Design and construction of a dairy fermenter to make Colombian "Suero Costeño" from whey

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Abstract – Suero Costeño is a fermented dairy product traditionally produced in the Colombian Caribbean Coast, especially in most municipalities of the Departments of Bolívar, Sucre, Córdoba and Cesar. The objective of this work was to design and build a dairy fermenter to produce Suero Costeño from cow milk and whey, coupled with temperature control, pH and stirring rate. First, the analysis and calculation of the materials used to design the fermenter were carried out. Finally, the equipment was constructed and validated by manufacturing of Suero Costeño using an experimental design fraction one third of a factorial design 3^2, where the factors (with their respective levels) were: cow milk (75 %, 65 % and 50 %) and whey (25 %, 35 % and 50 %). Then, the response variables measured were colour, odour, taste and general appearance. Temperature control (From T_{room} to 65 °C), stirring rate (up to 100 rpm) and pH were evaluated as well. The results of the sensory analysis of the Suero Costeño were acceptable and it was feasible its elaboration in the fermenter since it had the appropriate characteristics of this product. In addition, the yield in the fermenter was higher than that obtained by the traditional method, due to the control of variables such as temperature and agitation speed, which is fundamental in the process. Furthermore, the time to produce Suero Costeño with the equipment built in this work was reduced from 20 h in the artisanal process to 8 h in the fermenter.

Keyword: Sour cream, Colombian Caribbean Coast, pasteurization, whey, optimization.

I. INTRODUCTION

Fermentation is a simple, inexpensive and safe way to conserve milk. In areas where modern milking and milk collection equipment is available, where there is generally a great deal of knowledge and experience in the techniques for preserving raw milk, as well as good transport and distribution systems [1]. Suero Costeño is the product obtained from whole, skimmed hygienic milk, fermented by acidic and mesophilic bacteria with the addition of sodium chloride and other allowed ingredients [2,3]. It is classified as one of the fermented dairy products produced in the Colombian Caribbean Region [4]. Its origins are not exact, but it is popularly believed that it arose in the same way as other types of fermented products such as wine and beer have arisen, that is, accidentally [5]. The appearance of the Suero Costeño is characterised by a relatively fluid white colour, lumpy and some syneresis. Its characteristic aroma is moderately acidic and rancid with a salty taste [6].

The fermentation carried out in the Suero Costeño is characterised by a two-phase liquid-solid system, where the liquid part is called whey and the other one known as "Suero", a kind of sour cream [7]. Whey is defined as the liquid substance obtained by separation of the milk clot in cheese production. It is a translucent green liquid obtained from milk after the precipitation of casein [8]. There are several kinds of whey depending mainly on the elimination of casein, the first so-called sweet, is based on coagulation by renin at pH 6.5. The second one so-called acid results from the fermentation process or addition of organic acids or mineral acids to coagulate the casein as in the production of Colombian Caribbean Coastal cheese or "Queso Costeño" [9]. Approximately 90 % of the total milk used in the cheese industry is eliminated as whey, which retains about 55 % of the total milk ingredients such as lactose, soluble proteins, lipids and mineral salts. Some possibilities for the use of the whey have been proposed, however, a significant percentage of this waste is discarded as effluent, which creates a serious environmental problem, because it physically and chemically affects the soil structure, resulting in a decrease in the yield of agricultural crops and when it is discarded in water, reduces aquatic life by depleting dissolved oxygen [10].

The industrially produced Suero Costeño has a low consumption due to the difference in taste detected by consumers and the presence of syneresis [11]. These quality problems have been addressed by increasing fermentation time and adding thickeners, which increases costs and makes the product more perishable [12]. On the other hand, a fermenter is an equipment in which fermentation is carried out, controlling the temperature, pH and stirring rate [4]. The aim of this study was to design and build a dairy fermenter to produce Suero Costeño by using from raw cow milk and whey.

II. MATERIALS AND METHODS

For the development, it was necessary to take into account the control of the variables involved in the process: temperature (From T_{room} to 65 ºC) and mechanical agitation (From 0 rpm to 100 rpm) with a capacity of the vessel of 30 L at laboratory scale. The design of this prototype was carried out using CAD (Computer Aided Design) software as a tool. AISI 304 stainless was selected for the construction of the equipment.

