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OPTIMIZATION OF THE WHEY SEPARATION PROCESS

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Abstract

The separation process of the whey resulting from milk coagulation in cheese manufacturing was modelized and optimized for different coagulae. Preliminary investigations of the filtration process allowed to choose the kind of coagulum and the ranges of the key-parameters. The pressing process was further modelized and optimized using a 3^2 experiment design. The effects of time (t) of coagulum pressing and the pressing force were investigated in the respective range: 0-6 hours and 0,005-0,009 kg/cm^2. It was found that the optimum process is strongly correlated to the kind of coagulum. For instance, for coagulum obtained using promoter agents, this optimum occurs at a pressing time of 4,9 hours and a pressing force of 0,0064 kg/cm^2. For tainted milk, this optimum lies at t_{op} : 7,2 hours and 0,008 kg/cm^2. The results highlight the opportunity to achieve a high performance whey recovery using a low-cost process.

***Keywords**: Milk, cheese, coagulation, separation, modelisation, pressing time.*

Résumé

Le processus de séparation du lactosérum résultant de la coagulation du lait, dans la fabrication des fromages, a fait l'objet d'une modélisation et d'une optimisation pour différents types de coagulats. Des essais préliminaires sur le processus de filtration ont permis de choisir le type de coagulats selon leurs consistances et leurs teneurs en eau, ainsi que les domaines de variations des paramètres-clés. Le rendement en lactosérum a été ensuite modélisé et optimisé à l'aide d'un plan expérimental de type factoriel 3^2. Les effets du temps de pressage du coagulat (t) et de la force de pressage ont été étudiés dans les domaines: 0-6 heures et 0,005-0,009 kg/cm^2, respectivement. Il a été établi que les rendements les plus élevés en lactosérum sont étroitement liés à la nature du coagulat (consistance et teneur en eau). Ainsi, pour un coagulat résultant de l'action d'agents promoteurs de coagulation, un temps de pressage de 4,9 et une force de 0,0064 kg/cm^2 sont considerés des conditions optimales. Pour le coagulat d'un lait fermenté naturellement, les meilleurs rendements de lactosérum sont obtenus après un temps de pressage de 7,2 heures avec une force de 0,008 kg/cm^2. Les résultats issus de la présente étude permettent de souligner la possibilité de réaliser, à moindre coût, de hautes performances dans la récupération du lactosérum.

***Mots clés** : Lait, fromage, coagulation, séparation, modélisation, temps de pressage.*

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ملخص

لقد خضعت عملية استخلاص مصل اللبن عن تخثر الحليب خلال صنع الجبن لتنميط وتحسين بالنسبة لمختلف أنواع التخثر، كما تمت معالجة المردود من مصل اللبن حسب نموذج عملي حسب 2^3 عامل. وتمت دراسة مدة ضغط الخثرة (t) وشدة الضغط وذلك من 0 إلى 6 ساعات ومن 0.005 إلى 0.009 كلغ/سم^2 على التوالي. وكان أعلى مردود من مصل اللبن مقرون بطبيعية الخثرة (قوامها ومحتواها من الماء).

وتصادف الخثرة الناجمة عن ضغط مدته 4.9 سا وشدة 0.0064 كلغ/سم^2 إنتاجا في ظروف مثلى. أما بالنسبة للحليب المخمر طبيعيا، يصادف أعلى مردود من المصل 7.2 سا من الضغط و 0.008 كلغ/سم^2 من الشدة. توضح هذه الدراسة إمكانية الحصول على نتائج عالية في عملية استخلاص محصل اللبن وبنفقة منخفضة.

