STUDY ON DESIGN FACTORS OF DAIRY-RESIDUE RECYCLING

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ABSTRACT

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Two types of engineering units for recycling dairy residues (whey) were used in this study.

The first unit was a drum dryer unit for recycling of whey from liquid to solid form: to be used in food and feed industry. This unit was designed, constructed and evaluated depending on the drum speed, the drying temperature, and the properties of concentrated whey such as: density, and initial moisture content.

The performance of the drying unit was evaluated by determining the performance indicators (unit productivity, the thermal efficiency, the specific energy requirements, the drying rate, and the drying costs), and the quality of the final product, including: the bulk density, the final moisture content and the chemical analysis of the final product.

Results showed that the design was suitable for recycling liquid whey to solid form, where the best operation parameters were: The drying temperature (140 to150°C), the drum speed (4 r.p.m), and the initial moisture content (50 to 55%).

The previous parameters give a productivity, thermal efficiency, drying rate, specific energy and cost per dried unit mass as follows: (1100g/h, 41.5%, 0.49 kg H_2O/h, 0.45 kW.h/kg and 5.5 LE/kg) resp. The properties of the final product were: bulk density (0.469 to 0.498g/cm^3), final moisture content (10 to 25%),and protein percent was (10.5 to 16.7%).

The second unit was for pelleting. This unit was used to study the using of concentrated whey in pelleting manufacture as binder, and to study the effect of whey percents on the characteristics quality of pellets produced, and the effect of adhesion and cohesion of pelleting mixture on pelleting machine productivity.

Results of pelleting showed that concentrated whey behave as a good binder in pelleting processes, where the mechanical properties such as: durability, hardness and bulk density were improved.

Pellet Durability Index (PDI) increased with whey percent, where the durability was 82% at whey percent = 10.5% increased to 93% at whey percent = 21.2%.

Also, pellet hardness increased with whey percent. It increased linearly. In the range of (w_p=10.5% to 21.2%), hardness was 1.52N/mm^2 at w_p=10.5 increased to 2.6N/mm^2 at w_p= 1.2%.

Results also showed that bulk density of pellets ranged between (715 and 790 kg/m^3), where the highest density was at 5 mm then 8 mm and 10 mm of pellet diameter and increased with whey percent.

Productivity of pelleting unit was affected significantly as function of whey percent, where the productivity decreased with the whey percent for all forming dies. Productivity decreased by (61%) when whey percent as a binder increased by (60%).The pervious results are due to increasing of cohesion between particles of whey, and for increasing of adhesion between a mixture and the shell of extruder.

Key words: Agricultural residue, Dairy residue, Drum driers Whey recycling, pellets, Animal feed processing.

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LIST OF SYMBOLS

A: The drying surface, (m^2).

C_p: The specific heat of the drying product, (kJ/kg.°C).

DPI: Durability index, (%).

d: The diameter of the dent, (mm).

G_r: Grashof number, (-)

H_m: Meyer hardness, (N/mm^2).

h_p: Convective heat transfer coefficient, (W/m^2. °C).

h_{fv}: Latent heat of vaporization, (kJ/kg).

I: Current intensity, (Amp.).

k, k_p:Conductivities of the drum surface and the dried film, (W/m. °C) resp.

$m^{\cdot}_p$: Feeding rate, (kg/h).

m_{ci}, m_{cf}: The initial and the final moisture content of whey, (%).

$m^{\cdot}_w$: Water evaporation rate during the drying process (kg H_2O/h).

m_p: The product mass, (kg).

m_w: The mass lost of water from the product, (kg).

N: The drum speed, (r.p.m).

N_u: Nusselt number, (-).

P: Productivity, (kg/h).

P_r: Prandtl number, (-).

q_u: Useful energy, (W).

q_{in}: Total supplied energy, (W).

q_{loss}: Heat losses, (W).

q_s: Sensible heat, (W).

q_l: Latent heat of vaporization, (W).

q_p: Heat losses with the dried product, (W).

q_{s1}, q_{s2}: Heat losses from the drum sides, (W).

q_k: Heat losses from unused surface, (W).

S.E: Specific energy, (kW.h/kg).

T_{pf}, T_{pi}:The final and feed product temperature resp., (°C).