A. *Prototype design*

The equipment was designed as a tank agitated with a jacket, heated through a tubular immersion type electric resistance and had a control panel with three variables (temperature, pH and agitation speed). This control was digital and each variable was independently controlled. The inner tank was constructed in 14-gauge AISI 304 stainless steel with a sheet thickness of 1.9 mm and the outer part in 16-gauge 304 stainless steel with 312 stainless steel threaded couplings, and 316 stainless steel ball valves. The vessel and agitator dimensions were determined for a useful capacity of 30 L. The fermentation tank followed the standards for agitation tanks and it is shown in Figure 1.

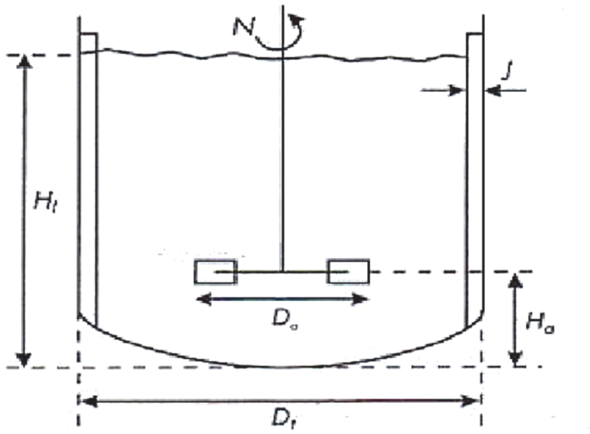

Figure. 1. Standard agitation system [13].

According to Figure 1, the variables that were considered to design the standard agitation system were: N = rotation rate; D_t = diameter of the tank; D_a = diameter of the stirrer; H_l = height of the liquid; H_a = distance from the base of the agitator tank and J: width of the baffle plates.
The capacity was based on design priorities, the requested volume was 30 L, but a safety factor was considered due to errors in the mathematical model, failure theory used or characteristics of the materials used. This safety factor depends fundamentally on the application of the current regulation, level of designer confidence or failure of the material (ductile, fragile) [14]. The fermenter was designed in a rectangular shape following the Equation (1), where L is the length, A is the width and h is the height. According to the selected measurements, a volume of 40 L was obtained.

$$V = L.A.h \quad (1)$$

B. *Selection of stirrer and electric motor*

For the design and calculation of the stirrer and the dimensions of the tank selected were taken into account the variables that influence the power consumed by the stirrer: D: tank diameter (m); D_a: stirrer diameter (m); H_l: height of the liquid (m); J: width of the baffle plate (m); E: height of the liquid towards the base of the tank; viscosity of the fluid (Pa*s); density of the fluid (kg m^{-3}); N: rotation rate of the stirrer (rps). The calculation of the consumed power (P) was done through dimensionless numbers, relating in a graph the Reynolds number (R_e)

and the power number (Pn). These graphs depend on the geometric characteristics of the stirrer and if the baffle plates are present.

According to the process to be implemented of Suero Costeño fermentation, a type of gate or anchor paddle stirrer was selected that operated in the speed range from 2 rpm to 200 rpm. From the ratio graph R_e vs Pn, and following curve 4 for the schematization of a power curve. For a tank without baffle plates, it was obtained a Pn of 0.3 and a P of 0.0148 W [15]. For this power, it was necessary to increase the mechanical power factor by 30 % (η). In addition to the above, a type of power should be considered to overcome inertia (Po) on the part of the motor, which was determined by Equation 2. Finally, the total required power was equal to the sum of P + Pt, which was 0.034 W.

$$Po = T \times \omega \tag{2}$$

To find this power we had to consider the formulas to find torque and force: P = 10.26 W. Thus, the total power for the motor was 0.034 W + 10.26 W. Le final result was 10.295 W.

