Rev. Int. Contam. Ambient. *11* (1), 47-57, 1995

SOLVING THE WHEY POLLUTION PROBLEM BY ULTRAFILTRATION: AN ECONOMIC ASSESSMENT

Rodolfo TREJO-VÁZQUEZ,[1] Sergio REVAH-MOISEEV,[1] Arturo JIMÉNEZ-GUTIÉRREZ[2] and Francisco Pablo RAMÍREZ-GARCÍA[3]

[1] Universidad Autónoma Metropolitana U. Iztapalapa, Apdo. Postal 55-534 México 09340, D.F.
[2] Instituto Tecnológico de Celaya, Apdo. Postal 57, Celaya, Gto. 38000, México
[3] Instituto Mexicano del Petróleo, Apdo. Postal 14-805 México 07730, D.F.

(Recibido marzo 1995, aceptado junio 1995)

Keywords: whey, UF-cheese, cheese economics, caseinated cheese

ABSTRACT

Now that clean production is seen as the best alternative to reduce pollution, a study on milk ultrafiltration as a strategy to reduce the economic weight of waste disposal of the cheesemaking industry for some selected cheese types (queso fresco, cottage, quarg, ricotta, soft-cheese type, mozzarella, cream, feta and camembert) is discussed. Cheese yield increments and a reduction in whey disposal volume could be achieved and hence represent a potential improvement in the economics of cheese making. Cheese, cream, whey and permeate are considered valuable products of the process, with fractional demand rates for the whey and permeate produced . The economic calculations include disposal costs for unsold streams of whey and permeate. The proposed modifications include the possibility of casein addition. Three scales of process were considered: 5,000, 30,000 and 100,000 kg/day of fresh milk. Several economic scenarios were tested to reflect normal conditions and the impact of adverse situations. The results show economic profitability of the modified processes for most cases, especially at 30,000 kg/day scale and over. Queso fresco, cream, ricotta, cottage and quarg were found to show the greater economic potential.

RESUMEN

La producción limpia se reconoce hoy día como la mejor alternativa de reducir la contaminación ambiental. En este contexto se ubica el presente trabajo, que es un estudio de la ultrafiltración de leche como estrategia para reducir la carga económica por disposición de desechos de la industria quesera en la elaboración de algunos tipos de queso (queso fresco, cottage, quarg, ricotta, tipo pasta blanda, mozzarella, crema, feta y camembert). Se encontró que bajo ciertas condiciones puede existir una mejora en la economía quesera a causa de los cambios en el rendimiento quesero y en las cantidades de desechos a disponer. Se eligieron productos valiosos como queso, crema, lactosuero y permeato, considerando en los dos últimos casos que la demanda del producto es una fracción de la cantidad producida. En el estudio económico se tomaron en cuenta los costos de disposición para las corrientes no vendidas del proceso. Entre las modificaciones se incluyó la adición de caseína. Se estudiaron tres escalas de proceso: 5,000, 30,000 y 100,000 kg/día de leche fresca. Se probaron distintos escenarios económicos para reflejar el impacto de situaciones adversas sobre las condiciones normales de mercado. Los resultados de la simulación muestran una ventaja económica para el proceso modificado en la mayoría de los casos, especialmente a las dos escalas mayores estudiadas. En cuanto a los tipos de queso mas favorecidos con la modificación, estos son queso fresco, crema, ricotta, cottage y quarg.

INTRODUCTION

The pollution impact of the Mexican industry has been studied recently and it was found to have increased twenty fold in the period from 1950 to 1989. This value is composed of two parts: first, there has been an overall growth of 1000% of the industrial activity, second, the industries that have developed most are more polluting.

In the industrial activities natural resources are transformed and wastes are produced. To achieve a sustainable development it is necessary to have clear and attainable environmental objectives, which must be supported by comprehensive legislation based on prevention rather than on correction.

Waste reduction rates are high among the waste management alternatives for a sustainable industrial development (Hirshhorn *et al.* 1993). This can be accomplished through different activities such as reducing material consumption, re-designing the product, optimizing production and changing to cleaner technologies. Since long ago, food industries face the challenge to dispose of their wastes properly without having a severe impact on their production costs. Cheesemaking industry is not the exception. Today, cheese has a high demand across the world, as shown in **figure 1.**

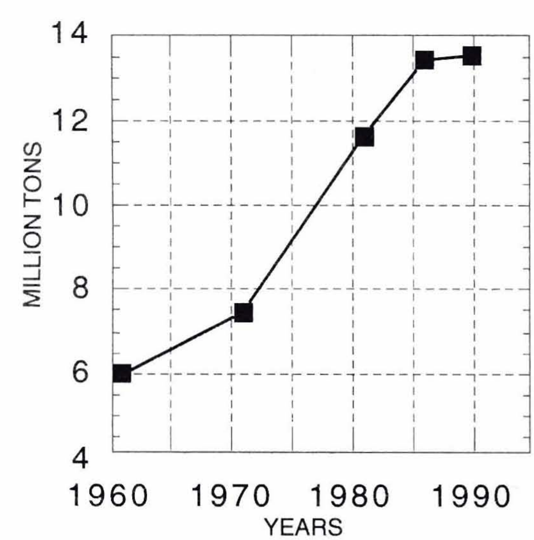

Fig. 1. World cheese consumption. (Anonymous 1985a, 1988, Eck 1990)

Conventional cheese processes (Kosikowski 1982) also lead to the production of whey, a bulky waste at a rate of about 10:1 with respect to the cheese product. Depending on the process, whey may be classified as "sweet" or "acid"; its typical composition is shown in **table I.**

Mainly due to lactose content, untreated whey is a very strong pollutant, with a potential BOD_5 ranging among 100 and 150 times the BOD_5 of domestic sewage (Jelen 1979), and it is necessary to consider wide options for its recovery, reuse or treatment. Literature shows several recovery options (Clarck 1979, Moulin and Galzy 1984, Zadow 1992), with drying and pre-drying fractionation being the most popular (Hansen 1989).