T_s, T_f: The drum surface and the film temperature resp., (°C).

T_d, T_a: The drying and the ambient temperature resp., (°C).

U: Oveall heat transfer coefficient, (W/m^2. °C).

V: The volatge between the mains of heater, (volt).

X, Xp: Thicknesses of the drum surface and the dried product, (mm).

ρ: Density , (kg/m^3).

η: Thermal efficiency, (%).

ε: The emissivity of the drum speed, (-).

σ: Stefan and Boltzman constant, ($W/m^2.K^4$).

β: The volume of expansion, (1/k).

μ : Viscosity, (N.m/s).

θ: The basic unit of the temperature in dimensional analysis.

I- INTRODUCTION

Agricultural residues generally originate from agricultural production, such as: plant, livestock production, as well as agricultural and food industries, such as: dairy industry, cereals, vegetables, fruits and meat processing. The agricultural residues have many forms as follows:

1- Solid residues: including all residues having a moisture content about (10 to 15%) such as, straw of cereal crops, hay, by-product of cereals such as: (bran, stiffs, husk, etc).

2- Semi solid residues: including materials that have moisture content about (40 to 50%) such as those produced from vegetable and fruits processing.

3- Liquid residues: produced from dairy industry, citrus, grape processing, and sugar industry, for example: whey from dairy industry, and molasses from sugar industry.

The utilization of the previous residues needs urgent investigation because recycling and reduction of such residues can reduce pollution, creation of new employments, decreasing prices of animal production such as feed, and reducing imported feedstuffs.

Agricultural residues, as animal feed, is achieved by processing residues to the suitable form using an adequate processing method such as: (pelleting, drying, grinding, etc.). Using residues in animal feed will reduce the feed cost, especially that it accounts for (60 to 80 %) of the total production of livestock **(El-Boushy and Vanderpol, 1994).**

In spite of many research studies on recycling of agricultural residues in animal feed production, dairy residues are beyond, especially recycling of liquid whey to solid form using drying process or pelleting manufacture.

On the other hand, dairy residues comprise (80 to 90)% of total volume of milk processed and contain about 50 % of nutrients in original milk **(Bylund, 1995).** Therefore, whey as a by-product of casein or cheese production may be recycled from liquid to solid form using a suitable food industry or animal feed as a milk replacer for calves, feeds for cattle, poultry, and pet foods or used in pelleting process.

Whey and its derivatives are also used in many food products, including dairy products, baked goods, candies, snack foods, dry mixes, processed meats, infant formulas, nutritional beverages, and in numerous other dried, frozen and prepared foods.

The economic benefits of using dried whey products are derived from reduced transportation cost, extended storage time, flavor, texture and the ability to increase the consumption of whey solids by the animals; then the dried whey used as milk replacer in calves feeding, and in pelleting process to enhance some physical and chemical properties of pellets.

Dairy residues are the largest residues generated from industry. In 2000, world whey production was 186 million tons yearly with an annual increasing of 3% **(FAO, 2000)**, where the most of developing countries can recycle all the production in human food and animal feed. However, the most of the developed countries deliver dairy residue into wastewater. Therefore, the aims of the present study are:

A- Design and construction of a simple drying unit (drum drier) for recycling of whey from liquid to solid form to be used in animal feed, through:

1-Studying heat and mass transfer during processing of agricultural materials especially during changing materials from liquid to solid form in very thin layers.

2- Studying the effect of some processing parameters (drum speed, the drying temperature, and whey properties), on the unit performance (thermal efficiency, productivity, etc.) and on the quality of the final product.

3- Establishing a general theory on drum drier from experimental data to be used in future for design and operating such processing units.

4- Estimating drying costs of whey.

B- Recycling of concentrated whey in pelleting process using an extruder pelleting machine. The specific aims for these studies are:

1- Using concentrated whey as binder in pellting manufacture.

2- Studying the effect of whey percent on the mechanical properties such as: durability, hardness, and density.

3- Studying the effect of cohesion and adhesion as a result of whey addition on the pelleting machine performance.

II-REVIEW OF LITERATURE

2.1 Agricultural Residue Types

Agricultural residues generally originate from agricultural production such as: plant, livestock production, and agricultural and food industries, such as: dairy industry, cereals, vegetables, fruits and meat processing.