***الكلمات المفتاحية:** اللبن، الجبن، استخلاص، تخثر الحليب، مدة ضغط.*

Whey is the aqueous phase removed after milk coagulation. Such a by-product contains proteins, lactose, vitamines and other compounds which can be valorized as additives or raw materials in food technologies, cosmetics and pharmaceutical industries [1-4]. A partial whey separation can be achieved by simple coagulum filtration, yielding significant amounts of primary whey (45-50%). A full separation requires two consecutive step, i.e., filtration and pressing, producing successively primary and secondary whey. For instance, a conventional cheese manufacturing facility can produce up to 4000 l /day, which unfortunately is not properly valorized [1]. Thus, whey recovery, as a by-process, appears as being an interesting low-cost alternative which does not need additional investments.

The purpose of this study consists of modeling, optimization and simulation of the coagulum pressing process through a factorial design which takes into account, the individual (simple) and the interaction effects of the pressing force and the process time. Such a procedure is very convenient, becauses it requires a minimal number of experiments through a judicious choose of the parameters ranges for optimizing the whey yields [5]. Previous works dealing with milk derivatives design using this procedure have already been reported [6-15].

In the present work, the effects of coagulum acidity, the coagulation time, and the pressing force upon the coagulum yield have been investigated. These experiments consist in the determination of the optimum conditions for obtaining the highest coagulum yields.

EXPERIMENTAL

In the first step, the evolution in time of the coagulum yield upon simple filtration without pressing has been studied. Seven different types of coagula (normal yoghurt, fatty yoghurt, sour coagulated milk, sour milk**,** tainted milk, coagulated milks obtained using powder or liquid coagulation promoting agent containing chimosine, as the coagulating enzyme) have been examinated. These experiments were achieved in order to choose the kind of coagulum for further investigations, and to determine the yields in primary whey as well as the time range for filtration.

In a second step, the optimization of the coagulum pressing process for obtained the highest yields in secondary whey aws achieved through a 3^2 factorial experiment design. In this context, the effects of two factors, namely the pressing time (X_1) and the pressing force (X_2) have been considered.

Thus, such an experiment can supply valuable results through 9 attempts for each coagulum [5]. For this purpose, the whey yield (expressed in terms of weight % related to the initial milk amount) has been measured for different types of coagulum (Y_i, respectively).

RESULTS

Primary whey by simple filtration

The evolution in time of the yield in primary whey through simple and static filtration, without pressing, for seven coagulum types, is presented in Figure 1. It appears that whey recovery without pressing is a relatively low process, and that the whey yield is strongly depending on the kind of coagulum and, consequently, on the acidity and the structure of the latter.

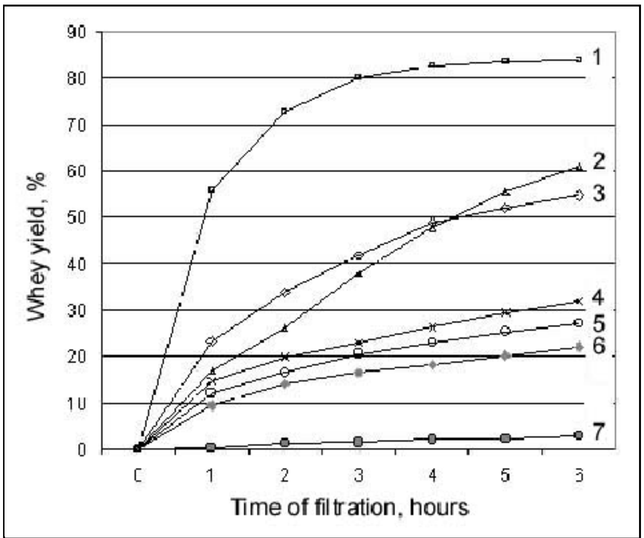

Figure 1: Evolution in time of the yield in primary whey for various coagulum types. 1. Coagulum obtained using solid promoter; 2. Coagulum obtained using liquid promoter; 3. Naturally tainted milk; 4. Fatty yoghurt; 5. Normal yoghurt; 6. Sour milk; 7. Coagulated sour milk.