TABLE I. TYPICAL COMPOSITION OF WHEY (Kosikowski 1979)

COMPONENT	% IN SWEET WHEY	% IN ACID WHEY
Total solids	6.35	6.50
Water	93.70	93.50
Fat	0.50	0.04
Total proteins	0.80	0.75
Lactose	4.85	4.90
Ash	0.50	0.80
Lactic acid	0.05	0.40

Dry whey or its components are used mainly in foods (Matthews 1984, Rajah and Blenford 1988), although applications in other fields have also been explored (Asher *et al.* 1985, Damerdji *et al.* 1988, Rudd *et al.* 1988).

Whey from traditional processes contains water, soluble milk proteins different from casein (called here whey proteins), lactose and salts (table I).However, as a waste effluent, it may also contain trace amounts of other materials, such as coagulants (renin, pepsin and other enzymes), lactic starters (bacteria), acids or acidifying substances, some salts and vitamins. Usually, whey demand is lesser than its production, and every cheese factory has to dispose of the unsold streams properly at some cost, which increases the production investments.

Solving the pollution problem for the cheese industry without loosing economic competitivity is an interesting reseach topic today. From several solutions that can be proposed to this problem, the economic assessment of using ultrafiltration (UF) to separate part of the milk components before cheese processing was chosen. In addition to being well known theoretically, UF is an accepted operation in practice (Kelly 1987, Chiang and Pan 1989, Harper 1991) and it was originally developed for whey protein separations.

Milk concentration by UF for cheesemaking has been successfully tested at industrial scales (Garoutte 1983, Lelievre and Lawrence 1988) for many fresh cheese types, and has even shown positive effects on milk transportation costs (Cox and Langdon 1985).

A modification to the traditional cheesemaking process by introducing an UF preconcentration stage was considered in this work for cases with and without casein addition. The economic implications of these alternatives were also evaluated.

An initial incentive is the possibility of a favourable balance in the production costs due to the waste reduction and improvement on cheese yield expected, and the recovery of a new permeate stream that would offer wide applications because of its standardized composition and absence of non-milk components.

TABLE II. SELECTED CHEESES AND MILK COMPOSITION IN PERCENTAGE

NAME	WATER	FAT	TOTAL PROTEIN	CARBOHYDRATE	ASH	REFERENCE
camembert	51.80	24.26	19.80	0.46	3.68	a
cottage	78.00	4.50	12.50	3.50	1.50	b
cream	53.75	34.87	7.55	2.60	1.23	a
feta	56.00	23.00	15.50	1.50	4.00	b
mozzarella	54.14	21.60	19.42	2.22	2.62	a
quarg	76.00	6.00	13.60	3.50	0.90	b
queso fresco	79.00	7.50	8.50	4.00	1.00	c
ricotta	71.70	12.98	11.26	3.04	1.02	a
soft-paste type	50.00	24.00	20.00	4.00	2.00	c
fresh milk	87.50	3.50	3.30	5.00	0.70	d

a Wolf 1982
b Cenzano *et al.* 1991
c Eck 1990
d Anonymous 1985b

This work includes a physical and economical modeling of the traditional cheese process and the modified cheese processes at feasible conditions.

Experiments were not included. Instead, a compilation of guides and empirical knowledge from experienced people and from the literature was used.

METHODS

Products and processes

Three stages are identified in traditional cheesemaking process: coagulation, draining and ripening. Cheeses can be classified into ripened and fresh. The former have less water, and it is usually difficult to modify the process without altering one or more of its sensory properties. For fresh type cheeses, the ripening stage is absent or is very simple, and this makes it easier to modify the traditional process. The composition of fresh milk and the family of cheeses selected for this study are shown in **table II.**

Some characteristics of the cheese processes considered in this work are mentioned below.

1. Traditional cheese process

This process can be described as a redistribution of the components of a complex mixture (milk) in two fractions: one is the solid phase of porous structure, made of fat and casein. This part contains a small amount of the second fraction (whey), which is an aqueous solution of lactose, salts and soluble proteins, called here whey proteins. The remaining whey is not included in the solid phase and will be separated by draining and pressing **(Figure 2).** It is important to observe that the liquid phase has a constant composition in and out the solid phase, so the cheese yield depends on the proportion of casein in milk, the proportion of water in cheese and the aqueous content of whey.

2. Modified cheese process using UF membranes

In this case, the process differs from the traditional in that milk has been previously ultrafiltered. As a result, the original complex mixture, standardized in casein and fat, is divided in three fractions; being the first one a stream composed of water, lactose and salts, in a proportion which is similar to the proportion present in the milk.

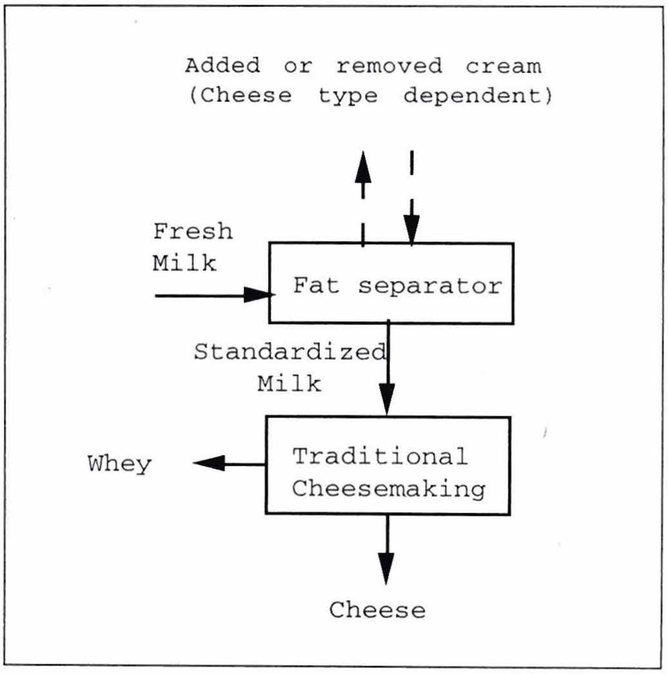

Fig. 2. Traditional cheesemaking process

This stream is called milk permeate. The two remaining fractions are as described in the traditional process, but here, the liquid phase will have a higher proportion of soluble proteins and therefore, the finished cheese will have a higher weight for an aqueous content given of the product **(Figure 3).**

