

Extrusion Technology in Dairy Industry: A Mini review

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ABSTRACT

Extrusion technology has become a very popular and is being increasingly used for the manufacture of food products. It is utilized in many areas of the food industry, including the production of snack foods, breakfast cereals, animal feed, and other diverse food products. Many workers have attempted to modernize and scale-up the production processes of Traditional Indian Dairy Products through technological and engineering innovations. Extrusion is a very useful technology for dairy processing operations involving conveying, mixing, kneading, cooking, shearing, shaping etc. which is yet to be exploited by the dairy industry.

Keywords: *Extrusion, Extruder, Milk, Milk Products, Dairy Industry.*

INTRODUCTION

Extrusion processing equipment has become the touchstone operating equipment in most snack food companies throughout the world. Food extrusion is a process in which a food material is forced to flow, under one or more varieties of conditions of mixing, heating and shear, through a die, which is designed to form and/or puff-dry the ingredients (Rossen & Miller, 1973). This process combines several unit operations including mixing, cooking, kneading, shearing, shaping and forming. Extrusion provides the foundation for continuous production. It is currently utilized to produce textured protein products, snack foods, toast and confectionary products (Onwulata et al., 1998). In spite of its immense

potential, in the dairy industry extrusion technology is rarely utilized. In the dairy industry extrusion technology is hardly known but some research work has been done, for example on casein/caseinate conversion, production of processed cheese, mozzarella cheese, *sandesh*, *rasogolla*, *peda* etc. This article highlights the application of extrusion process and its important implications in dairy industry.

Fundamentals of Extrusion System

In an extrusion process, a set of mixed ingredients are forced through an opening in a perforated plate or die with a design specific to the food and is then cut to a specified size by blades.

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The machine which forces the mix through the die is an extruder, and the product is known as the extrudate. The extruder consists of a long, rotating screw tightly fitting within a stationary barrel, at the end of which is the die. The screw is housed in a metal barrel, which can be of variable length and through which cooling water or steam can circulate. Food extrusion machines use single or twin screws to transport, mix, knead, shear, shape, and/or cook multiple ingredients into a uniform food product by forcing the ingredient mix through specific shaped dies to produce extrudates of specific shapes and lengths (Harper, 1981).

Single-screw cooking extruders consisted of compressive screws with decreasing channel depth turning at high speeds to increase shear and mechanical energy input for heating. The resulting friction induces heating of a product. In some cases, the barrel is jacketed for steam to allow additional contact heating in the metering section (Fellow, 2000). Categories of single-screw extruders includes (i) Cold Forming (Pasta-type) Extruders (ii) High-Pressure Forming Extruders (iii) Low-Shear Cooking Extruders and (iv) Collet Extruders (Harper, 1981). Twin screw extruders consist of two parallel screws in a barrel. The degree of quality control and processing flexibility they offer makes them attractive to food industries. Twin screws produce a more uniform flow of the product through the barrel due to the positive pumping action of the screw flights (Riaz, 2000). There are four types of twin-screw extruders (i) Non-intermeshed, co-rotating (ii) Non-intermeshed, counter rotating (iii) Intermeshed, co-rotating and (iv) Intermeshed, counter rotating. From these four types of twin-screw extruders, the co-rotating, intermeshed screw type has found the widest acceptance in the food industry. In this type of system, the tip of one screw wipes the cavity formed by the other screw, thus inducing positive displacement of product inside the barrel minimizing jamming/burning of the product which are so prevalent in single screw

extruder (Guy, 2001). If the food is heated above 100 °C, the process is known as extrusion cooking (or hot extrusion) while when food is processed at temperatures below 100 °C, the process is known as low pressure extrusion (or cold extrusion).

