow. The most common Chevron's angles in dairy industry are between 30º and 65 º [44]. For what the heat transfer coefficients of convection were decided for every fluid using the following relation:

$$h = (Nu.k)/D_e \quad (8.22)$$

Which allow to calculate the global coefficient of design U_c:

$$U_c = 1/(1/h_f + e/K + 1/h_s) \quad (8.23)$$

Where,

e: thickness of plate.

K: Conductivity of the material, in this case stainless steel 316

Later it can be determined the global real heat transfer coefficient, U_D, from a soiling factor R_d that for milk pasteurization is $0{,}1.10^{-3}$ (m^2.K)/W [45],[67].

$$U_D = 1/(1/U_c + R_d) \quad (8.24)$$

Once done this, it is necessary to compare this calculated value with the guess of the beginning of the method. In order that the iteration is considered to be valid, the relation between U_D supposed and the calculated one must be between 0,995 and the 1,05. Otherwise U_D calculated would turn out to be the guess and the process would be repeated until the above mentioned condition is reach.

$$0{,}995 < U_{Dsup}/U_{Dcalc} < 1{,}005 \quad (8.25)$$

Next it should be verified if the energetic balance is fulfilled.

$$Q = F.U_D.A.\Delta T_m = m_f.C_p.(T_s - T_e) \quad (8.26)$$

If the balance is not fulfilled, another temperature of the fluid of service t_s will be assumed

When the condition has been fulfilled for the determination of the global heat transfer coefficient, the number of units of heat transfer NUT and the efficiency ε can be calculated.

$$NUT = (U_c.A)/(m.Cp)_{min} \quad (8.27)$$

Where $(m.Cp)_{min}$ or C_{min} is the reason of minimal calorific capacity.

$$\varepsilon = \frac{1-\exp(-\mathrm{NUT}(1-c)}{1-c.\exp(-\mathrm{NUT}(1-c)} \quad (8.28)$$

With $c=C_{min}/C_{max}$

For values of high NUT the efficiency increases slowly for which the utilization of a heat exchanger is not economically profitable (this happens for a NUT value higher than 3*)*. The NUT is a size measurement of the interchanger bearing in mind that is directly proportional to the heat transfer area. NUT acceptable values are considered between 1,5 and 3,5 to effects of calculation ([36], [45], [53]).

With this information it can be evaluated the number of steps for each fluid, N_s

$$N_s = (\mathrm{NUT}.m.Cp)/(2.A_p.U_c.N_p) \quad (8.29)$$

With this it can be obtained the design parameters of a plate heat interchanger. Even this, it is necessary to calculate the pressure drop that will take place. It will be important information to select the pumps that flow the fluids.

In this aspect, the loss of total pressure is the sum of the loss of pressure for each fluid of entry and exit of the equipment.

$$\Delta P_T = \Delta P_f + \Delta P_w \quad (8.30)$$

With,

$$\Delta P = (2.f.L_p.G^2)/(g.\rho.D_e) \quad (8.31)$$

And the friction factor for a turbulent regime [33],

$$f = \frac{0.6}{Re^{0.3}} \quad (8.32)$$

According to the literature in a heat interchanger the maximum loss of pressure is established to be 0,7 bar, above this value it would not be economically profitable.

The process described will be repeated for the four sections. On the other hand, some restrictions have been kept in mind in the regeneration section:

- It is recommended that the way of heating has a difference from 2 to 10ºC with the temperature of pasteurization.

- Values of regeneration efficiency, R_g, can reach up to 75 % [26]. It will decide from the relation:

$$R_g = ((t_r - t_i)/(t_p - t_i)).100 \quad (8.33)$$

Where,

t_p: pasteurization temperature (84ºC)

t_i: Temperature of enter of not pasteurized fluid

t_r: Temperature of the fluid pasteurized after the regeneration

The iteration system followed to design the plate heat exchanger is represented in the Figure.5.

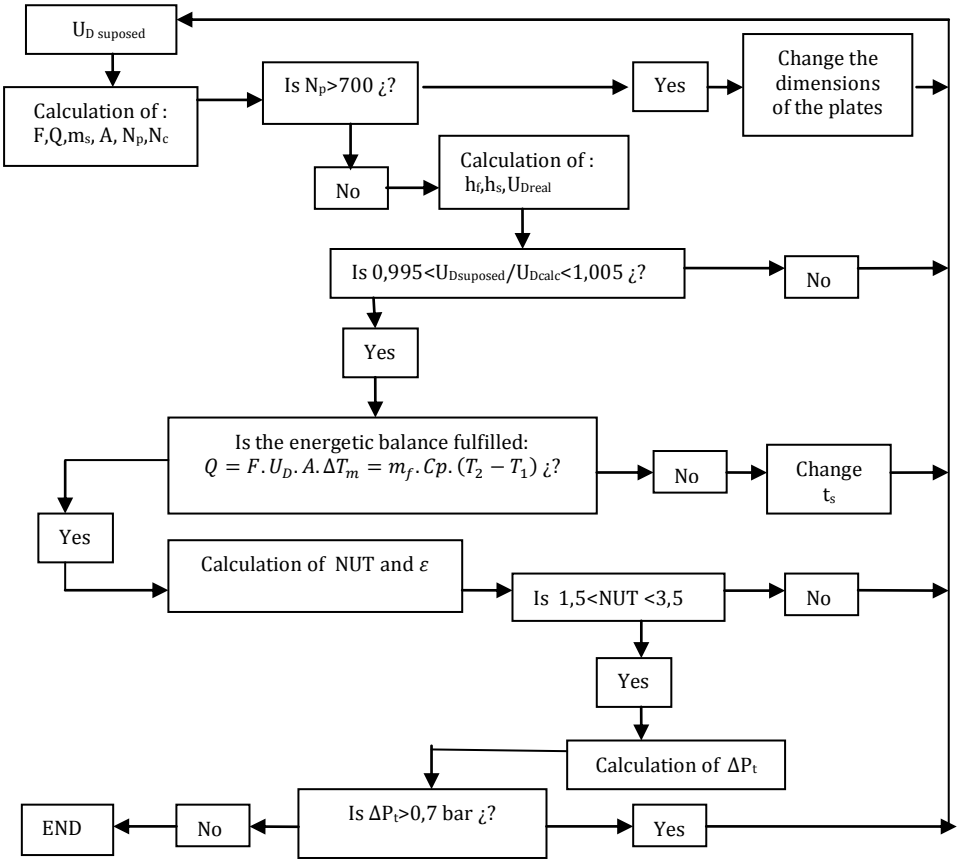

Figure 5. Iteration scheme of heat exchanger design.

8.5.2.3. Summary of results obtained for reaction

Once applied the procedure of calculation explained in paragraph 9.6.3.1, the thermal results obtained for a pasteurization temperature of 84ºC are presented in Table 10. The most significant differences with the model presented in Figure 4 are in the temperatures of the cold service fluids. This way, so that the balance sheets are fulfilled, the cold water has to enter in

the cooling I section at 10ºC until 22ºC and not 18ºC until 40 ºC as expected. Moreover, the propylene glycol enters in cooling II section at -1,0ºC and is gets cold until 11ºC. These changes will influence in the flow of service fluid necessary.

On the other hand, in Tables 11 to 14, it can be seen that the values obtained fit well with those in Table 7. The pressure drop does not exceed the 0,7 bar established as advisable due to the low rates reached which are slightly below 1 m/s. So the design is economically profitable. The effective surfaces needed are rather small for the high transmission of heat that is obtained; the efficiency is highly supported by the turbulent flow. Moreover, the global coefficient transference, U, is important and about 2.500 W/(m^2.K). The regeneration percentage is between 60 and 75 % ([27],[26], about 65 %, for what the heat recuperation in this section is important. The NUT values are acceptable around 3 which is rather high due to the fact that the plates are long and narrow with corrugations and angles offering more resistance to the fluid passing through them. Higher the NUT value is, more narrowly the interchanger tends to its thermodynamic limit altering the efficiency and the transference of the exchanger. So it is obtained a plate heat exchanger of 168 plates and four sections which seems in concordance with the literature and it is economically profitable. Nevertheless, it is necessary to evaluate the sterilitzation factor to consider the pasteuritzation effective and to validate the model.