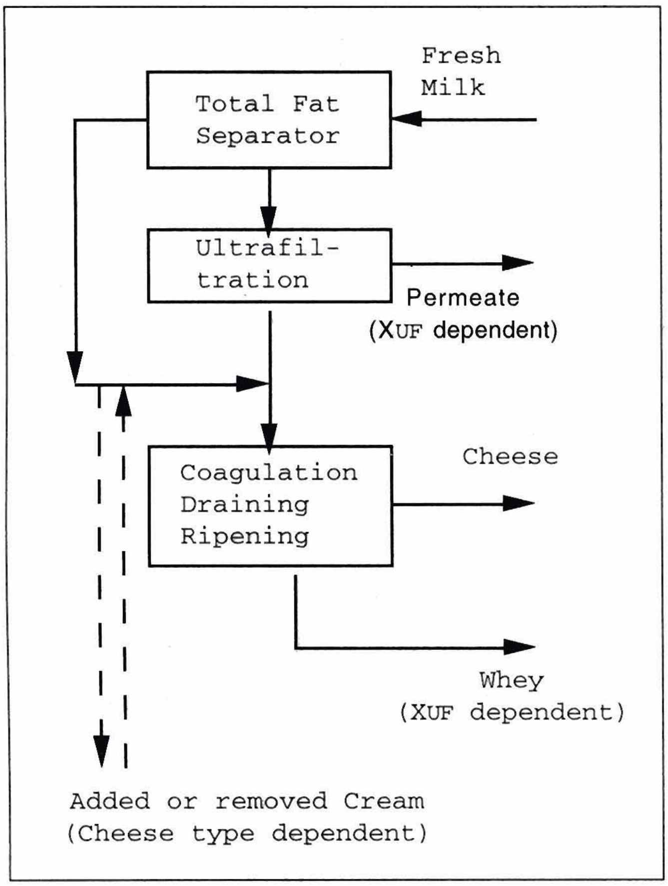

Fig. 3. Modified cheese process with ultrafiltration

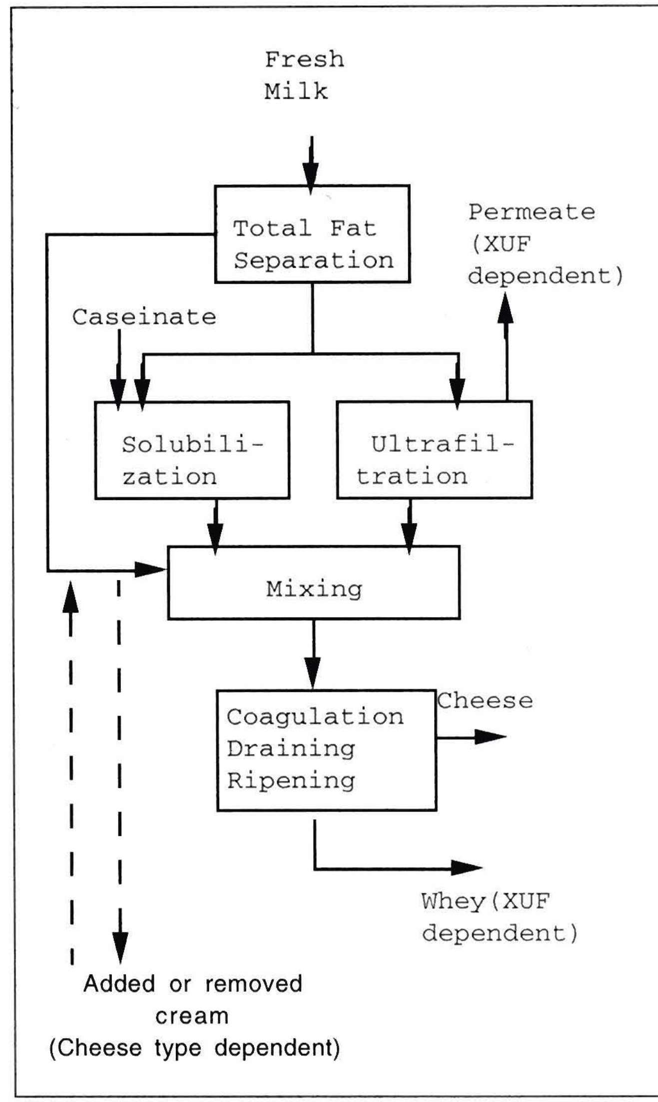

Fig. 4. Modified cheese process with ultrafiltration and casein addition

3. Modified cheese process using UF membranes and casein

In this case, the cheese yield can be expanded even more by adding casein to the milk, since this induces a proportional recovery of the remaining components, according to the final composition of the cheese. To consider simultaneously the ultrafiltration and casein addition, the defatted milk is divided into two streams, one of them is ultrafiltered and the other is used to solubilize the casein **(Figure 4).**

Limits imposed to the modified process

To consider operative conditions already tested in practice for ultrafiltration and casein addition, experts cheese makers and literature reports were consulted.

UF milk concentration, measured by a concentration factor X_{UF} (which is defined as the ratio of fresh milk weight to concentrated milk weight) should not exceed a value of 7, as experts suggest to keep proper permeate fluxes during industrial operation (Lawrence 1989). In addition, the presence of whey proteins and the increased amounts of fermentable carbohydrates in the curd, tend to alter some of the ripening patterns. The original sensory properties of the cheese may be modified differently depending mainly on the type of cheese and the amount of whey proteins.