It was also found that the highest whey yields (up to 50 %) were obtained for filtration time higher than 3 hours and for coagulum resulting from milk treatment with chimosine-containing promoters and from tainted milk. For the other coagulum samples, the whey yields do not exceed 30% even after 6 hours of filtration, indicating that yoghurt and sour milk do not deserve to be valorized for primary whey recovery. These coagulum types have very compact structures which make them to be directly used as food products.

Thus, as a preliminary results, it clearly appears that without pressing, whey recovery becomes interesting (up to 50 %) only for filtration time exceeding 1-3 hours, and only for certain coagulum types.

Secondary whey through pressing process

The second step of the present study was foccused towards the pressing process of those coagulum samples which display the best performances in whey recovery, i.e., milk treated with both types of coagulation promoters (solid and liquid).

For studying the individual effects of the pressing time (X_1) and of the pressing force (X_2), as well as their possible interactions, nine attempts for each coagulum sample were carried out, and the results are presented in Table 1.

Pressing force, kg/cm^2 (X_2)	Pressing time, hours (X_1)	Yield in secondary whey (%)		
		Naturally tainted milk	Milk + solid promoter	Milk + liquid promoter
		A=42°T	A=70°T	A=20°T
0.004 (-1)	0 (-1)	0	0	0
	3 (0)	7,76	1,05	3,52
	6 (+1)	8,47	1,05	4,7
0.006 (0)	0 (-1)	0	0	0
	3 (0)	13,88	1,88	9,41
	6 (+1)	25,17	2,11	13,64
0.008 (+1)	0 (-1)	0	0	0
	3 (0)	14,58	0,47	17,64
	6 (+1)	17,41	0,47	22,11

Table 1: Yield in secondary whey through pressing process.

The X_i value are expressed in terms of adimensional or reduced parameters, e.g., -1 for the minimum, 0 for the medium, and +1 for the maximum parameter value in the respective ranges of variation [5]. The data in parentheses represent the coresponding real value of the parameter (unreduced). ***A*** is the coagulum acidity, expressed in terms of °Thörner [16-20].

For each experiment, three levels of variation were established for each parameter, i.e. a minimum, a medium and a maximum value. Also, for each experimental attempt, an amount of 85 ml of coagulum was initially left for filtration by 6 hours. In each case, the filtration coagulum was pressed with the three pressing forces (0.004 kg/cm^2 (-1), 0.006 kg/cm^2 (0) and 0.008 kg/cm^2 (1)). Each attempt required different pressing times for pressing (0 hours (-1), 3 hours (0) and 6 hours (+1)).

The results obtained were used as input data for the modeling of the coagulum pressing process. It results that the yield in secondary whey does not exceed 26 % even after 6 hours of pressing, and is strongly depending on the coagulum type but not necessarely on the pressing force. Indeed, for the naturally tainted milk and for milk treated with solid promoter, the highest yields were obtained using a medium pressing force. This suggests that each coagulum exhibits a certain structure characterized by a certain porosity, and that an excessive pressing force leads to a collapse of the structure, hindering thereby the whey diffusion.

Mathematic model for the pressing process

Using a judicious calculation algorithm and the so-called t-student test [5], one has established the following mathematic models which fully describe the pressing process for the three coagulum samples:

1. Naturally tainted milk:

$Y_1=15.26 + 8.5X_1 + 2.62X_2 - 3.52X_1^2 - 4.84X_2^2 +2.23X_1X_2$

2. Milk treated with solid coagulating agent:

$Y_2= 1.3 + 0.6X_1 - 0.19X_2 - 0.52X_1^2 - 0.27X_2^2 - 0.14X_1X_2$

3. Milk treated with liquid coagulating agent:

$Y_3= 7.27 + 6.74X_1 + 5.25X_2 - 3.41X_1^2 + 0.1X_2^2 + 4.35X_1X_2$

The accuracy of the determination of the coefficients for all the models strongly depends of the precision of the experiment. In our case, the error does not exceed 2%.

The 3-D representations of these three mathematical models are illustrated by Figures 2 - 4.