Section of the pasteurizer	Description of fluids	Hot Side		Cold Side	
		T_e (ºC)	T_s (ºC)	t_e (ºC)	t_s (ºC)
Regeneration	Pasteurized milk-raw milk	84,0	70,0	45,0	68,0
Warming	Hot water-raw milk	90,0	82,0	76,0	84,0
Cooling I	Pasteurized milk-cold water	70,0	28,0	10,0	22,0
Cooling II	Pasteurized milk-frozen water	28,0	4,0	-1,0	11,0

Table 10. Temperatures of entry and exit of each section and fluid.

Regeneration section	Hot Side Sterilized Milk	Cold Side Raw milk	Warming section	Hot Side Water	Cold Side Raw Milk
Mass flow (kg/s)	3,00	1,82	Mass flow (kg/s)	3,38	1,79
Flow rate (m^3/h)	10,90	6,50	Flow rate (m^3/h)	12,57	6,50
Pressure Drop (bar)	0,28	0,11	Pressure Drop (bar)	0,15	0,05
Passes x Channel	1 x 11	1 x 10	Passes x Channel	1 x 16	1 x 16
Linear Velocity (m/s)	0,77	0,47	Linear Velocity (m/s)	0,57	0,29

Regeneration Section		Warming Section	
Heat exchanged (kW)	113,43	Heat exchanged (kW)	165,93
Number of plates	31	Number of plates	20
Effective heat surface (m^2)	6,64	Effective heat surface (m^2)	4,19
U ($W/m^2.K$)	2.379,28	U ($W/m^2.K$)	2.304,81
Liquid volume (l)	13,5	Liquid Volume (l)	8,7
Frame length (mm) For a capacity of 39 plates	437	Frame length (mm) For a capacity of 39 plates	437
NUT	2,6	NUT	1,74
Efficiency	0,48	Efficiency	0,71
		R_g (%)	64,10

Cooling I section	Hot Side Sterilized Milk	Cold Side Water	Cooling II section	Hot Side Sterilized Milk	Cold Side Propylene Glycol
Mass flow (kg/s)	1,83	6,05	Mass flow (kg/s)	1,86	3,47
Flow rate (m^3/h)	6,50	21,87	Flow rate (m^3/h)	6,50	12,12
Pressure Drop (bar)	0,05	0,46	Pressure Drop (bar)	0,02	0,06
Passes x Channel	1 x 16	1 x 16	Passes x Channel	1 x 44	1 x 44
Linear Velocity (m/s)	0,3	1,0	Linear Velocity (m/s)	0,11	0,20

Cooling I section		Cooling II section	
Heat exchanged (kW)	303,606	Heat exchanged (kW)	173,91
Number of plates	31	Number of plates	86
Effective heat surface (m^2)	6,55	Effective heat surface (m^2)	18,61
U ($W/m^2.K$)	2.755,71	U ($W/m^2.K$)	1.361,27
Liquid volume (l)	13,5	Liquid volume (l)	37,4
Frame length (mm) (for 39 plates)	437	Frame length (mm) (for 39 plates)	1029
NUT	3,2	NUT	3,5
Efficiency	0,93	Efficiency	0,90

Tables 11, 12, 13, 14. Parameters calculated for each section of the exchanger.

8.5.2.4. Pasteurization factor

To consider the pasteurization effective it is necessary that at least 90 % of the present microorganisms in milk are destroyed (Appendix 11). It is subjected of a temperature at which

sterilization factor F_0 is not minor than 5 [46], [47]. The lethal effect of the pasteurization in the microorganisms can be expressed as a logarithmic function:

$$F = t = D.\log\frac{N_0}{N} = 25.\log\frac{10^9}{1} = 225 \qquad (8.34)$$

Where,

N: Number of microorganisms per gram left the product after a time t.

N_0: Number of microorganisms per gram at the time t=0.

D: time needed to destroy the 90% of the microorganisms in the product. It is time of thermal destruction or of decimal reduction in seconds

t: heating time at a determinate temperature

So, considering that the lethal wanted value is F_0=5, the time needed to reach the minimum temperature of pasteurization is the following one, where Z refers to the increase of temperature needed to reach a thermal destruction of 90% D in degrees. In this case T=84ºC, D=25 s for Z=10,5 (Appendix 11 and 12).

$$\frac{\log D_0}{D} = \frac{(T-T_0)}{Z} \qquad (8.35)$$

$$t = F_0 \,.\, 10^{\frac{(T-T_0)}{Z}} = 0{,}065\ s \qquad (8.36)$$

This is related to the time of retention when the exchanger works at a pasteurization temperature of 84ºC. To assure a correct treatment it is recommended to maintain at 15s to 84ºC.

9. SIMULATION

The following Figure collects the software simulation data obtained. It is in detail for each of the sections in the appendix 13 to 16. In the specification sheet of the appendix 17 there is described the interchanger simulated, and its layout is presented in the appendix 18.

J. Negre C. PHE - Design & Datalist

Customer:	JNC	Date:	martes, 21 de abril de 20	PHE-Type	
Att.:		From:		S20A-IS161300	
Ref:		Our ref.:	001_MI		
				V10A34	

Heat recovery (%)		Sec: 1		Sec: 2		Sec: 3	
		Hot side	Cold side	Hot side	Cold side	Hot side	Cold side
Fluid		Milk	Milk	Water	Milk	Milk	Water
Flowrate	(m3/h)	8,23	6,50	12,72	6,50	6,50	11,93
Inlet temperature	(°C)	84,40	50,00	90,00	68,00	70,00	18,00
Outlet temperature	(°C)	70,00	68,00	81,90	84,40	28,00	40,00
Pressure drop	(bar)	0,23	0,18	0,23	0,07	0,08	0,29
Connection placement							
Numb. of plates / Thermal length		18	TK	28	TK	30	TKTL 33%
Effective heat surface	(m^2)	3.4		5.5		5.9	
Plate arrangement (passes*channel)		1 * 9 + 0 * 0	1 * 8 + 0 * 0	1 * 14 + 0 * 0	1 * 13 + 0 * 0	1 * 14 + 0 * 0	1 * 15 + 0 * 0
Heat exchanged	(kW)	129		116		304	
		Sec: 4		Sec:		Sec:	
		Hot side	Cold side	Hot side	Cold side	Hot side	Cold side
Fluid		Milk	PropGlycol				
Flowrate	(m3/h)	6,50	26,04				
Inlet temperature	(°C)	28,00	2,00				
Outlet temperature	(°C)	4,00	8,00				
Pressure drop	(bar)	0,02	0,30				
Connection placement							
Numb. of plates / Thermal length		93	TKTL 69%				
Effective heat surface	(m^2)	19.1					
Plate arrangement (passes*channel)		1 * 46 + 0 * 0	1 * 46 + 0 * 0	* + *	* + *	* + *	* + *
Heat exchanged	(kW)	173					

COMMENTS:

Technical specifications

Total volumen all sections	(liter)	74	Total number of plates	169
Total heat transfer area	(m^2)	33.8	Plate material	0.4 mm AISI 316
Max. Working/test pressure	(bar)	10.0	Gasket material / Max. temp.	NITRIL HT HANG ON (H)
Max. Working/test pressure	(bar)	13.0	Connections product side ß	DN 50 Dairy union DIN
Max. design temperature	(°C)	100	Connections medium side ß	DN 50 Dairy union DIN
Total frame length	(mm)	1329	No. of intermediate frames	3

Conditions of quotation		Accessories:
PRICE EACH	NNN 8981	NNN 0
Condiciones de Pago		
Condiciones de Venta		
Validez de la oferta		
Plazo de entrega		
Diseñado por		
OTHER CONDITIONS		

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Figure 6. Sofware simulation of the plate heat exchanger [23].

10. RESULTS AND DISCUSSION

It can be verified that results obtained are in accordance with the literature and fit with the simulation. This way, the number of necessary plates calculated is 168 against 169 [48]The total heat effective surface calculated is 35,99 m^2 and 33,8 m^2 [48], with a 6,5 % of relative error which is very acceptable.

This exchanger has a total frame length of 1.329 mm with a capacity of 267 plates [48]. Therefore and since it was mentioned previously it has a capacity for almost 110 additional plates, which is one of the advantages of the plate interchanger.

The comparison of Tables 15 to 18 with the results obtained by calculation and simulation values provided, are exposed later to verify the validity of the results for each section.