Considering the above aspects, and taking into account different reports of the literature (Gilles and Lawrence 1981, Anonymous 1984, Gilles 1984, Huffman and Kristoffersen 1984, Quintana *et al.* 1984, Shimp 1985, Robinson 1986, Garrett 1987, Hansen 1987, Kelly 1987, Christensen and Colding 1988, Hansen 1988, Lelievre and Lawrence 1988, Lawrence 1989, Eck 1990, McGregor and White 1990, Reinbold 1990), as well as the opinion of experts, we established as upper limits 5 for the UF con-

TABLE III. OPERATION LIMITS CONSIDERED IN THIS WORK FOR UF CONCENTRATION OF MILK DEPENDING ON THE DESIRED CHEESE IN THE MODIFIED PROCESS

CHEESE TYPE	X_{UF} LIMIT	WHEY PROTEIN AS PERCENTAGE OF THE CHEESE PROTEIN CONTENT
camembert	5.0	10.13
cottage	3.7	20.00
cream	5.0	16.96
feta	5.0	13.30
mozzarella	5.0	10.98
queso fresco	2.6	20.00
quarg	4.1	20.00
ricotta	4.0	20.00
soft-paste type	5.0	9.73

centration factor and 20% for the whey protein content in the total cheese protein content. The results obtained with these criteria are shown in **table III.**

Regarding casein addition, it should be mentioned that in some countries there are objections to such a practice, and the derived products are labeled as "cheese imitations", to differentiate them from the "authentic" cheeses, that should be made by the traditional process. In other countries, however, casein addition is accepted within certain limits, since it allows the production of cheese more economically without loss of nutritional value. As an example, in some counties of the EU, it is permitted to add casein up to 5 kg per cubic meter of fresh milk, for cheeses without origin denomination (Eck 1990).

For casein addition in this study technical data from a commercial calcium caseinate (ALANATE 391) were used. Its reported composition is: protein (casein) 90.7%, salts 3.8%, water 3.7%, fat 1.4% and lactose 0.4%.

Considering that some countries have no legal limits for casein addition, solubility and viscosity properties were considered. A value of 2 kg of casein per one hundred kilograms of fresh milk was used with experts agreement.

Fat and casein losses were considered the same for both processes, although it is known that these losses are reduced with the UF modified process (Lawrence 1989).

Before ultrafiltration, milk was completely defatted; in cases in which casein addition was considered, part of the defatted milk was mixed with solubilized casein producing a 10% casein mixture, while the remaining milk was ultrafiltered **(Figure 4).**

Characteristics of the UF equipment

Equipment specifications were taken from Slack (1981). The equipment consists of spiral wound membranes

TABLE IV. STRUCTURE OF UF CYCLES DEPENDING ON X_{UF} VALUES

UF concentration factor (X_{UF})	operation time (hours)	cleaning time (hours)	total cycle time (hours)
2	4	2	6
3	4	2	6
4	3	2	5
5	3	2	5

HFM-100-SO from ABCOR, with a molecular weight cutoff of 8000-10000. These membranes constitute compact elements, called UF modules. Each module has an area of 4.186 m^2 (45 ft^2) and a holdup of 7.28 l. The operation limits are 689.475 kPa (100 psig) for pressure; 54°C for temperature and a maximum flow rate with clean membrane of 182 l/min.The UF modules were considered to work in a pattern of cycles in terms of operation and cleaning periods as shown in **table IV.**

Other assumptions

Additional assumptions are listed below.

a. From the total protein content in fresh milk 78% is casein.
b. Milk proteins consist of casein and whey proteins.
c. UF membrane retains the casein, fat and whey proteins completely.
d. Every cheese type has a fixed and unique composition, as shown in **table II.**
e. Butter is not produced and the whole production of cheese and cream is sold.
f. Fat is separated from milk by centrifugation as a cream stream consisting in a mixture of 40% fat in defatted milk.
g. Fat and casein losses: at 8% for the total fat and one kilogram of casein for each housand kilogram of fresh milk, as reported by various authors (Peppler and Perlman 1979, Kosikowski 1982, Anonymous 1985b, 1989).
h. It is assumed that the economic feasibility was evaluated to modify a traditional cheese process in a healthy cheese industry, which produces only one cheese type, and attemps to operate at a profit.
i. It is assumed that whey and permeate have a fixed fractional demand, given as a percentage of their production in the traditional and modified processes respectively. We studied here demand levels of 0, 50 and 95%.

According to all the above assumptions, a model of the processes was developed to calculate the amount of cheese, cream, whey and permeate for every cheese type. These results were combined with the data listed in **table V**

TABLE V. ADDITIONAL PARAMETER VALUES USED FOR SIMULATION

1. The milk UF concentration factors (X_{UF}) used were 2, 3, 4 and 5
2. Five casein addition rates were considered: 0, 0.5, 1, 1.5 and 2 kg added to 100 kg of fresh milk
3. Three scales of process were considered: 5,000 Kg/day of fresh milk (scale 1), 30,000 kg/day (scale 2) and 100,000 kg/day (scale 3)
4. Permeate price: 0.03125 dollars/kg
5. ALANATE´S 391 price: 6.25 dollars/kg
6. Whey price: 0.02 dollars/kg
7. Cream price (to sale or buy): 1.25 dollars/kg
8. Cost for disposal of whey or permeate: 0.00625 dollars/Kg (Rudd *et al.* 1988)
9. Three demand levels were considered for both whey and permeate: 0%, 50% and 95%
10. Costs for UF equipment, including membranes and chemicals for cleaning, from Slack(1981), updated by The Nelson Index
11. Electricity cost: 0.043 dollars/kW-hr
12. Operation labor cost: 7500 dollars/man-year
13. Costs for treatment of UF cleaning effluents: 5% of membranes plus cleaning chemicals costs
14. Cheese prices, in US dollars/kg (taken from field study in Celaya, Guanajuato, México, and fitted with literature data from Anonymous (1993)): cottage 1.56, feta. 2.66, quarg 1.88, camembert 3.20, ricotta 1.88, queso fresco 1.41, soft-paste type 3.44, cream 2.12, mozzarella 3.91
15. Overall tax rate: 50%
16. Money depreciation rate for accounting and tax purposes: 0.1
17. Miscelaneous expenses as maintenance, insurances, and others: 5% of the investment

and well-known equations of process economic analysis (Jiménez 1994) to obtain an economic assessment of the process modification.

To compare alternatives, a differential return on investment (DROI) was used, expressed as $(U_2-U_1)/(I_2-I_1)$, where U_2 is the net yearly profit of the modified process and U_1 the corresponding amount for the traditional process, while I_2 and I_1 are respectively the investments for the modified and for the traditional process. The difference (I_2-I_1) was the requiered investment to change a traditional process plant into a UF modified process plant, and the difference (U_2-U_1) was the net profit obtained in excess over the profit of the traditional process if the process modification was undertaken. Clearly, DROI must be positive to provide an economic incentive; furthermore, a minimum value should be established to take risk into account.