Extrusion Technology in Dairy Industry

The modernization of traditional dairy product manufacturing by Indian organized dairies generally followed the approach of adopting existing machineries to fit in the unit operations involved in the processing. The food extrusion machine as meant for production of puffed food extrudates, is being utilizing for processing and manufacturing of milk products. In the dairy industry, extrusion has yet to be making any impact in India. The scanty information is available in literature concerning its application; some of them are discussed below:

Mechanized Production of Rasogolla

Traditional dairy products and sweets are an integral part of Indian heritage and have great social, religious, cultural, medicinal and economic importance. *Rasogolla* is one of the *chhana* based traditional Indian dairy products highly popular in India. Many workers tried to mechanise the production process of *chhana* based dairy products by extrusion technology. Tavva (1999) designed and developed a kneader-extruder system for mechanized production of *rasogolla*. There should have kneading elements in extruder screw to enhance the performance of mixing and kneading operations. The processing parameters of screw speed 60 rpm and clearance of 1.25 mm is optimum for proper and efficient kneading of *chhana*. This devised screw kneader is later integrated with *channa* ball forming machine for further mechanization of process of *rasogolla* production. The integrated kneader cum ball former machine consisted of a feed hopper, kneading chamber, rotor, oscillator, reduction gear box and power transmission system with 2 HP motor (Choudhary et al., 2002 & Karunanithy et al., 2007).

Production of Extruded Sandesh

Sandesh is most popular milk sweet prepared from acid and heat coagulated product *chhana*. The processing steps involved in manufacturing of *sandesh* viz. mixing, kneading and cooking of *chhana* -sugar mix has been optimized for its mechanized production from cow milk. A screw type kneader is necessary for achieving the desired homogeneity of the *chhana*-sugar mix after the initial mixing by a planetary mixer for mechanized production of *sandesh* (Kumar &

Das, 2003). Later, a single screw vented extruder had devised for cooking of *chhana*-sugar mix and integrated with the kneading system for the continuous mechanized production of *sandesh* from cow milk (Kumar & Das, 2007). The design specifications of single screw extruder are presented in the Table 1. The operating parameters of extruder screw speed 4.4 rpm, cooking temperature 75 °C, feed flow rate 2.5 kg/h and product flow rate of 1.7 kg/h at the exit of the system is optimum for production of extruded *sandesh*.

Table 1: Specifications of the Vented Extruder for Production of Sandesh

Feed rate (f)	4.5 kg/h
Diameter of barrel (D_b)	0.042 m
Root diameter of screw (d)	0.033 m
Flight height (h)	0.004 m
Mean diameter of screw (D)	0.041 m
Helix angle of screw in feed section	17.44 ⁰
Total number of helix in feed section (n)	3
Initial helix angle in the evaporation section	17.44 ⁰
Final helix angle in the evaporation section	13.24 ⁰
Total number of helix in the evaporation section	9
Helix angle of screw in cooling section	13.2 ⁰
Total number of helix in cooling section	8
Length of feed section (l_f)	0.22 m
Length of evaporation section (l_e)	0.317 m
Length of cooling section (l_c)	0.249 m
Total axial length of flighted section of screw (L)	0.688 m
L/D ratio of screw	16.78
Speed of screw (N)	7 rpm

Mechanize Cooling of Khoa

Khoa is an intermediate product widely used as a base material for various indigenous milk sweets. Traditionally, *khoa* is cooled in open trays during its manufacturing at ambient conditions. This long duration conventional natural cooling of *khoa* not only increases total production time but also results to various browning reactions and microbial contamination. Shaw et al. (2015) devised a double jacketed screw conveyor system for continuous cooling of *khoa* and to avoid the problems associated with the traditional cooling method. This system could be integrated with continuous *khoa* manufacturing equipment's for rapid cooling of *khoa* to ambient temperature. The screw

speed of 9 rpm and 10⁰ inclination angle of cooling barrel is the optimum parameters for cooling of *khoa*. Chilled water circulation through the barrel jacket at the rate of 500 l/h is necessary to generate the cooling effect during the operation. This continuous cooling system not only reduces manufacturing time but also help in hygienic processing of *khoa*.