	Calculated values		J.Negre values		Absolute error		Relative error %	
Regeneration section	hot side	cold side	hot side	cold side	hot side	cold side	hot side	cold side
U (W/(m2.K))	2304,81		2121,47		183,34		8,64	
pressure drop (bar)	0,28	0,11	0,23	0,18	0,05	0,07	21,74	38,89
number of plates	20		18		2		11,11	
efective heat surface (m2)	4,19		3,4		0,79		23,24	
liquid volume (l)	8,7		8		0,7		8,75	
heat exchange (kW)	165,93		129		36,93		28,63	
flow rate (m3/h)	10,9	6,5	8,23	6,5	2,67	0	32,44	0,00

	Calculated values		J.Negre values		Absolute error		Relative error %	
Warming section	hot side	cold side	hot side	cold side	hot side	cold side	hot side	cold side
U (W/(m2.K))	2379,28		2336,77		42,51		1,82	
pressure drop (bar)	0,15	0,05	0,22	0,07	0,07	0,02	31,82	28,57
number of plates	31		28		3		10,71	
efective heat surface (m2)	6,64		5,46		1,18		21,61	
liquid volume (l)	13,5		12		1,5		12,50	
heat exchange (kW)	113,43		116		2,57		2,22	
flow rate (m3/h)	12,57	6,5	12,7	6,5	0,13	0	1,02	0,00

	Calculated values		J.Negre values		Absolute error		Relative error %	
Cooling I section	hot side	cold side	hot side	cold side	hot side	cold side	hot side	cold side
U (W/(m2.K))	2755,71		2836,49		80,78		2,85	
pressure drop (bar)	0,05	0,46	0,08	0,29	0,03	0,17	37,50	58,62
number of plates	31		30		1		3,33	
efective heat surface (m2)	6,55		5,88		0,67		11,39	
liquid volume (l)	13,5		13		0,5		3,85	
heat exchange (kW)	303,606		303		0,606		0,20	
flow rate (m3/h)	6,5	21,87	6,5	11,93	0	9,94	0,00	83,32

	Calculated values		J.Negre values		Absolute error		Relative error %	
Cooling II section	hot side	cold side	hot side	cold side	hot side	cold side	hot side	cold side
U (W/(m2.K))	1361,27		1161,4		199,87		17,21	
pressure drop (bar)	0,014	0,06	0,02	0,3	0,006	0,24	30,00	80,00
number of plates	86		93		7		7,53	
efective heat surface (m2)	18,61		19,11		0,5		2,62	
liquid volume (l)	37,4		41		3,6		8,78	
heat exchange (kW)	173,91		173		0,91		0,53	
flow rate (m3/h)	6,5	12,12	6,5	26,04	0	13,92	0,00	53,46

Table 15, 16, 17, 18. Results comparison with calculated values with the simulation ones.

The pressure drop does not coincide with the information provided by the manufacturer with errors of 40 %. These depend on a great extent on the design of the plates. Another difficulty is that the manufacturer does not detail the design of the plates; there is not information about the corrections as angle of the corrugations. The relation between high size and width is kept in mind in the calculations although for cooling sections mass flows of service fluid do not agree. For what, the reason of this mistake is the lack of information of the plates used in the equipment. Also, it can be said that the value of the pressure drop is more or less similar in magnitude when the plates are of a certain size.

On the other hand, about the global coefficient U, the error ranges between 2 and 18% and the number of plates calculated is quite close to the provided ones. It can be said that below 25-30% the model can be validated being acceptable errors.

11. CONCLUSIONS

In the present project, it has been determined that the best method to obtain free lactose milk is the enzymatic hydrolysis by means of soluble enzyme.

- The enzyme *β-galactosidase* from *K.lactis* shows its major stability at 45ºC and with a pH of 6,5, what offers the ideal conditions for the hydrolysis.
- The kinetic model of Michaelis-Menten of inhibition for galactose has proposed that the hydrolysis of lactose by means of *β-galactosidase* implies that the lactose and the galactose occupy the active place of the enzyme with the same probability.
- The utilization of soluble enzyme is more profitable since it does not importantly affect neither the initial investment nor the costs of production. The drop in prices of this type of enzymes in regard to the immobilized and the social prejudices referring to the biotechnology are reasons that explain this preference.
- To obtain the final product where the enzymes have been deactivated and micro-organisms eliminated, the continue method of pasteurization, HTST, allows to preserve the properties of milk, like calcium and vitamins, and it makes suitable for human consumption.
- The information found in the literature regarding the parameters and variables that take part in this thermal treatment has allowed to model mathematically an HTST pasteurizer. This model has been validated by means of the simulation of the plate exchanger provided by the company with errors below 25% [48].

It should be interesting to study the possibility to obtain free-lactose milk from membrane technologies at the same time dairy whey is treated. So, the conversion of the lacteal whey in a product with an added value and with the possibility of being exported could bring an economic positive impact as well as an interesting commercial and development possibility.

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13. ACRONYMS

HTST: High Temperature Short Time

U.H.T: Ultra High Temperature

DQO: Chemical Demand of Oxygen

MES: Suspended matter

DBO: Biochemical Demand of Oxygen

GHG: Greenhouse Gases

FAO: Food and Agriculture Organization

GRAS: Generally Recognized as Safe

FCC: Food Chemical Codex

Overwritten symbols

PropGlycol: Propylene Glycol

Nomenclature

A : Heat transfer area, m^2

A_f : Area of total flow of fluids, m^2

a_p: Effective width, m

C_{min}: Reason of minimal calorific capacity, W/K

C_p: Calorific capacity, J/(kg.ºC)

D: Time necessary to destroy the 90% of the micro-organisms in the product. It is the time of thermal destruction or of decimal reduction in seconds

D_e: Hydraulic diameter, m

E: Thickness of plate, m

E_p: Separation between plates, m

F: Correction factor

F_0: Lethal value

f: Friction factor

G_f: Mass velocity of product to treating, kg/(m^2.s)

G_w: Mass velocity of service fluid, kg/(m^2.s)

H: Heat transfer coefficient of convection, W/(m^2.K)

K: Heat transfer coefficient of conductivity, W/(m.K)

K: Conductivity of the material, in this case stainless steel 316, W/(m.K)

m_f : Flow of product to treating (raw or pasteurized milk), kg/s

m_w: Flow of the service fluid (water or raw milk)

N: Number of micro-organisms per gram which rest in the product after a time t.

N_0: Number of micro-organisms per gram at the time t=0.

N_c: Number of channels for each fluid

N_{ct}: Number of total channels

N_p: Number of plates

N_s: Number of steps of each fluid

N_u: Nusselt number

NUT: Number of units of heat transfer

P_r : Prandtl number

ΔP_t: loss of total pressure,Pa

ΔP_f : Loss of pressure of fluid treated, Pa

ΔP_w: Loss of pressure of service fluid, Pa

Q: heat flow exchange, J/s

R_e: Reynolds number

R_d: Soiling factor

R_g: Regeneration efficiency, %

t: Time of heat at a determinate temperature

t_e: Temperature of entry of service fluid ,ºC

t_i: Temperature of enter of not pasteurized fluid

t_p: Pasteurization temperature (84ºC)

t_r: Temperature of the fluid pasteurized after the regeneration

t_s: Temperature of entry of service fluid ,ºC

T_e: Temperature of entry of product to treating, ºC

T_s: Temperature of exit of product to treating, ºC

ΔTm: Logarithmic average temperature

U_c: Global coefficient of design, W/(m^2.K)

U_D: Real heat transference coefficient, W/(m^2.K)

Z: Increase of temperature needed to reach a thermal destruction of 90% D, ºC

Greek symbols

ε : Efficiency

ρ: Density, kg/m^3

μ: Viscosity, kg/(m.s)

APPENDICES

APPENDIX 1: COMPETITIVE INHIBITION BY PRODUCT

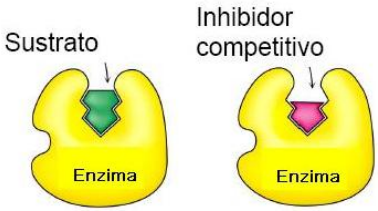


Figure 7. Competitive inhibitor occupying the active place [65].