The economic analysis for the modified process included a cost of waste treatment for unsold whey or permeate streams. Other investment needed to implement UF modules in the modified process such as land, facilities and services buildings, were taken into account by duplicating the estimated cost for the UF equipment. Thus, DROI values included the necessary waste treatment costs and other derived overhead costs for the modified process.

TABLE VI. ECONOMIC SCENARIOS CONSIDERED

SCENARIO	CONDITIONS
O	The whole cheese and cream production is sold to normal price* Disposal costs for unsold whey and permeate streams are normal Permeate price is normal Whey price is normal Permeate demand is 95% Whey demand is 0%
A	Same as case O, but cheese and cream prices are 20% under normal
B	Same as case O, but disposal costs for unsold whey and permeate streams are 20% over normal
C	Same as case O, but permeate price is 20% under normal
D-1	Same as case O, but permeate demand is 50%
D-2	Same as case O, but permeate demand is 0%
E-1	Same as case O, but whey demand is 50%
E-2	Same as case O, but whey demand is 95%
F-1	Same as case O, but whey demand is 50% and whey price is 20% over normal
F-2	Same as case O, but whey demand is 95% and whey price is 20% over normal
P	The whole cheese production is sold to 20% under normal cheese prices Disposal costs for unsold whey and permeate streams are 20% over normal Whey price is 20% over normal Permeate demand is 0% Whey demand is 95%

* Normal prices and costs are refered to values listed in Table V

Economic scenarios

Comparisons of traditional and modified cheesemaking processes were performed under eleven economic scenarios, presented in detail in **table VI.** Scenario O contains the conditions for a normal behavior and serves as a framework for the other cases. Several possible contingencies are represented in the remaining scenarios, such as lower cheese price (scenario A), higher costs for waste treatment of unsold whey and permeate (scenario B), lower permeate price (scenario C), lower permeate demand (scenario D), higher whey demand (scenarios E), higher whey demand and higher whey prices (scenario F), and a combination of adverse conditions, presented as scenario P.

It is important to note that scenario O was not intended to represent an ideal goal, but a fairly realistic situation after permeate was introduced to the market. On the other hand, although scenario P does not represent an expected situation, it serves to identify the most resilient processes from an economic viewpoint.

RESULTS AND DISCUSSION

To validate the simulator´s performance, Van Slyke and Price equation was used (Van Slyke and Price 1949). Based on experimental data, Van Slyke and Price developed an empirical expression to predict the yield of cheddar cheese (one of the most widely studied cheeses), as a function of the milk composition. For the same fresh milk composition, and the same fat and lactose losses, the yields predicted by the Van Slyke-Price expression and by this work agreed within 2.1%, so our estimations based on mass balances, as opposed to empirical correlations, were reasonably good.

Economic results were classified and interpreted for the cases with and without casein addition in terms of DROI values for every cheese type. The operating conditions considered were technically feasible, and prices and costs, valid for 1993, were as real as possible. Considering the current profitability margin of cheese factories at the referenced year, DROI values higher than 0.15 were assumed to provide an attractive choice.

For the selected conditions of the best DROI values shown in **tables VII** and **VIII,** the impact on DROI on different scales and economic scenarios was studied. In all cases, the best DROI values with and without casein addition were found at scenario O.

The attractive range of DROI values was divided in three intervals: DROI-C (convenient) for DROI values ranging from 0.15 to 0.30. DROI-V (very convenient) for DROI values ranging from 0.30 to 0.60 and DROI-H (highly convenient) for DROI values higher than 0.60.

Table IX shows the results obtained for the cheeses under study including cases with and without casein addition. The number and type of economic scenarios included in each DROI range denotates qualitatively the impact of selected parameters on DROI values. A widther number of scenarios at a greater DROI range column could be interpreted as a higher margin of benefits for the modified cheese process and vice versa.

TABLE VII. BEST DROI VALUES WITHOUT CASEIN ADDITION

CHEESE TYPE	BEST DROI VALUES	REQUIRED INVESTMENT* IN THOUSAND DOLLARS 1993	CONDITIONS	
			SCALE OF PROCESS	CONCEN-TRATION FACTOR (X_{UF})
CAMEMBERT	0.1115	96.92	1	3
CAMEMBERT	0.3871	265.33	2	4
CAMEMBERT	0.5039	514.90	3	3
COTTAGE	0.3387	96.92	1	3
COTTAGE	0.9041	244.46	2	3
COTTAGE	1.3592	514.90	3	3
CREAM	0.3962	96.92	1	3
CREAM	1.1803	265.33	2	4
CREAM	1.5756	514.90	3	3
FETA	0.1715	96.92	1	3
FETA	0.5938	314.33	2	5
FETA	0.7299	514.90	3	3
MOZZARELLA	0.1757	132.39	1	5
MOZZARELLA	0.6187	314.33	2	5
MOZZARELLA	0.7341	514.90	3	3
QUESO FRESCO	0.5008	61.44	1	2
QUESO FRESCO	1.2378	164.70	2	2
QUESO FRESCO	2.0419	337.67	3	2
QUARG	0.3768	114.00	1	4
QUARG	1.1470	265.33	2	4
QUARG	1.4672	628.51	3	4
RICOTTA	0.4380	114.00	1	4
RICOTTA	1.3048	265.33	2	4
RICOTTA	1.6892	628.51	3	4
SOFT-PASTE TYPE	0.1168	96.92	1	3
SOFT-PASTE TYPE	0.4049	265.33	2	4
SOFT-PASTE TYPE	0.5240	514.90	3	3

*Included UF equipment and estimated expenses needed for its operation like land, facilities and service buildings