Production of Extruded Peda

Peda is popular milk sweet of Indian subcontinent and is the largest produced among the *khoa* based Indian dairy products. Traditionally, *peda* is mostly prepared by heating a mixture of *khoa* and sugar in a *karahi* (iron pan) with the help of *khunti* until the desired granular, hard texture and flavour develops. Its mechanized process involves

heating *khoa* to 60 °C and adding sugar, flavour and other ingredients in a planetary mixer. The dough after cooling to 5 °C is fed to *peda* shaping machine followed by packaging (Banerjee, 1997). The extruder system could be used for cooking of *khoa*, sugar, SMP mix to get the soft grade extruded *peda* with desired quality. In their study, Sandey et al. (2018) obtained the best quality extruded *peda* from blend containing 10% skim milk powder, 55 % *khoa*, 05 % *ghee* & 30 % sugar by processing the blend in extruder machine at 80 °C barrel temperature and 28 rpm screw speed.

Production of different Cheese Products

The processed cheese blocks and spreads are manufacture first time from cheddar cheese by using extrusion cooking parameters of barrel temperatures 80-160 °C, screw speeds 100-220 rpm, feed moisture content 41-62 %; flow rate 32.5 kg/h and mean residence time of 100 s (Zuber et al., 1987). The extruder system unitizing the processing steps involved in processed cheese making such as mixing, melting, emulsifying and pasteurizing of the cheese mix constituents.

Cavalier et al. (1990) prepared good quality cheese analogues calcium caseinate and butter oil in a continuous manner with a total residence time of 2 min by using twin-screw extruder cooker equipped with a cooling die. The optimum conditions for cheese analogues production are barrel temperature of 80 to 120 °C; screw speed of 100 to 150 rpm and 30 kg/h constant feed rate. The resultant products cheese analogues contained moisture 50 to 60 %, fat 20 to 40 % (on dry basis) and pH in the range of 5.6 to 6.1. The extruded cheese strips are quite similar in textural characteristics as compared to the batch cheese of same composition. More casein dissociation and a lower degree of fat emulsification are the major quality concern in extruded cheese analogues which could be improved by addition of sodium citrate (1 %) or disodium hydrogen phosphate (2 %).

The processed cheese possess of fibrous structures are manufacture by using twin screw extruder system from 2 weeks

ripened Gouda cheese and 8 months ripened Emmental cheese (Kazuo et al., 1993). In order to enrich fibrousness in resultant product each type of cheese is firstly grounded and then blended with whey protein concentrate. The mixture is then feed into extruder barrel and extruded at 70 to 80 °C. The extruded thermoplastic mass is then cooled to approx. 45 °C in a low-shear kneader. The cheese samples containing low moisture (44 %) and emulsifying salt levels of 1% processed in extruder system at 80 °C resulted in acceptable quality processed cheese (Adhikari et al., 2009).

Twin screw extruder system successfully performed the stretching and forming operations which involved in Mozzarella cheese making. These operations are carried out at extrusion temperature of 60 °C, screw speed of 10 rpm and 20 kg/h mass flow rate (Ferrari et al., 2003). The smaller size, sphere shape (10 - 20 mm dia. and 5 - 10 g weight) of Mozzarella cheese product can be manufactured by fitting specially designed die plate at the end of extruder barrel. This extruder system eliminates the need of separate forming machine. Similarly, Mozzarella type cheese product could be prepared from ground acidified fresh curd by extrusion process (Berg & Van Mill, 1990).

Production of Functional Milk Powder

There has been increasing interest in the development of highly functional powders such as techno- and bio-functional ingredients which require good cold-water solubility in a relatively short time whilst maintaining the integrity of the powder components. Thus, improving powder functionality, particularly the rehydration characteristics, is becoming critically important. In order to enhance the functionality of milk powders, pre-concentrated milk (approx. 65 % total solid) is converted into textured foam. The extrusion-porosification process is done to produce textured foam at low processing temperature (below 25 °C) and short residence time (40-45 s) in a Twin-Screw Extruder-Aerator before conventional drying. It is then dried (from 65 % to 90 % dry solid content) using an

intensified spray drier and the porous powder is finally dried in a fluid bed drier to obtain a dry solid content of 96 % (Bouvier et al., 2013). The extrusion porosification treatment prior to drying caused dissociation of casein micelles which promotes the high dispersibility in extrusion porosified milk

powder. The extrusion-porosified milk concentrate powders have very high dispersibility index (96 %) as compared to spray dried milk powders (38 %). The typical characteristics of extrusion porosified powders obtained from whole milk are presented below (Table 2).