C. *Resistance power calculations*

The calculation of the resistance power was calculated according to the energy conservation method, also taking into account the increase in fluid temperature from 28 °C to 63 °C in an estimated time of 30 min. Equations 3 (energy conservation method), 4 (energy storage) and 5 (power to heat the fluid) were used for this:

$$E_{input} = E_{stored} \tag{3}$$

$$E_{stored} = \mu_0 \Delta U_f \tag{4}$$

$$Pot = \frac{E_{stored}}{t} \tag{5}$$

Where E_{input} is the energy input to the system; E_{stored} is the stored energy; μ_0 is the mass of the solution; U_f is the internal energy differential; P_{ot} is the power to heat the fluid and *t* is the estimated heating time. In addition, the heat required to heat the solution according to Equation 6 (heat required for heating the solution) was taken into account [15]:

$$Q = m \times Cp \times (t_f - t_i) \tag{6}$$

The results of the calculations are clearly explained in Table I.

TABLE I. Heat calculations in processing liquids

Liquid	Mass (kg)	V (L)	ρ (kg m^{-3})	Cp (kcal kg^{-1} °C^{-1})	T_i (°C)	Te (°C)	ΔT (°C)	Q (kcal)
Milk	30.93	30.00	1032	0.93	28	63	35	1007.75
Water	19.37	19.37	1000	1.00	28	80	52	1007.75

It was observed that Q (milk) = Q (water) since it was the same that was transmitted in the process. The C_p at 65 °C was taken into account, which was 4.077 J g^{-1} °C^{-1}. Now, the initial resistance had a Pot = 2174 kW. The chosen resistance was acquired in the company Resista©, of tubular immersion type, the pipe was made of copper and the plates or plugs in stainless steel.

D. *Cooling system*

Once the fermenter was assembled, it was connected to the cooling system. The main objective of this system was to cool the Suero Costeño in the equipment after the pasteurization process. This system was connected to a fermenter jacketed piping, and water flow was passed through 34 m of calibrated 304 5/16-inch stainless steel tubing, this water flow came out at a temperature of approximately 2 °C, because the cooling system was controlled by the CH305 unit which created an ice bank where the tubing was located. In this way, by keeping the ice block thickness constant, a sufficient control of the temperature of the internal fluid of the coil to be cooled was achieved. In this system in the case of pasteurization, the milk temperature was the controlled variable. The hot water through the team jacket transferred its heat to the milk. To regulate the temperature value of the milk without the intervention of an operator, it was continuously measured using a sensor. The Suero Costeño processing simulation was performed with PD, PI, and PID controllers.

E. Experimental design

Three types of Suero Costeño were produced in the fermenter, where each type of product had a combination of raw cow milk and whey (Table II). A one-third fraction of a 32-factorial design was made, where the factors (with their respective levels) were: milk (75 %, 65 % and 50 %) and whey (25 %, 35 % and 50 %). The response variables were colour, smell, taste and general appearance. The aforementioned was measured with the help of 30 semi-trained panellists on a five-point hedonic scale, where 5 was "I like it extremely" and 1 was "I don't like it at all". Sensory test data obtained were analysed using the SPSS® statistical package (V. 22, 0,0-SPSS Inc.) by using of analysis of variance (ANOVA). Significant differences were evaluated using the Tukey test. Differences were significant for $p < 0.05$. The results of the semi-trained panel tests were plotted using Microsoft Excel®.

TABLE II. Suero Costeño samples made in the dairy fermenter

	Raw material combinations			
	Raw milk (%)	Volume (L)	Whey (%)	Volume (L)
Suero Costeño A	75	22.5	25	7.5
Suero Costeño B	65	19.5	35	10.5
Suero Costeño C	50	15.0	50	15.0

The Suero Costeño with the best sensory characteristics was the type C serum, which was subjected to physicochemical analysis and compared with a commercially obtained Suero Costeño to see which had the best characteristics.

III. RESULTS AND DISCUSSIONS

A. Construction

The construction and assembly of the equipment were carried out by means of fastening elements to make maintenance easier. Figure 2 shows the fermenter connected to the refrigeration system.