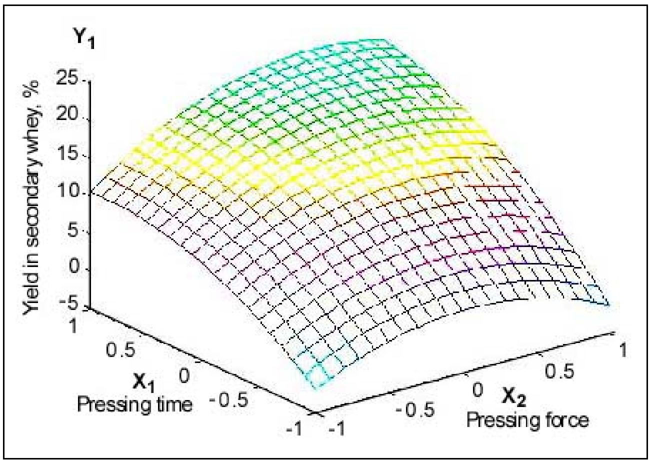

Figure 2: Dependence of the yield in secondary whey versus the time and the force of pressing for the naturally tainted milk.

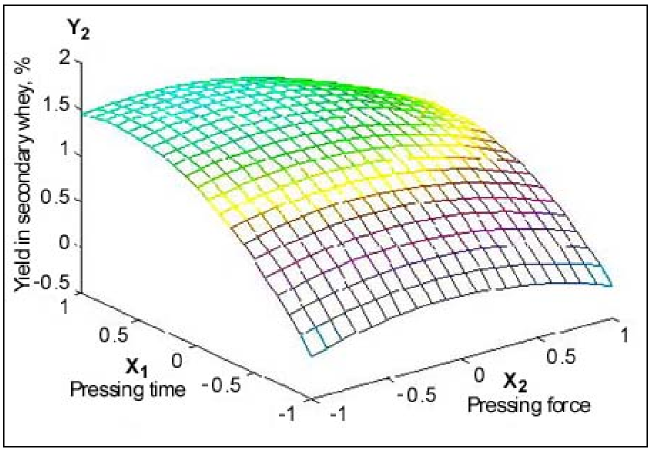

Figure 3: Dependence of the yield in secondary whey versus the time and the force of pressing for milk treated with solid coagulating agent.

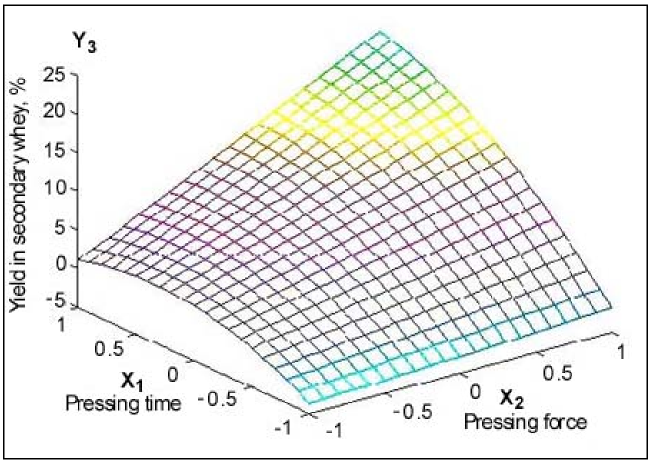

Figure 4: Dependence of the yield in secondary whey versus the time and the force of pressing for milk treated with liquid coagulating agent.

Effect and interactions of the parameters

According to the absolute value and the sign of each coefficient, one can appreciate respectively the intensity and the direction of each effect or interaction of the parameters. In table 2, these effects are discussed.

X_i	Type of effect	Effect simulation		
		Y_5	Y_6	Y_7
X_1	Individual effect	Very strongly advantageous	Weakly advantageous	Strongly advantageous
X_2	Individual effect	Moderately advantageous	Weakly disadvantageous (negative)	Strongly advantageous
$X_1.X_2$	Interaction	Moderately advantageous	Weakly disadvantageous (negative)	Strongly advantageous

Table 2: The effect simulation.