Table 2: Characteristics of Extrusion Porosified Whole Milk Powder

S. N.	Characteristics	Extrusion Porosified Powder	Standard values
1.	Moisture (%)	2.5-3.9	< 4
2.	Fat (%)	27-28	27-29
3.	Insolubility index (ml)	0.1-0.2	< 0.5
4.	Titratable acidity (%)	0.1	<0.15
5.	Flavour and odour	Good	Good
6.	Appearance & colour	Normal	Normal
7.	pH (10 % solution)	6.73 – 6.77	>6.6
8.	Free fat (%)	3.2 to 6.7	<5
9.	Peroxide value (meq. O ₂ /kg fat)	0.3	<1
10.	Water activity	0.22 – 0.27	< 0.5
11.	Density (kg/L)	0.41 – 0.44	>0.4

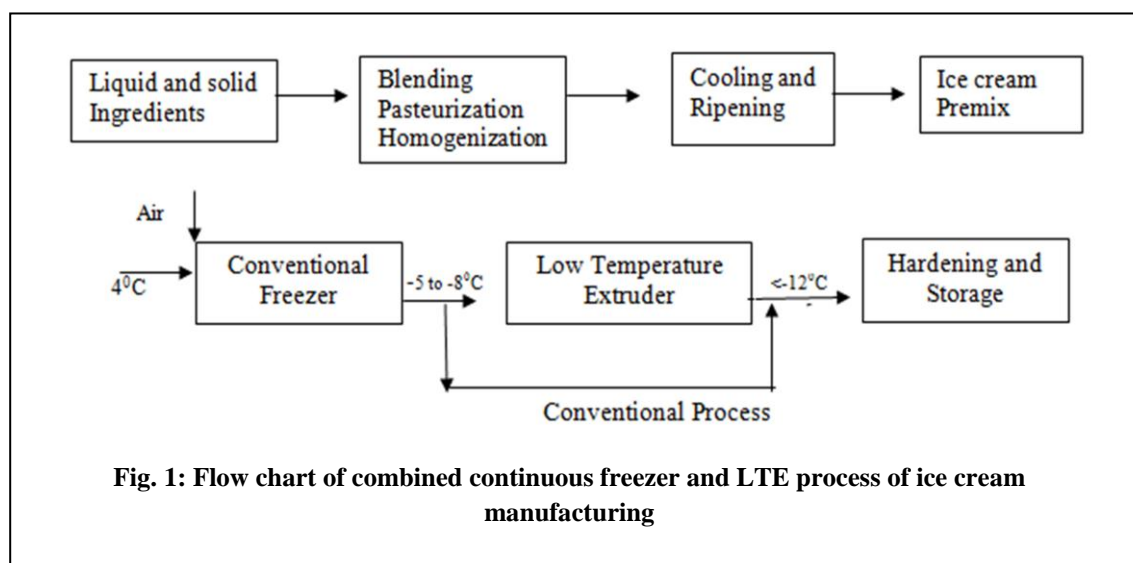
Low Temperature Extrusion of Butter

The butter is a premium dairy product consumed in large quantities by the masses. It is generally stored at refrigerated conditions and used when the need arises. The ghee-based butter (butter-G) is developed to reduce the cost of refrigerated storage and enables to produce butter as and when required (Aage, 1984 & Rizvi et al., 2002). Sangeetha (2002) studied the feasibility of using twin screw system at low temperatures of 2, 6 and 10 °C and at linear screw speeds of 0.03, 0.05, 0.08, 0.10 & 0.13 m/s for cooling and working operations involved in Butter-G manufacture. Later on, improvised form of refrigerated conjugated intermeshing twin screw extruder had devised for continuous manufacture of butter-G (recombined butter) from ghee on commercial scale (Chennigararaju et al., 2005). By using this system, acceptable quality recombined butter (@ 80 kg/h) could be produced at a constant temperature of 6 °C with screw speed greater than 0.32 m/s. The devised system has advantageous that it eliminates the need of separate cooling and working equipment.