APPENDIX 2: LIMIT VALUES OF MILK EMISSIONS

PROCESADO DE ALIMENTOS, BEBIDA Y LECHE

SECTORES INDUSTRIALES

Actividades Industriales de la Directiva IPPC:
a) tratamiento y transformación destinados a la fabricación de productos alimenticios a partir de:
- materia prima animal (que no sea la leche) de una capacidad de producción de productos acabados superior a 75 T/día
- materia prima vegetal de una capacidad de producción de productos acabados superior a 300 T/día (valor medio trimestral)

b) tratamiento y transformación de la leche, con una cantidad de leche recibida superior a 200T/día (valor medio anual)

PARÁMETROS CARACTERÍSTICOS ORIENTATIVOS(1)

Fuente: Documento de orientación para la realización del EPER. Apéndice 5. (1)
a) N_T, P_T, TOC, Cl^-
b) N_T, P_T, TOC, Cl^-

VALORES LÍMITE DE EMISIÓN (VLE)(2)

PARÁMETRO	VALOR LÍMITE DE EMISIÓN(3)
DBO_5 (mg/l)	< 25
DQO (mg/l)	< 125
SS_T (mg/l)	<50
pH (uds)	6 - 9
Aceites y grasas (mg/l):	< 10
N_T (mg/l)	< 10
P_T (mg/l)	0,4 - 5
Coliformes (-/100 ml):	400

NOTAS

(1) El documento de referencia cita los siguientes parámetros/sustancias contaminantes: DBO, DQO, SST, MES, pH, Aceites y grasas, NO_3^-, NO_2^-, NH_4^+ y $PO_4^{=}$

(2) VLE de tipo general. El Documento define también para algunos procesos y basándose en casos reales, VLE diferentes para algunos parámetros, mediante aplicación de sistemas de depuración específicos, o incluso parámetros diferentes.

(3) Se pueden obtener mejores VLE de DBO_5 y DQO. En algunos casos no se podrán conseguir los VLE de Nitrógeno y Fósforo total debido a las condiciones locales y económicas.

APPENDIX 3: COMPARISON OF IMMOBILIZATION METHODS

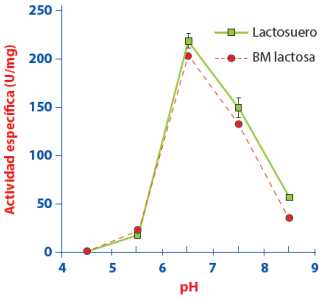
CARACTERÍSTICAS	ADSORCIÓN	ENL. COVALENTE	ENTRECRUZA-MIENTO	MEMBRANAS
PREPARACIÓN	Simple	Difícil	Intermedia	Difícil
FUERZA DE UNIÓN	Débil	Fuerte	Fuerte	Intermedia
ACTIVIDAD ENZIMÁTICA	Intermedia	Alta	Baja	Baja
REGENERACIÓN DEL SOPORTE	Posible	Rara	Imposible	Imposible
COSTE	Baja	Alta	Intermedia	Intermedia
ESTABILIDAD	Baja	Alta	Alta	Alta
APLICABILIDAD	Si	No	No	Si
PROTECCIÓN FRENTE A ATAQUE MICROBIANO	No	No	Posible	Si

Table 19. Immobilization methods [24].

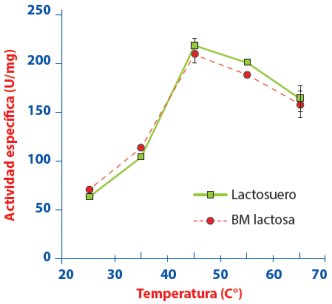
MÉTODO	VENTAJAS	INCONVENIENTES
ADSORCIÓN	Los centros activos permanecen inalterados.	Posible desorción de enzimas por cambios en pH, temperatura…
	No se requieren reactivos y las etapas de activación son sencillas	Métodos no específicos para cada reacción/enzima
	Método sencillo y económico.	
ENLACE COVALENTE	Estabilidad del enzima. No se desliga.	Método caro y complicado.
	Método muy flexible, según se elija el agente portador y método de enlace.	La actividad puede reducirse si los reactivos usados son tóxicos para el enzima.
		Los centros activos pueden modificarse/dañarse durante el proceso.
ENTRECRUZAMIENTO	Enzima muy estable, fuertemente enlazado.	Puede dañar los centros activos.
	Puede usarse en combinación con la adsorción para prevenir pérdida de catalizador.	Puede haber problemas difusionales que limiten el rendimiento.
		Pérdida de enzima durante preparación.
MEMBRANAS	Simplicidad.	Problemas difusionales debidos a la membrana.
	Posibilidad de uso simultáneo de varios enzimas.	Posible inactivación de enzimas, sometidos a fuerzas de cizalla elevadas.
	Uso de membranas selectivas: control de sustratos/productos en mezclas.	Mal funcionamiento a bajas concentraciones de sustrato (adsorción de éste en la membrana)
	Protección del enzima ante inhibición, envenenamiento…	Estricto control del tiempo de residencia para sustratos de bajo peso molecular.
	No hay pérdidas.	
	Adecuado para sustratos de alto peso molecular, buen contacto enzima-sustrato: altas conversiones.	

Table 20. Advantages and disadvantages of immobilization enzyme methods [48].

APPENDIX 4: STUDIES OF PH AND TEMPERATURE FOR LACTASE FROM *KLUYVEROMYCES LACTIS*



Graphic 1. pH effect above the activity of lactase from *kluyveromyces lactis* using a concentration of lactose of 128g/l *[2].*



Graphic 2. Temperature effect above the activity of lactase from *kluyveromyces lactis* using a concentration of lactose of 128g/l *[2].*

APPENDIX 5: LACTOSE HYDROLISIS METHODS IN THE DAIRY INDUSTRY

INSTITUCION	PAIS	FUENTE DE ENZIMA	TIPO DE INMOVILIZACION Y SOPORTE	APLICACION	OPERACION
Snamprogetti	Italia	*K. lactis* (Maxilact)	Atrapamiento en fibras de triacetato de celulosa	Reducción de lactasa en leche. Proceso por lote.	Industrial Central Latteria di Milano.
Gist-Brocades	Holanda	*K. lactis* (Maxilact)	No reportado	Procesamiento de leche.	Planta piloto.
Röhm-Gmbh	Alemania Federal	*A. oryzae*	Unión covalente a material poroso (Plexazym LA-1)	Procesamiento de suero ácido y leche. Reactor de lecho fijo.	Planta piloto.
Sumitomo	Japón	*A. oryzae*	Unión covalente a resina de intercambio iónico.	Procesamiento de suero y leche.	Planta piloto.

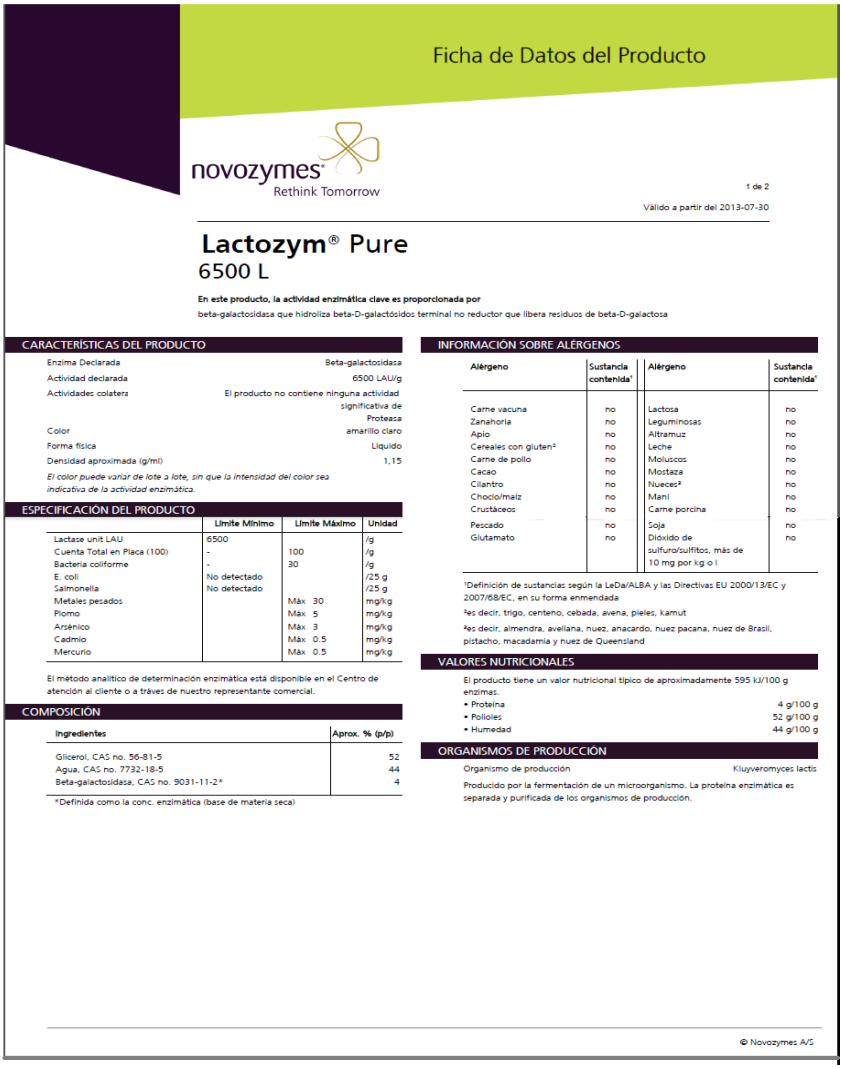
Table 21. Immobilized lactase techniques available in the market [21].