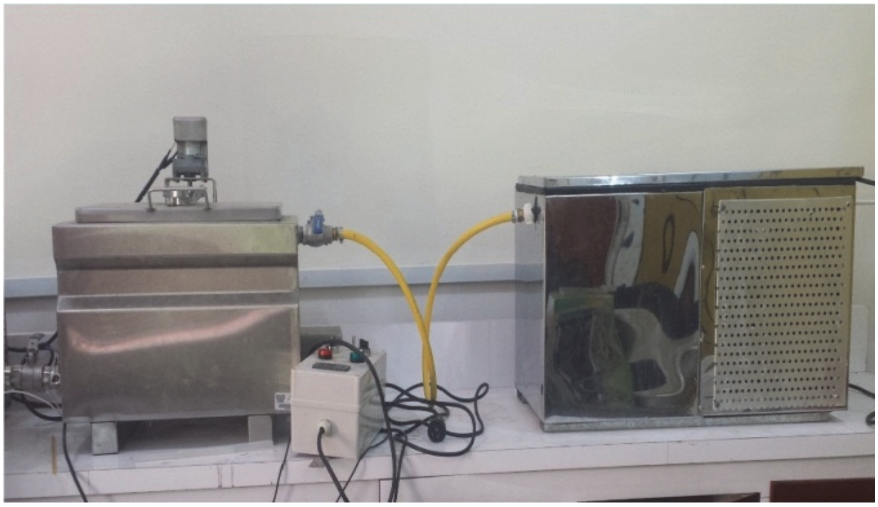

Figure. 2. Fermentation equipment coupled with a cooling system

B. Equipment performance testing

Figure 3 shows the pH behaviour and growth rate of microorganisms during the fermentation process of the Suero Costeño in the equipment built in this work. It was observed that the pH showed an overall average of 4.8, from a minimum of 4.3 at 5 h, and stabilizing to a maximum of 4.6 in the last 2 h of fermentation. On the other hand, when analysing the growth rate of lactic acid microorganisms, a behaviour was observed that was adjusted to a logarithmic tendency, i. e., during the first hours of fermentation there was an accelerated growth, becoming stabilized at 8 h of the process. In each hour of transformation, a sample of fermented Suero Costeño was taken, for carrying out lactic bacteria counts, it was observed that the data varied from 1 Log_{10} CFU mL^{-1} (reading 1) until a maximum of 9.1 Log_{10} CFU mL^{-1} (reading 16). Studies carried out by Simanca *et al.,* [16] reported that during the Suero Costeño fermentation no acetic bacteria growth was observed; instead, nine lactic acid bacteria, six coccus and three bacilli were isolated, while only one strain had coagulant activity, syneresis and gas production, which are associated with the fermentation of warm regions.

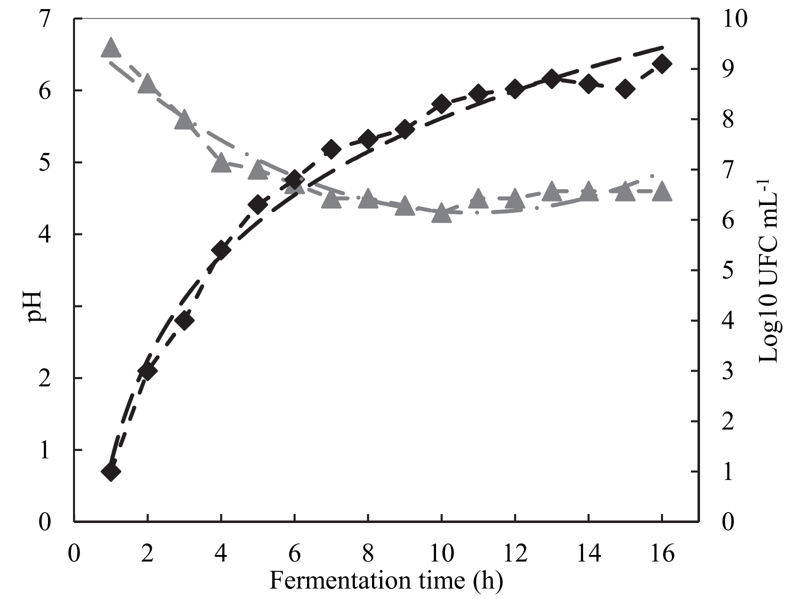

Figure 3. Changes in pH and microorganism growth rate during the fermentation of Suero Costeño. In Figure: pH (▲), pH tendency (— · –), number of microorganism in Log_{10} UFC mL^{-1} (◆) and its tendency (— —).