Low Temperature Extrusion of Ice-cream

Low temperature extrusion (LTE) is a novel technology to get most acceptable quality of

final ice cream (Wildmoser et al., 2004). The LTE of ice cream is done after freezing in conventional scraped surface freezer. The aim of including this process in the ice cream manufacturing is to improve the microstructure and other quality characteristics. In this process, frozen product is shear treated in single or twin screw low temperature extrusion system in the temperature range of about -10 to -20 °C. The system is operated between 5 and 50 rpm rotational screw speed. The detailed description of combined ice cream freezer and LTE process is shown in (Fig. 1). During the operation, the ice cream coming out of continuous freezer is pumped into the low temperature extruder system which greatly influences the size of ice crystals and air bubbles and improves the viscosity of the final ice cream. The ice crystal and air bubble size are reduced due to the shear stress which results in more smoother and creamier ice cream than conventional one (Shrivastav & Goswami, 2017). Tremendous energy cost saving through elimination of ice-cream freezing in large static hardening freezers is also possible with the development of this kind of low temperature extrusion freezers (Wildmoser & Windhab, 2001).



Caseinate Production

The extrusion cooker system are used as a continuous chemical reactor for conversion of acid casein into sodium caseinate. The neutralization of acid casein is done by using sodium bicarbonate in a twin-screw extruder at barrel temp. 65-160 °C, screw speed 150 rpm, moisture content 19-30 % and mean residence time of 40 s (Tossavainen et al., 1986). This process produced sodium caseinate with high solubility (97-100 %) and low lysinoalanine concentration (less than 30 µg/g). Barraquio et al. (1988) performed acid coagulation of skim milk powder in an extruder system at barrel temperatures of 50-94 °C, screw speed of 50-90 rpm and moisture content of 25-35 %. Washing and neutralization of the acid coagulated extrudates can also be done in extruder system to produce a more functional caseinate like product. Similarly, Fichtali (1990) designed a process to convert surplus skim milk powder into acceptable quality acid casein continuously by using co-rotating twin screw extruder. The operating parameters for acid casein production are screw speed 100 rpm, extruder operating temperature 55 °C, feed rate 15 kg/h, flow rate 45 l/h, HCl concentration 25 %, coagulation pH 4.31, product temperature at the die exit 46 ± 1 °C, barrel L/D ratio 15:1 and minimum residence time 40 s. It was further reported that acid casein could be successfully neutralized (pH 6.7 to 6.9) in a same co-rotating twin screw

extruder by using reagent grade sodium hydroxide (2.5-2.8 % by weight of casein solids). Millauer et al. (1984) studied the production of caseinate by extrusion and the effect of the incorporation of whole milk powder and casein into flat-bread.

CONCLUSIONS

Extrusion is an efficient method of converting raw materials into finished food products. Its major advantages include energy efficiency, absence of process effluents and versatility with respect to ingredient selection and shape and textures of products. The production of most of the heat desiccated and acid and heat coagulated Indian milk products involves various processing steps viz. kneading, mixing, transferring, cooking, shaping/forming, cutting etc. A multifunctional extrusion machine owing to its versatile nature could perform and unitize all these mechanical processes which would be helpful in saving space, process time, maintenance, handling and labour cost etc. It could be adopted for redesigning the process technology of Indian dairy products like *burfi*, *gulabjamun*, *cham-cham*, *pantua* etc.

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