TABLE VIII. BEST VALUES FOR DROI WITH CASEIN ADDITION

CHEESE TYPE	BEST DROI VALUES	REQUIERED INVESTMENT* OF THOUSAND OF DOLLARS (1993)	CONDITIONS SCALE OF PROCESS	CONCENTRATION FACTOR (X_{UF})	CASEIN ADDED 10 KG OF MILK
CAMEMBERT	0.0862	48.40	1	2	2
CAMEMBERT	0.3600	136.41	2	2	2
CAMEMBERT	0.5777	274.68	3	2	2
COTTAGE	0.3812	77.78	1	3	2
COTTAGE	0.9983	200.17	2	3	2
COTTAGE	1.5741	408.40	3	3	2
CREAM	0.4107	48.40	1	2	2
CREAM	1.1927	253.27	2	4	0.5
CREAM	1.6869	274.68	3	2	2
FETA	0.1536	48.40	1	2	2
FETA	0.5938	136.41	2	2	2
FETA	0.8316	274.68	3	2	2
MOZZARELLA	0.1539	48.40	1	2	2
MOZZARELLA	0.6187	314.33	2	5	0
MOZZARELLA	0.8449	274.68	3	2	2
QUESO FRESCO	0.6968	48.40	1	2	2
QUESO FRESCO	1.6599	136.41	2	2	2
QUESO FRESCO	2.7162	274.68	3	2	2
QUARG	0.3768	113.99	1	4	0
QUARG	1.1470	253.27	2	4	0.5
QUARG	1.4958	408.40	3	3	2
RICOTTA	0.4380	113.99	1	4	0
RICOTTA	1.3048	253.27	2	4	0.5
RICOTTA	1.7269	408.40	3	3	2
SOFT PASTE TYPE	0.0910	48.40	1	2	2
SOFT PASTE TYPE	0.3702	136.41	2	2	2
SOFT PASTE TYPE	0.5989	274.68	3	2	2

*Included UF equipment and estimated expenses needed for its operation like land, facilities and service buildings

Except for camembert and soft paste type at scale 1, all the cheeses showed attractive DROI values for some scenarios. Queso fresco rates as the very best of the studied cheeses, followed by crema and ricotta.

Scenario F2 was unattractive for all the studied cheeses, which means that at the condition of high whey demand (95%) and high whey price (20% over normal) was not profitable in the modified process. However, if the whey price is normal and the whey demand is high (95%), queso fresco can almost reach attractive DROI values at scales 2 and 3.

Soft paste type seems to be less sensitive to small changes in cheese prices than camembert. Feta and mozzarella have a very close economic behavior. Cottage and quarg have close behavior at scale 1, but at higher scales, cottage seems to be more sensitive to whey demands of 50% than quarg, as well as ricotta compared to cream cheese.

In cheese factories, whey demand varies widely from one case to another. In the scenarios studied, the whey demand parameter was considered at a complete range (0-95%) and, as a premise, it would have a heavy weight in the model.

From the definition of DROI, one can not expect a strictly linnear but a smooth curved behavior between DROI and whey demand. From DROI values of scenarios O, E1 and E2 fitted by a parabolic empirical expression, we calculated the critical value of whey demand in order to give a DROI value of 0.15, taking into account the conditions of scenario O (except whey demand). The results are presented in **table X.**

CONCLUSIONS

In general the results of this study show that ultrafiltration of milk before cheesemaking may contribute significantly to reduce waste in the cheesemaking plant as well as to rise plant productivity and recover a greater fraction of milk components. This is reflected in a waste disposal cost reduction which supports the idea that clean environmental practices can be economicaly sound.

The scale of the process was an important factor in the attractiveness of the modified process. Also, with few exceptions, casein addition reduced slightly DROI values and reduced significantly the UF investment required.

TABLE IX. ATTRACTIVE DROI VALUES AND THEIR SCENARIES

CHEESE AND ROW NUMBER	SCALE	CASEIN ADDITION W=WITH WO=WITHOUT	DROI-C (CONVENIENT)	DROI-V (VERY CONVENIENT)	DROI-H HIGHLY CONVENIENT)
CAMEMBERT (1)	1	W	-	-	-
(2)	1	WO	-	-	-
(3)	2	W	A,C,D1	O,B	-
(4)	2	WO	A,C	O,B	-
(5)	3	W	-	O,A,B,C	-
(6)	3	WO	-	O,A,B,C,D1,E1,F1	-
SOFT PASTE TYPE (7)	1	W	-	-	-
(8)	1	WO	-	-	-
(9)	2	W	D1	O,A,B,C	-
(10)	2	WO	C	O,A,B	-
(11)	3	W	D1	O,A,B,C	-
(12)	3	WO	-	O,A,B,C,D1,E1,F1	-
FETA (13)	1	W	O,B	-	-
(14)	1	WO	O,E1,F1	-	-
(15)	2	W	D2	O,A,B,C,D1	-
(16)	2	WO	D2	O,A,B,C,D1	-
(17)	3	W	E1	A,D1	O,B,C
(18)	3	WO	-	D1,E1,F1	O,A,B,C
MOZZA-RELLA (19)	1	W	0,B	-	-
(20)	1	WO	O,E1,F1	-	-
(21)	2	W	D2	A,C,D1	O,B
(22)	2	WO	D2	A,C,D1	O,B
(23)	3	W	E1	A,D1	O,B,C
(24)	3	WO	-	D1,F1	O,A,B,C,E1
COTTAGE (25)	1	W	A,D1	O,B,C	-
(26)	1	WO	A,D1,D2	O,B,C	-
(27)	2	W	F1	D2,E1	O,A,B,C,D1
(28)	2	WO	F1	D2,E1	O,A,B,C,D1
(29)	3	W	-	E1,F1	O,A,B,C,D1,D2
(30)	3	WO	-	E1,F1	O,A,B,C,D1,D2
QUARG (31)	1	W	A,D1,D2	O,B,C	-
(32)	1	WO	A,D1,D2	O,B,C	-
(33)	2	W	-	E1,F1	O,A,B,C,D1,D2
(34)	2	WO	-	E1,F1	O,A,B,C,D1,D2
(35)	3	W	-	F1	O,A,B,C,D1,D2,E1
(36)	3	WO	-	F1	O,A,B,C,D1,D2,E1
CREAM (37)	1	W	D2,E1,F1	O,A,B,C,D1	-
(38)	1	WO	D2	O,A,B,C,D1,E1,F1	-
(39)	2	W	-	-	O,A,B,C,D1,D2,E1,F1
(40)	2	WO	-	-	O,A,B,C,D1,D2,E1,F1
(41)	3	W	-	-	O,A,B,C,D1,D2,E1,F1
(42)	3	WO	-	-	O,A,B,C,D1,D2,E1,F1
RICOTTA (43)	1	W	D2,E1	O,A,B,C,D1	-
(44)	1	WO	D2,E1	O,A,B,C,D1	-
(45)	2	W	-	F1	O,A,B,C,D1,D2,E1
(46)	2	WO	-	F1	O,A,B,C,D1,D2,E1
(47)	3	W	-	-	O,A,B,C,D1,D2,E1,F1
(48)	3	WO	-	-	O,A,B,C,D1,D2,E1,F1
QUESO FRESCO (49)	1	W	D2,F1	O,A,B,C,D1,E1	-
(50)	1	WO	E1,F1	A,D1,D2	O,B,C
(51)	2	W	-	-	O,A,B,C,D1,D2,E1,F1
(52)	2	WO	E2	-	O,A,B,C,D1,D2,E1,F1
(53)	3	-W	-	-	O,A,B,C,D1,D2,E1,F1
(54)	3	WO	-	E2	O,A,B,C,D1,D2,E1,F1