Tabla 2.3 – Métodos comerciales para la obtención de hidrolizados de lactosa.

Procedimiento	Referencias	Observaciones
Hidrogenación mediante uso de catalizador.	**Patente U.S. nº 2.642.462** **Patente U.S. nº 2.868.847**	Catalizador de níquel. Catatizador de rutenio; se obtiene cierta cantidad de polialcoholes
Hidrólisis ácida a 100ºC (en fase homogénea y heterogénea)	**(Ryder (1989), González Siso (1996))**	Se produce reacción de Maillard con pardeamiento de la disolución. Aplicación de calor y pH bajos
Hidrólisis enzimática con enzima libre.	**(Ryder (1989), Gist-Brocades)**	Simplicidad de operación. Alto consumo de enzima.
Hidrólisis enzimática con enzima inmovilizada.	Método Valio. **(Virkkala (1988) , Zadow (1992),)**	Hidrólisis de lactosa en suero y leche desnatada. Inmovilización de enzima en resina
	Método Snam Progetti **(Snam Progetti (1970))**	Enzima retenida sobre fibras de acetato de celulosa o poliméricas. Para leche o suero.
	Método Corning **(Zadow (1992))**	Enzima unida por enlace covalente a partículas de sílice. Para sustratos ácidos. Plantas en Kentucky y Gran Bretaña (350 Tm/año)
	Método Sumitomo **(Zadow (1992))**	Enzima inmovilizada en resina. Para leche y sueros, en condiciones de pH neutros y temperaturas de 35-40ºC
Producción de leche con bajo contenido en lactosa.	**(Gist-Brocades)**	Obtención de leche parcialmente deslactosada para consumo directo u otros usos (queso).
Producción de jarabes de suero.	**(Gist-Brocades)**	Suele sufrir procesos de concentración **(Figuras 2.4 y 2.5)** para ser utilizado en usos diversos (panadería, etc.)

Table 22. Comercial methods of lactose hydrolysis [14].

APPENDIX 6: PRODUCT SHEET OF LACTOSYM PURE



Ficha de Datos del Producto

novozymes
Rethink Tomorrow

1 de 2

Válido a partir del 2013-07-30

Lactozym® Pure 6500 L

En este producto, la actividad enzimática clave es proporcionada por
beta-galactosidasa que hidroliza beta-D-galactósidos terminal no reductor que libera residuos de beta-D-galactosa

CARACTERÍSTICAS DEL PRODUCTO

Enzima Declarada	Beta-galactosidasa
Actividad declarada	6500 LAU/g
Actividades colaterales	El producto no contiene ninguna actividad significativa de Proteasa
Color	amarillo claro
Forma física	Líquido
Densidad aproximada (g/ml)	1,15

El color puede variar de lote a lote, sin que la intensidad del color sea indicativa de la actividad enzimática.

ESPECIFICACIÓN DEL PRODUCTO

	Límite Mínimo	Límite Máximo	Unidad
Lactase unit LAU	6500		/g
Cuenta Total en Placa (100)	-	100	/g
Bacteria coliforme	-	30	/g
E. coli	No detectado		/25 g
Salmonella	No detectado		/25 g
Metales pesados		Máx 30	mg/kg
Plomo		Máx 5	mg/kg
Arsénico		Máx 3	mg/kg
Cadmio		Máx 0.5	mg/kg
Mercurio		Máx 0.5	mg/kg

El método analítico de determinación enzimática está disponible en el Centro de atención al cliente o a través de nuestro representante comercial.

COMPOSICIÓN

Ingredientes	Aprox. % (p/p)
Glicerol, CAS no. 56-81-5	52
Agua, CAS no. 7732-18-5	44
Beta-galactosidasa, CAS no. 9031-11-2*	4

*Definida como la conc. enzimática (base de materia seca)

INFORMACIÓN SOBRE ALÉRGENOS

Alérgeno	Sustancia contenida[1]	Alérgeno	Sustancia contenida[1]
Carne vacuna	no	Lactosa	no
Zanahoria	no	Leguminosas	no
Apio	no	Altramuz	no
Cereales con gluten[2]	no	Leche	no
Carne de pollo	no	Moluscos	no
Cacao	no	Mostaza	no
Cilantro	no	Nueces[3]	no
Chocho/maíz	no	Maní	no
Crustáceos	no	Carne porcina	no
Pescado	no	Soja	no
Glutamato	no	Dióxido de sulfuro/sulfitos, más de 10 mg por kg o l	no

[1]Definición de sustancias según la LeDa/ALBA y las Directivas EU 2000/13/EC y 2007/68/EC, en su forma enmendada

[2]es decir, trigo, centeno, cebada, avena, pieles, kamut

[3]es decir, almendra, avellana, nuez, anacardo, nuez pacana, nuez de Brasil, pistacho, macadamia y nuez de Queensland

VALORES NUTRICIONALES

El producto tiene un valor nutricional típico de aproximadamente 595 kJ/100 g enzimas.

• Proteína	4 g/100 g
• Polioles	52 g/100 g
• Humedad	44 g/100 g

ORGANISMOS DE PRODUCCIÓN

Organismo de producción: Kluyveromyces lactis

Producido por la fermentación de un microorganismo. La proteína enzimática es separada y purificada de los organismos de producción.

novozymes®

Lactozym® Pure
6500 L

CONDICIONES DE ALMACENAMIENTO

Temperatura de almacenamiento: 0-10 °C (32-50 °F)

El embalaje debe mantenerse intacto, seco y lejos de la luz solar. Siga las recomendaciones y utilice el producto antes de la fecha de consumo preferente para evitar la necesidad de una dosis mayor.

Utilizar preferentemente antes de: Encontrará la fecha de consumo preferente en el certificado de análisis o en la etiqueta del producto.

El producto proporciona un rendimiento óptimo si se almacena según las recomendaciones y se utiliza dentro de los 24 meses siguientes a la fecha de producción.

Novozymes garantiza la entrega al menos 12 meses antes de la fecha de consumo preferente.

El producto puede entregarse a temperatura ambiente. Tras la entrega, el producto debe almacenarse según se recomienda entre 0-10 °C/32-50 °F.

PRECAUCIONES DE SEGURIDAD Y MANEJO

Las enzimas son proteínas. La inhalación de polvo o aerosoles puede inducir sensibilización y provocar reacciones alérgicas en personas sensibilizadas. Algunas enzimas pueden irritar la piel, ojos y membranas mucosas cuando el contacto es prolongado. Consulte el Manual de Seguridad o MSDS para obtener más información sobre la manipulación segura del producto y los derrames.

CUMPLIMIENTO DE NORMAS

El producto cumple con las especificaciones de pureza recomendadas para enzimas de grado alimenticio dadas por la Joint FAO/WHO Expert Committee on Food Additives (JECFA) y por Food Chemical Codex (FCC).

Los certificados Halal y Kosher están disponibles en el Centro de atención al cliente o por medio de su representante de ventas.

CERTIFICACIONES

Novozymes suscribe al Pacto Mundial de las Naciones Unidas y la Convención de las Naciones Unidas sobre la diversidad biológica y los informes sobre el rendimiento de la sostenibilidad a través de la iniciativa Global Reporting Initiative (GRI). Vea todos nuestros compromisos en www.novozymes.com.

NOVOZYMES ISO 9001 REGISTERED

NOVOZYMES ISO 14001 REGISTERED

SEGURIDAD ALIMENTARIA

El producto es controlado por el sistema de gestión de calidad de Novozymes y se elabora según un plan de HACCP que tiene el apoyo de un programa completo como requisito previo.

El producto cumple con los requisitos de pureza recomendados por el comité JECFA de la FAO/OMS y los requisitos de pureza recomendados por la FCC con respecto a las micotoxinas.

ENVASES

El producto está disponible en diferentes tipos de envases. Póngase en contacto con el representante de ventas para obtener más información.