C. *Final extraction of Suero Costeño*

The test for the manufacture of Suero Costeño was carried out in a time lapse of 8 h of fermentation, which was the optimal point since the product was obtained in a shorter processing time compared to the traditional method and with similar sensory characteristics. In order to obtain Suero Costeño, the whey was first removed, the clot formed was left to rest and mixed with sodium chloride according to the Acevedo *et al.,* [12]. It should be noticed that the yield in the fermenter built in this work was higher than that obtained by the traditional method, due to the control of variables such as temperature and agitation speed, which is fundamental in the process. Furthermore, the time to produce Suero Costeño with the equipment built in this work was reduced from 20 h in the artisanal process to 8 h in the fermenter.

D. *Comparison of Suero Costeño produced in the fermenter and a commercial product*

The Suero Costeño elaborated with 50 % whey and 50 % raw milk (FS) was compared in terms of the sensory and physicochemical characteristics with a commercial product (CS). According to the results of Table III, it could be observed that the most widely accepted Suero Costeño was the SC. However, the results obtained were strongly similar. It should be considered that the process carried out in this work is not still optimised.

TABLE III. Sensory analysis of commercial Suero Costeño and the obtained in this work.

	Taste		Odour		Colour		General Appearance	
Panellist	FS	CS	FS	CS	FS	CS	FS	CS
1	5	4	4	4	5	2	4	3
2	4	2	4	3	5	4	4	4
3	4	3	2	3	4	2	4	2
4	1	4	1	2	1	4	1	5
5	1	5	1	4	2	4	1	4
6	4	5	4	5	4	5	4	5
7	5	4	4	3	4	4	4	4
8	5	2	4	2	5	2	5	2
9	3	4	1	2	1	3	2	4
10	3	5	2	5	3	5	3	5
11	2	4	2	4	1	4	2	5
12	5	4	5	3	5	3	5	3
13	4	2	4	1	4	3	4	2
14	4	5	1	5	3	5	3	5
15	4	5	2	5	3	2	2	4

16	4	5	4	5	4	5	4	5
17	4	4	4	4	4	5	4	4
18	1	5	1	5	1	4	1	5
19	1	5	1	4	3	5	1	5
20	3	5	4	5	1	5	3	5
21	1	5	1	5	1	5	1	5
22	3	4	3	5	1	5	3	4
23	1	5	1	5	2	5	2	4
24	4	3	4	1	4	1	5	3
25	4	5	4	5	4	5	4	5
26	3	5	5	5	4	5	4	5
27	3	5	4	5	4	5	3	4
28	4	5	4	5	4	5	3	5
29	4	5	4	5	4	5	4	5
30	4	5	3	5	3	5	3	5
Average	3.26±1.33	4.30±0.98	2.93±1.41	4.00±1.31	3.13±1.40	4.00±1.22	3.10±1.20	4.20±0.99

On the other hand, Table IV shows that both samples of Suero Costeño had a high moisture content. In addition, in terms of fat content, SC had the highest percentage. The protein and ash content was similar in both samples, reflecting a similar solids content in these products. It is important to note that the most acidic Suero Costeño was FS, presenting the highest value, and also presented the lowest values in the pH scale. Possibly it was mainly attributed to the product elaboration process, which required a longer fermentation time compared to the product manufactured by the trading company. Other studies in Suero Costeño reported similar values than the obtained in this work [2,4,12,16].

TABLE IV. Physicochemical analyses carried out on Suero Costeño samples

Parameter	SC	SF
Fat	3.41±0.17	1.16±0.01
Moisture	79.19±2.67	80.44±2.93
Protein	5.99±1.19	6.08±1.34
Ash	2.29±0.11	2.55±0.27
Carbohydrate	15.56±2.44	10.87±2.18
Acidity	1.03±0.08	2.19±0.19
pH	4.97±0.05	4.41±0.04

IV. CONCLUSION

It was possible to design and build a fermenter coupled to a refrigeration system, controlling the temperature, pH of the solution and agitation speed. The Suero Costeño processing time was reduced from 20 h in the artisanal process to 8 h in the fermenter. The automatic control system kept both temperature and pH stable during fermentation so that the acidity of the final product remained within an acceptable range. The equipment met the construction requirements of Colombian legislation; therefore, it could be promising for the manufacture of Suero Costeño, reducing processing times, improving the quality of the final product and minimizing production costs.

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