Deeper insights in the result examination indicate that for milk treated with solid coagulating agent, the pressing process does not seem to be greatly influenced by the parameters variation, suggesting thereby that such a coagulum does not present any interest for secondary whey recovery.

As a general feature, the pressing time displays relatively more intensive effects than the pressing force and that the interactions of both parameters are so significant that they cannot be neglected, suggesting that the parameters effects cannot be investigated separately.

Optimization of the pressing process

On the basis of the as-obtained models, the optimum conditions of the coagulum pressing process were determined using an analytical method. Thus, the possibility for the occurence of an optimum required that the first-degree derivatives to be equal to zero. Such a criterion will be used in the calculation of the optimum parameters values, expressed both in reduced (adimensional) and real values (respectively in hours and kg/cm^2). The results are presented in Table 3.

X_i		Optimal values of the parameters		
		Y_5	Y_6	Y_7
Time	X_1	1	0,63	1
	hours	6	5	6
Pressing force	X_2	0,63	- 0,5	1
	kg/cm^2	0.0072	0.005	0.008

Table 3: Reduced and real values of the optimal operating conditions for obtaining the highest yields in secondary whey.

It appears that milk coagulated using solid coagulating promoter needs moderate pressing process for yielding significant amounts of secondary whey, in contrast to the naturally tainted milk and to milk coagulated using liquid promoter which require longer times and stronger pressing forces.

DISCUSSION

During the experiments it has been observed that the primary whey obtained by simple filtration exhibited a relatively low acidity of ca. 30 - 50°T, as compared to the 60 - 90°T acidity of the secondary whey. The yields in primary whey is depending on the type of coagulum, its acidity, the filtering time and the pressing force. Thus, after 6 hours, the highest amount of whey was obtained by filtration of the milk with powder coagulation promoter (84%). The most compact coagulum seems to be the sour coagulated milk, which, after filtering, released the smallest amounts of whey (2,7%).

The most valuable sources for obtaining primary whey appear to be milk coagulation using solid promoter (84%), liquid promoter (61%) and the naturally tainted milk (55%). Significant amounts of whey (more than 40%, which means almost 2000 l of whey for each 6000 l of milk processed) can be obtained even after short filtering periods (around 3 hours). This results shows that the primary whey recovery can be regarded as being a low-cost alternative.

With small additional investments, the secondary whey can be obtained after a moderate pressing process. Indeed, by additional pressing, an important amount of secondary whey can be recovered. The best results are obtained by pressing the naturally tainted milk (25%) and milk coagulated using both types of promoter (22%). In our opinion, such relatively high yields in secondary whey are due to the expanded structure and, subsequently, to the large porosity which allow the whey diffusion in these kinds of coagulum.

The yield in secondary whey does not seem to be proportional to the pressing force. Indeed, one has observe that, in certain cases, an excessive pressing force leads to a yield decrease, probably due to a framework collapse, destroying thereby the structure porosity. For this reason, one assumes that the optimum conditions determined in this experiment could be used in cheese manufacturing industries, especially when milk coagulates quickly.

The highest yields in total whey are obtained by filtering and pressing milk coagulated using solid promoter (more than 80%), as compared to voluntary tainted milk (60%), milk coagulated using liquid promoter (48%), fatty yoghurt (41%), sour milk (32%) and yoghurt (31,5%).

CONCLUSION

Larges amounts of primary whey can be obtained by simple filtration of coagulated milk. The whey yield is strongly depending on the coagulum structure, through the porosity of the latter. Under pressing forces, the process duration presents optimal value, suggesting that excessive values of these parameters affects the coagulum structure.

As a general feature, a strong reverse correlation was found between the effects of both the pressing force and pressing time, since it appears increased pressing force requires shorter time. A result synthesis allows to highlight the opportunity to use a low-cost technology for whey recovery using specific coagulum structures.

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