Novozymes Latin America Ltda.
Rua professor Francisco Ribeiro 683
CEP 83707-660 - Araucária - Parana
Brazil

Tel. +55 41 641 1000
Fax +55 41 643 1443

Para más informaciones, o direcciones de nuestras oficinas, visite: www.novozymes.com

Dairy

novozymes
Food & Beverages

Novozymes Lactozym® Pure pH and temperature curves

Information sheet

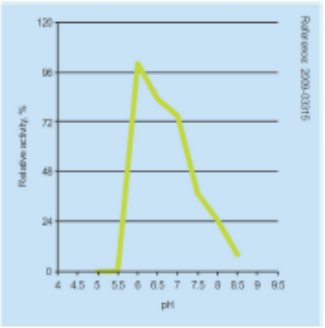


Fig. 1. Effect of pH on activity of Lactozym Pure

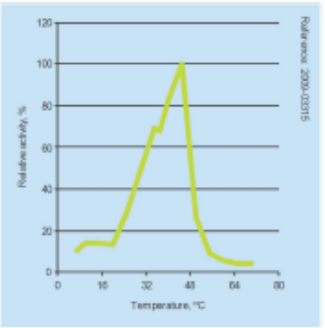


Fig. 2. Effect of temperature on activity of Lactozym Pure

Rethink Tomorrow

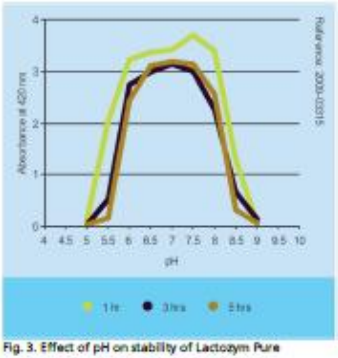


Fig. 3. Effect of pH on stability of Lactozym Pure

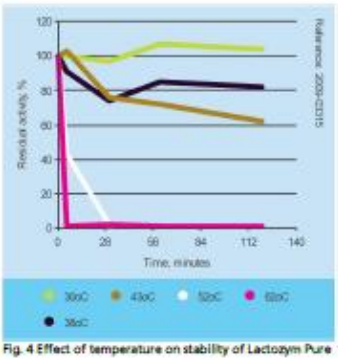


Fig. 4 Effect of temperature on stability of Lactozym Pure

Graphs are generated under laboratory conditions in buffered solutions and may not reflect performance in the application. It is, therefore, recommended to evaluate the performance of the enzyme under the specific application conditions.

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Novozymes is the world leader in bioinnovation. Together with customers across a broad array of industries we create tomorrow's industrial biosolutions, improving our customers' business, and the use of our planet's resources. Read more at www.novozymes.com.

APPENDIX 7: BUDGET OF LACTASE IMMOBILITZATION

MINISTERIO DE CIENCIA E INNOVACIÓN

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

INSTITUTO DE CATÁLISIS Y PETROLEOQUÍMICA

Presupuesto Nº 2015/1002

INMOVILIZACION COVALENTE DE LACTASA

Centro: INSTITUTO DE CATALISIS Y PETROLEOQUIMICA (ICP), CSIC, MADRID

Investigador responsable: Francisco J. Plou

Objetivo: Obtención de 100 miligramos de lactasa de *K. lactis* unida covalentemente a glioxil-agarosa

PRESUPUESTO

	EURO
Estudio previo de la estabilidad de la lactasa en condiciones de inmovilización	*300.00*
Inmovilización de lactasa	*300.00*
Determinación de la actividad del inmovilizado	*100.00*
TOTAL	*700.00*
IVA (21%)	*147.00*
TOTAL	***847.00***

Aceptación del presupuesto por parte de la institución

Nombre:

Cargo:

CORREO ELECTRÓNICO:

fplou@icp.csic.es

CANTOBLANCO.
28049 MADRID
TELÉFONO: +34-91 585 4869
FAX:+34- 91 585 4760

APPENDIX 8: PROPYLENE GLYCOL

PROPILENGLICOL.FDS

Ficha de Datos de Seguridad — ACOFARMA

Conforme al Reglamento (CE) Nº 1907/2006 (REACH).

1.- Identificación de la sustancia o del preparado y de la sociedad o empresa

Identificación de la sustancia o del preparado

Denominación: Propilenglicol Ph.Eur.

Identificación de la sociedad o empresa:

Acofarma Distribución S.A.
Llobregat, 20
08223-Terrassa. España.
Tel: 93 736 00 88 / Fax: 93 785 93 62

Teléfono de urgencias: Instituto Nacional de Toxicología. Madrid. Tel: 91 562 04 20

2.- Identificación de los peligros

Clasificación de la sustancia o de la mezcla
De acuerdo al Reglamento (EC) No1272/2008
Irritación ocular (Categoría 2)
Esta sustancia no esta clasificada como peligrosa según la Directiva 67/548/CEE.
Elementos de la etiqueta

Pictograma
Palabra de advertencia Atención
Indicación(es) de peligro
H319 Provoca irritación ocular grave.
Declaración(es) de prudencia
P305 + P351 + P338 EN CASO DE CONTACTO CON LOS OJOS: Aclarar cuidadosamente con agua durante varios minutos. Quitar las lentes de contacto, si lleva y resulta fácil. Seguir aclarando.
Otros Peligros - ninguno(a)

3.- Composición/información sobre los componentes

CAS-Nº.:	57-55-6	EINECS: 200-338-0
PM:	76.10	
Fórmula molecular:	$C_3H_8O_2$	

4.- Primeros auxilios

Tras inhalación: Aire fresco.
Tras contacto con la piel: Aclarar con abundante agua. Eliminar la ropa contaminada.
Tras ingestión: Beber abundante agua, provocar vómito y llamar al médico. Lavado de estómago.

5.- Medidas de lucha contra incendios

Medios de extinción adecuados:
Agua, CO_2, espuma, polvo.
Riesgos especiales:
Inflamable. Vapores más pesados que el aire. En caso de incendio pueden formarse vapores tóxicos.
Posible formación de mezclas explosivas con aire.

Ficha de Datos de Seguridad ACOFARMA

Denominación: **Propilenglicol Ph.Eur.**

6.- Medidas a tomar en caso de vertido accidental

Medidas de precaución relativas a las personas:
Recoger con materiales absorbentes y proceder a la eliminación de los residuos. Aclarar después.

7.- Manipulación y almacenamiento

Manipulación:
Sin otras exigencias.
Almacenamiento:
Almacenar bien cerrado. En lugar bien ventilado. Alejado de fuentes de ignición.
Entre +15ºC y +25ºC.

8.- Controles de exposición/protección personal

Protección personal:

Protección respiratoria:	Necesaria en presencia de vapores/aerosoles.
Protección de las manos:	Precisa.
Protección de los ojos:	Innecesaria.

Medidas de higiene particulares:
Sustituir la ropa contaminada. Lavarse las manos al finalizar el trabajo.

9.- Propiedades físicas y químicas

Estado físico:	Líquido	
Color:	Incoloro	
Olor:	Característico	
Valor pH (a 100 g/l H_2O)	(20ºC)	6-8
Viscosidad dinámica	(20ºC)	45 mPa*s
Punto de fusión		-59 ºC
Punto de ebullición		189 ºC
Punto de ignición		410 ºC
Punto de destello		103 ºC
Limites de explosión	bajo	2.6 Vol%
	alto	12.6 Vol%
Presión de vapor	(20º)	aprox. 0.2 mbar
Densidad	(20ºC)	1.04 g/cm^3
Solubilidad en agua	(20°C)	soluble
Descomposición térmica		sobre punto de ebullición

10.- Estabilidad y reactividad

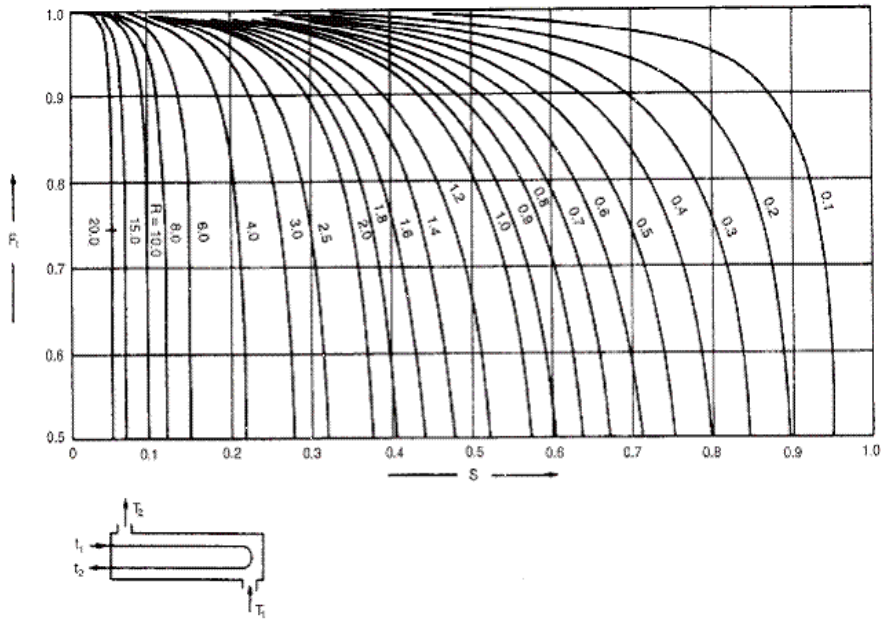
Condiciones a evitar:
Información no disponible.
Materias a evitar:
Con oxidante: En estado gaseoso/vapor existe riesgo de explosión con el aire.