TABLE X. UPPER LIMIT FOR WHEY DEMANDS IN ORDER TO ACHIEVE A DROI VALUE OF 0.15 IF THE REST OF CONDITIONS OF SCENARIO O ARE SUSTAINED

TYPE, CASEIN ADDITION STATUS AND SCALE*	MAX FRACTIONAL WHEY DEMAND FOR DROI=0.15	TYPE, CASEIN ADDITION STATUS AND SCALE*	MAX FRACTIONAL WHEY DEMAND FOR DROI=0.15
CAMEMBERT WO-1	—	CAMEMBERT W-1	—
CAMEMBERT WO-2	0.30	CAMEMBERT W-2	0.29
CAMEMBERT WO-3	0.40	CAMEMBERT W-3	0.46
SOFT PASTE TYPE WO-1	—	SOFT PASTE TYPE W-1	—
SOFT PASTE TYPE WO-2	0.31	SOFT PASTE TYPE W-2	0.31
SOFT PASTE TYPE WO-3	0.42	SOFT PASTE TYPE W-3	0.48
FETA WO-1	0.15	FETA W-1	0.02
FETA WO-2	0.46	FETA W-2	0.46
FETA WO-3	0.51	FETA W-3	0.55
MOZZARELLA WO-1	0.17	MOZZARELLA W-1	0.03
MOZZARELLA WO-2	0.49	MOZZARELLA W-2	0.49
MOZZARELLA WO-3	0.52	MOZZARELLA W-3	0.58
COTTAGE WO-1	0.44	COTTAGE W-1	0.49
COTTAGE WO-2	0.68	COTTAGE W-2	0.71
COTTAGE WO-3	0.68	COTTAGE W-3	0.74
QUARG WO-1	0.48	QUARG W-1	0.48
QUARG WO-2	0.78	QUARG W-2	0.78
QUARG WO-3	0.74	QUARG W-3	0.67
CREAM WO-1	0.67	CREAM W-1	0.71
CREAM WO-2	0.86	CREAM W-2	0.87
CREAM WO-3	0.84	CREAM W-3	0.85
RICOTTA WO-1	0.58	RICOTTA W-1	0.58
RICOTTA WO-2	0.88	RICOTTA W-2	0.88
RICOTTA WO-3	0.84	RICOTTA W-3	0.77
QUESO FRESCO WO-1	0.72	QUESO FRESCO W-1	0.85
QUESO FRESCO WO-2	0.86	QUESO FRESCO W-2	0.98
QUESO FRESCO WO-3	0.89	QUESO FRESCO W-3	0.99

* W=WITH, WO=WITHOUT
1, 2 AND 3 ARE THE SCALES OF PROCESS

The best economic strategy in terms of casein addition and UF was dependent on the particular type of cheese considered. Different economic behavior corresponded to different cheese types. This study helped identify this behavior for the group studied and to point queso fresco, cream and ricotta as the best options for a process modification.

ACKNOWLEDGEMENTS

The authors wish to thank Ing. Francisco Lemus-Martínez from Quesos El Sauz, in Cortazar, Guanajuato, México, M.C. Fernando Vázquez from Quesos La Caperucita, in Querétaro, México, M.C. Jaime Valencia and M.C. Saúl Rivera from Grupo PROLESA; Alicia Méndez from Kerry Ingredients and Iván Nájera from New Zealand Milk Products for their experienced suggestions about practical limits on UF and casein addition, and for providing prices of products, equipments, services and labor.

REFERENCES

Anonymous (1984). Milk ultrafiltration becomes on-farm reality. *Holstein World*, December *10*, 44.

Anonymous (1985a). *Production yearbook Vol 39. FAO Statistics Series Nº 70.* Food and Agriculture Organization of The United Nations, Rome, pp. 16-17.

Anonymous (1985 b). *Dairy science and technology. Principles and applications.* La Fondation de Technologie Laitiere du Quebec, Quebec Canada, pp. 1-2.

Anonymous (1988). *Production yearbook Vol 42 . FAO Statistics Series Nº 88.* Food and Agriculture Organization of the United Nations, Rome, pp. 19-20.

Anonymous (1989). *Annual report 1987-88, Center for Dairy Research. College of Agricultural and Life Sciences.* University of Wisconsin-Madison, pp. 67-68.

Anonymous (1993). Dairy product markets. In: *The cheese reporter, Vols. 117-118,* Madison, Wisconsin.

Asher Y.J., Consentino G.P., Duvnjak Z., Kosaric N., Lim H.C., Luttmann R., Magee R.J., Munack A., Parulekar S.J., Thoma M. and Wieczorek A. (1985). *Agricultural feedstock and waste treatment and engineering.* Springer-Verlag, Berlin, pp. 7-10.