Propylenglycol is a so versatile product that has turned into the favorite product of food industries. The more common applications is the fact of being a way of heat transfer of low temperature. It is applied in systems of cooling brewery and lacteal industries, as well as for other equipments of refrigeration in direct contact with food or drinks. In watery solution, it presents excellent antifreezes properties.

The Propylenglycol is completely miscible with water. It is the only one between the glycols with low toxicity allowing its utilization as direct additive in food. However, the functions of a good cooling liquid are to control the quality of the water, to protect of the corrosion and to reduce the temperature of the system. Due to the possibilities of corrosion that can happen for the mentioned applications, it is advisable use a product inhibited that provides to the system freeze and corrosive protection. The Propylenglycol USP/EP is the base of the liquid DOWFROST, one of the fluids of heat transfer patented by Dow. It expires with the requirements of the FDA and the USDA for its use in applications where there can be accidental contact with food. DOWFROST offers a series of advantages on other cooling products as the frozen water or the brine. Given the very low toxicity of the fluid, there exists less risk that the product remains unusable if there was pollution due to small escapes in the system.

A concentration of 30 % of DOWFROST allows temperatures of operation of-12,2°C. In contrast, the systems of frozen water do not reach low temperatures to 1,1°C. For applications that need temperatures furthermore low, one can use a concentration of 50 % of propylenglycol for producing the system up to-33°C. The frozen water and the brine can turn out to be corrosive enough for the metallic parts of the system. The fluid of heat transfer DOWFROST expires with all the procedure of the method of test of corrosion ASTM D1384. This process has notable advantages on the conventional freezing provided that it diminishes drastically the time of the cycle of freezing, the requirements of space for the equipment are minor and the flexibility of the plant is improved. It has a useful life of 20 years in the refrigeration system [49],[50].

APPENDIX 9: GRAPHIC DETERMINATION OF F FACTOR



APPENDIX 10: KUMAR CONSTANTS

CONSTANTES DE KUMAR (1984) PARA TRANSFERENCIA DE CALOR Y PÉRDIDAS DE PRESIÓN

Chevron Angle β	Reynolds	C_h	y	Reynolds	K_p	z
≤30	≤10	0.718	0.349	<10	50	1
	>10	0.348	0.663	10-100	19.4	0.589
				>100	2.99	0.183
45	<10	0.718	0.349	<15	47	1
	10-100	0.4	0.598	15-300	18.29	0.652
	>100	0.3	0.663	>300	1.441	0.206
50	<20	0.63	0.333	<20	34	1
	20-300	0.291	0.591	20-300	11.25	0.631
	>300	0.13	0.732	>300	0.772	0.161
60	<20	562	0.326	<40	24	1
	20-400	0.306	0.529	40-400	3.24	0.457
	>400	0.108	0.703	>400	0.76	0.215
≥65	<20	0.562	0.326	<50	24	1
	20-500	0.331	0.503	50-500	2.8	0.451
	>500	0.087	0.718	>500	0.639	0.213

Fuente: Bejan, Heat Transfer Handbook (12)

APPENDIX 11: Z AND D VALUES FOR STERILIZATION FACTOR

Valores de *D* y *z* para diferentes microorganismos [2]

Organismo	Temp. (°C)	*D* (seg)	*z* (°C)
➢ *Bacillus steratotermophilus*			
TH4 (en agua)	120	1.000	7.3
FS 7954 (en tampón fosfato)	121	6	8.3
NCIB 8919 (en agua)	121	186	7.0
➢ *Bacillus subtilis*			
5230 (en agua)	121	6.0	8.3
5230 (en tampón fosfato)	121	21.9	8.8
➢ *Clostridium botulinum*			
Tipo A (en agua)	121	6.0	8.3
A35B (en tampón fosfato)	121	19.2	10.8
213B (en vegetales)	121	6.6	9.8
213B (en tampón fosfato)	110	96	10.3
62A (en puré de guisantes)	121	5.34	8.3
➢ *Clostridium thermosaccharolyticum*			
S9 (en agua)	132	4.4	6.9
➢ *Desulfotomaculum nigrificans*			
ATCC7946	121	1.550	6.7
➢ *Escherichia coli*			
Agua	55	402	3.6

Table 21. D and Z values [45]

APPENDIX 12: MICROBIOGICAL LIMITS ESTABLISHED FOR COW'S MILK

Limits established in the annexes I and III of the Regulation CEE 2377/90 for the raw cow's milk

The raw cow's milk destined for the production of consumption milk treated térmically, of fermented, studded milk, coagulate or aromatized and of creams will fulfill the following procedure:

Content of germens to 301C (per ml) < 100.000 (a)
Content of somatic cellules (per ml) < 400.000 (b)

a) Geometric average observed during a period of two months, with two samples, at least, a month.
b) Geometric average observed during a period of three months, with a sample, at least, a month, or, when the production is very variable depending on the station, the method of calculation of the results will adapt in accordance with what arranges the community procedure.

MICROBIOLOGICAL CRITERION FOR THE PASTEURIZED MILK

It exists Microbiological Norm applicable to the pasteurized milk, on order of February 11, 1987 (B.O.E. 20-2-87), where the General Norm is modified for the pasteurized milk. ·

Inventory of aerobic colonies mesophylls..... Maximum 1 x 10^5/ml ·
Total Enterobacteriaceae..... Maximum 1 x 10 col./ml ·
Tries of phosphatase .....Negative

APPENDIX 13: SIMULATION OF REGENERATION SECTION

J. Negre C. PHE - Design & Datalist

V10A34
JNC 20/04/2015
001 Item: 588

PHE-Type	S20A-ST16-18-TK-LIQUID	Hot side	Cold side
Flowrate	(m3/h)	8,23	6,50
Inlet temperature	(°C)	84,40	50,00
Outlet temperature	(°C)	70,00	68,00
Pressure drop	(bar)	0,23	0,18
Heat exchanged	(kW)	129	
Thermodynamic properties:		Milk	Milk
Density	(kg/m³)	990,59	1.006,44
Specific heat	(kJ/kg*K)	3,97	3,95
Thermal conductivity	(W/m*K)	0,54	0,52
Mean viscosity	(mPa*s)	0,61	0,71
Wall viscosity	(mPa*s)	0,71	0,61
Fouling factors	(m²*K/kW)	0,10	0,10
Dimensioning factor	%	68,97	
Inlet branch		F1	F3
Outlet branch		F4	F2

Design of Frame / Plates:		
Plate arrangement (passes*channel)		1 x 9 + 0 x 0
Plate arrangement (passes*channel)		1 x 8 + 0 x 0
Number of plates		18
Effective heat surface	(m²)	3,36
Overall K-value Duty/Clean	(W/m²*K)	2.121,47 3.584,73
Plate material		0.4 mm AISI 316
Gasket material / Max. temp.		NITRIL HT HANG ON (H) / 140
Max. design temperature	(°C)	120,00
Max. Working/test pressure	(bar)	10,00 13,00
Max. Differential pressure	(bar)	10,00
Approval		None
Liquid volume	(liter)	8
Frame length	(mm)	437 Max. No. of Plates 39
Net weight	(kg)	154
Frame type		ST

Connections HOT side : 2 INCH Threaded pipe BSP, AISI 316
Connections COLD side: 2 INCH Threaded pipe BSP, AISI 316

Category C2L BLUE RAL 5010
EU Pallet (1200x800) 22

J. Negre C. S.L Paris 1-7 nave 28 08191 (Rubí)
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APPENDIX 14: SIMULATION OF WARMING SECTION

J. Negre C. PHE - Design & Datalist

V10A34

JNC 20/04/2015

001 Item: 588

PHE-Type	S20A-ST16-28-TK-LIQUID		Hot side	Cold side
Flowrate	(m3/h)		12,70	6,50
Inlet temperature	(°C)		90,00	68,00
Outlet temperature	(°C)		81,89	84,40
Pressure drop	(bar)		0,22	0,07
Heat exchanged	(kW)		116	
Thermodynamic properties:			Water	Milk
Density	(kg/m³)		967,99	991,56
Specific heat	(kJ/kg*K)		4,20	3,96
Thermal conductivity	(W/m*K)		0,67	0,54
Mean viscosity	(mPa*s)		0,35	0,62
Wall viscosity	(mPa*s)		0,40	0,58
Fouling factors	(m²*K/kW)		0,06	0,06
Dimensioning factor	%		41,30	
Inlet branch			F1	F3
Outlet branch			F4	F2
Design of Frame / Plates:				
Plate arrangement (passes*channel)			1 x 14 + 0 x 0	
Plate arrangement (passes*channel)			1 x 13 + 0 x 0	
Number of plates		28		
Effective heat surface	(m²)	5,46		
Overall K-value Duty/Clean	(W/m²*K)	2.336,77	3.301,80	
Plate material		0.4 mm AISI 316		
Gasket material / Max. temp.		EPDM HT HANG ON (H) / 140		
Max. design temperature	(°C)	120,00		
Max. Working/test pressure	(bar)	10,00	13,00	
Max. Differential pressure	(bar)	10,00		
Approval		None		
Liquid volume	(liter)	12		
Frame length	(mm)	437	Max. No. of Plates 39	
Net weight	(kg)	163		
Frame type		ST		

Connections HOT side : 2 INCH Threaded pipe BSP, AISI 316

Connections COLD side: 2 INCH Threaded pipe BSP, AISI 316

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APPENDIX 15: SIMULATION OF COOLING I SECTION

J. Negre C. PHE - Design & Datalist

V10A34
JNC 20/04/2015
001 Item: 588

PHE-Type S20A-ST16-30-TKTL33-LIQUID		Hot side	Cold side
Flowrate	(m3/h)	6,50	11,93
Inlet temperature	(°C)	70,00	18,00
Outlet temperature	(°C)	28,00	40,00
Pressure drop	(bar)	0,08	0,29
Heat exchanged	(kW)	303	

Thermodynamic properties:		Milk	Water
Density	(kg/m³)	1.013,57	995,51
Specific heat	(kJ/kg*K)	3,95	4,18
Thermal conductivity	(W/m*K)	0,52	0,61
Mean viscosity	(mPa*s)	0,83	0,82
Wall viscosity	(mPa*s)	1,39	0,57
Fouling factors	(m²*K/kW)		
Dimensioning factor	%	0,00	
Inlet branch		F1	F3
Outlet branch		F4	F2

Design of Frame / Plates:		
Plate arrangement (passes*channel)		1 x 14 + 0 x 0
Plate arrangement (passes*channel)		1 x 15 + 0 x 0
Number of plates		30
Effective heat surface	(m²)	5,88
Overall K-value Duty/Clean	(W/m²*K)	2.836,49 2.836,49
Plate material		0.4 mm AISI 316
Gasket material / Max. temp.		EPDM HT HANG ON (H) / 140
Max. design temperature	(°C)	120,00
Max. Working/test pressure	(bar)	10,00 13,00
Max. Differential pressure	(bar)	10,00
Approval		None
Liquid volume	(liter)	13
Frame length	(mm)	437 Max. No. of Plates 39
Net weight	(kg)	164
Frame type		ST

Connections HOT side : 2 INCH Threaded pipe BSP, AISI 316
Connections COLD side: 2 INCH Threaded pipe BSP, AISI 316

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APPENDIX 16: SIMULATION OF COOLING II SECTION

J. Negre C. PHE - Design & Datalist

V10A34
JNC 20/04/2015
001 Item: 588

PHE-Type S20A-IS16-93-TKTL69-LIQUID		Hot side	Cold side
Flowrate	(m3/h)	6,50	26,04
Inlet temperature	(°C)	28,00	2,00
Outlet temperature	(°C)	4,00	8,00
Pressure drop	(bar)	0,02	0,30
Heat exchanged	(kW)	173	

Thermodynamic properties:		Milk	30 PropGlycol
Density	(kg/m³)	1.030,19	1.031,71
Specific heat	(kJ/kg*K)	3,89	3,88
Thermal conductivity	(W/m*K)	0,49	0,46
Mean viscosity	(mPa*s)	2,09	6,35
Wall viscosity	(mPa*s)	2,96	3,72
Fouling factors	(m²*K/kW)		
Dimensioning factor	%	0,00	
Inlet branch		F1	F3
Outlet branch		F4	F2

Design of Frame / Plates:		
Plate arrangement (passes*channel)		1 x 46 + 0 x 0
Plate arrangement (passes*channel)		1 x 46 + 0 x 0
Number of plates		93
Effective heat surface	(m²)	19,11
Overall K-value Duty/Clean	(W/m²*K)	1.161,40 1.161,40
Plate material		0.4 mm AISI 316
Gasket material / Max. temp.		EPDM HT HANG ON (H) / 140
Max. design temperature	(°C)	120,00
Max. Working/test pressure	(bar)	10,00 13,00
Max. Differential pressure	(bar)	10,00
Approval		None
Liquid volume	(liter)	41
Frame length	(mm)	1029 Max. No. of Plates 150
Net weight	(kg)	266
Frame type		IS

Connections HOT side : 2 INCH Threaded pipe BSP, AISI 316
Connections COLD side: 2 INCH Threaded pipe BSP, AISI 316

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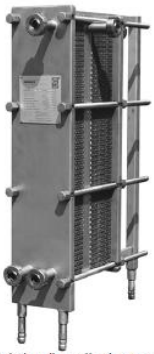
APPENDIX 17: PLATE HEAT EXCHANGER

SONDEX

S4A + S8A
Plate Heat Exchanger



Recommended Applications:
The **S4A & S8A** range of **Sondex** plate heat exchangers is specially designed for the HVAC area, heat recovery, the food, industrial and chemical market.

Design Principle:
The **Sondex** type **S4A and S8A** plate range with lengths up to 0.75 m and a "long" thermal pattern will cover many duties up to 8 m3/h in a single pass solution, meaning that all the connections are on the head side. This will ensure easy pipe- and service work, and by dismantling the exchanger for service, no pipes need to be removed.

The heat transfer is obtained, when the warm medium transfers energy through the thin, strong flow plates between the channels and delivers it to the cold opposing medium without mixing the two media.
Counter-current flow creates the optimal efficiency.

The plate- and inlet design allows effective, easy CIP (Cleaning in Place) of all "flow" surfaces.

Flow plates:
The corrugated "herringbone" pattern ensures turbulent flow in the whole effective area. Furthermore, this pattern brings "metallic" contact between the plates, and together with locking devices on the gaskets, the plate pack is easily assembled.

The plate pack is held firm and safely between between the fixed head and movable follower of the frame.

Data Required for Correct Quotation:
Duty, flow rate, type of media, temperatures, working pressure/temperature, pressure losses and thermodynamic properties determine the exchanger type, size of heat surface and plate pattern.

Technical Information

Frame:
Painted frame and stainless steel frame, with the clamping bolts placed around the frame edge.
Standard colour by painted frame: Blue RAL 5010.
Available in other colours.

Working pressure:
The frames are designed for a working pressure of MPa/1.0/1.6 MPa.

Intermediate Frames:
Intermediate frames and corner blocks for IS and FS frames in stainless steel.

Construction Standard:
According to PED 97/23/EC: A-D "Merkblätter"
According to ASME CODE: ASME VIII, DIV. 1

Connections:
1¼" pipe or threaded pipe ISO7 BSP/NPT in stainless steel or titanium.
1"/DN25 dairy pipe or union.
According to all known standards.

Plates:
Standard material:
AISI 316 and titanium.
Also 2 x 0.4 mm "Sonder Safe" plates, forfood and industry.
Not standard: 254 SMO, hastelloy C 276 and other pressable materials.

Gaskets:
The gasket is the unique "hang-on", non-glued type.
Standard material: Nitrile, EPDM and Viton.

Extra Equipment:
Safety cover in stainless steel.
Insulating jacket.
Assembling spanner.
Foundation feet for the IS frame.

APPENDIX 18: PLATE HEAT EXCHANGER LAYOUT