Cenzano I., Madrid A. and Madrid R. (1991). Composición, valor nutritivo y valor calórico de los quesos. *Lácteos Mexicanos 6*, 14-16.

Chiang B.H. and Pan W.D. (1989). Membrane separation technology and its application in food processing. *Proceedings of The National Science Council, Republic of China. Part A: Physical Science and Engineering 13*, 211-226.

Christensen P. and Colding H. (1988). Recombined cheese. *North Europ. Food Dairy J. 3*, 99-105.

Clarck Jr. W.S. (1979). Our industry today: whey processing and utilization. *J. Dairy Sci. 62*, 96-98.

Cox G.C. and Langdon I.A. (1985). Economic evaluation of reverse osmosis for reduction in milk transport costs. *Australian J. Dairy Technol.* September, 113-117.

Damerdji O., Derouiche F., Legrand C., Capiaumont J. , Bour J.M., Maugras M., Belleville F., Navet P., Paquet D. and Linden G. (1988). Utilization of whey fractions as a substitute for fetal calf serum in culture media. *Biotechnol. Techniq. 2*, 253-258.

Eck A. Ed. (1990). *El queso.* Omega Editores, Barcelona, pp. 451-455.

Garoutte C.A. (1983). Studies on whey processing and cheese manufacture by ultrafiltration. PhD thesis, Department of Food Sciences, University of Wisconsin-Madison, pp. 1-50.

Garrett N.L.T. (1987). Continuous production of cheddar cheese according to the Sirocurd method. *North Europ. Food Dairy J. 5*, 135-143.

Gilles J. and Lawrence R.C. (1981). The manufacture of cheese and other fermented products from recombined milk. *New Zealand J. Dairy Sci. Technol. 16*, 1-12.

Gilles J. (1984). The manufacture of white cheese using high total solids recombined milk. *New Zealand J. Dairy Sci. Technol. 19*, 37-42.

Hansen R. (1987). Cream cheese without whey proteins. *North Europ. Food Dairy J. 1*, 21-23.

Hansen R. (1988). Cheesemaking in a new way. *North Europ. Food Dairy J. 9*, 310-312.

Hansen R. (1989). Borculo: the world´s biggest whey powder factory. *North Europ. Food Dairy J. 1*, 1-10.

Harper W.J. (1991). Manufacture of whey protein concentrate by ultrafiltration.In: *whey protein workshop (CDR/ADPI) Proceedings.* Wisconsin Center for Dairy Research, Madison, pp. 1-20.

Hirschhorn J., Jackson T. and Baas L. (1993). Towards prevention -the emerging environmental management paradigm- In: *Clean production strategies* (T.Jackson, Ed.) Lewis Publishers, New York, p. 25.

Huffman L.M. and Kristoffersen T. (1984). Role of lactose in cheddar cheese manufacturing and ripening. *New Zealand J. Dairy Sci. Technol. 19*, 151-162.

Jelen P. (1979). Industrial whey processing technology: an overview. J. *Agric. Food Chem. 27*, 658-661

Jiménez A. (1994). *Diseño de procesos en ingeniería química.* Instituto Tecnológico de Celaya, México, pp. 1-50.

Kelly P.M. (1987). Application of membranes to whole milk separations: a review. *Irish J. Food Sci.Technol. 11*, 153-161.

Kosikowski F.V. (1979). Our industry today. Whey utilization and whey products. *J. Dairy Sci. 62*, 1149-1160.

Kosikowski F.V. (1982). *Cheese and fermented milk foods.* F.V. Kosikowski and Assoc., New York, pp. 2-75.

Lawrence R.C. (1989). The use of ultrafiltration technology in cheesemaking. *Bull. Int. Dairy Federat. 240*, 2-15.

Lelievre J. and Lawrence R.C. (1988). Manufacture of cheese from milk concentrated by ultrafiltration. *J. Dairy Res. 55*, 465-478.

Matthews M.E. (1984). Whey protein recovery processes and products. *J. Dairy Sci., 67*, 2680-2692.

McGregor J.U. and White C.H. (1990). Optimizing ultrafiltration parameters for the development of lowfat cheddar cheese. *J. Dairy Sci. 73*, 314-318.

Moulin G. and Galzy P. (1984). Whey, a potential substrate for biotechnology. *Biotechnol. Genet. Engineer. Rev. 1* 347-374.

Peppler H.J. and Perlman D., Eds. (1979). *Microbial technology. Vol 1.* Academic Press, New York, pp. 85-90

Quintana M., Barneto R. and Martin D. (1984). Evolución de la microflora durante la maduración del queso fabricado con leche ultrafiltrada. *Rev. Agroquím. Tecnol. Aliment. 24*, 256-261.

Rajah K.K. and Blenford D.E. (1988). *Lactose in the baking industry.* Association of Lactose Manufacturers, The Hague, The Netherlands, pp. 3-20

Reinbold R.S. (1990). Factors that affect cheese yield. *Modern Dairy*, February, 10-11.

Robinson R.K., Ed. (1986). *Modern dairy technology. Vol 1.* Elsevier Applied Science Publishers, London, pp. 21-60.

Rudd D.F., Treviño A.A. and Jiménez A. (1988). An economic assessment of the production from whey of acetic acid, acetone, butanol, ethanol, 2,3-butanediol, glycerol, isopropanol, propylene glycol and methyl ethyl ketone. Internal Report, Department of Chemical Engineering, University of Wisconsin-Madison, pp. 1-40.

Shimp L.A. (1985). Process cheese principles. *Food Technol.* May, 63-69.

Slack A.W. (1981). Ultrafiltration of raw whole milk on the farm. M. Sc. thesis, Department of Food Sciences, University of Wisconsin-Madison, pp. 1-260.

Van Slyke L.L. and Price W.V. (1949). *Cheese.* Orange Judd Publishing, New York, pp. 2-75.

Wolff I.A. Ed. (1982). *Animal Products.* In: *CRC handbook of processing and utilization in agriculture. Vol 1,* CRC Press, Florida, pp. 1-48.

Zadow J.G. (1992). *Whey and Lactose Processing.* J.G. Zadow and Assoc., New York, pp. 1-97.