Kajikawa (1996) classified agricultural residues by their chemical properties as follows:

1 -Those with a high protein contents such as: oil seeds, corn gluten, and by products from poultry, meat and fish processing.

2 -Those with a high level of total dray nutrient (TDN) due to a high fat content like rice bran.

3-Those with high levels of TDN due to high fermentable carbohydrates such as: whey, molasses, sugar beet pulp and fruit juice pulp.

4- Those with a high fiber content such as: straw and corn cobs.

2.1.1 Crop Residues

Deleeuw (1997) defined crop residues (CRs) as the plant materials that remain after food crops have been harvested. He also stated that they may be left in the filed as grazing for livestock or transported to the homestead for stall-feeding.

Kellems and Church (1998) reported that residues are normally low-quality roughage. They include straws and chaff from cereal grains (wheat, barley and others). Other residues include grass straws, Stover from corn and sorghum, corncobs, cottonseed hulls, and other agricultural residues such as vegetables and leaves.

Awady (2002) explained that agricultural residues in Egypt are mainly composed of wheat, barley, rice straw and cotton wastes and other residues, which amount to about 20400 million ton per year. Table (1) shows the production of cereal residues in some Arab Countries.

Table (1): Cereal crop residues in some Arab Countries (1000 tons dry matter), **(AOAD, 1997).**

Country	Wheat	Sorghum	Rice	Barley	Corn	Cotton
Egypt	4914	857	2843	399	3219	1242
Syria	7942	35.3		8034	250	754
Iraq	7497		474	7127	384	80.21
Sudan	1617	45043	4.97		36.04	709
Saudi Arabia	3491	934		915	10.99	
Tunisia	5110			2010		3.03

2.1.2 By-products of Food Industry

These residues generate after processing, milling, and manufacturing of agricultural materials in millings or in factories such as: dairy industry, cereals milling, and vegetable and fruit processing. The important residues generated from food processing are:

2.1.2.1 Cereals By-Products

These by-products generate by milling of cereal grains for productions of flour or for production of animal feed, such as: wheat, barley, rice, and corn.

Staples and Harris (1991) reported cereal by-products as follows:

1- Rice mill by-products

Rice mill by-product is a low-energy, high-fiber (28%) feedstuff that consists of rice hulls, bran, polishing and broken grains. In contrast to soybean hulls, the fiber content is low in digestible energy. Rice mill by-product or rice mill feed contains 6 to 7% protein, 42% TDN and only 12% effective fiber. Since it is not a good source of fiber and is a low-energy feedstuff, it should be fed to replacements, dry cows, and low producing cows when there is an economic advantage.

Kellems and Church (1998) reported that wheat by-products account for about 28% of the kernel intake. Wheat by-products composed of wheat bran, wheat middling and wheat mill bran. They also said that wheat midds contain 18-20%crude protein.

Sahay and Singh (1999) reported that the by-products of paddy-rice are: rice husk 20-24%, rice bran 4-6%, rice germ 1-2% and small broken grains 2-3%. The approximate composition of some rice by-products is given in table (2).

Table (2): Composition of bran, polish, and germ of rice (**Sahay and Singh, 1999**).

Constituents	Bran	Polish	Germ
Protein	14.1	10.8	24.1
Fat	18.5	9.1	19.3
Fiber	5.1	1.1	
Ash	11.2	5.8	6.2

Rice bran is composed of the bran layer and germ of the rice, which are removed in milling for human consumption. Rice bran contains about 12% protein, 12% fat, 10% crude fiber and 60% TDN.

Rice bran is palatable to dairy cattle and may be used at levels of 10 to 15% for high producing cows and at higher levels for lower producing cows. The lower energy content of rice bran limits its usage for maximizing energy intake in early lactation. Rice bran is high in phosphorus and low in calcium.

2- Soybeans hulls

Soybean-hulls are a by-product of soybean processing for oil and meal production. Since soybean hulls have urease activity, a problem may develop in rations containing urea. Heat treatment destroys the urease activity. Soybean mill run is a heat-treated soybean hull.

The products contain about 11 to 12% protein, 32 to 34% crude fiber, and 65% TDN (as fed). Soybean hulls are very palatable for dairy cattle and are frequently used at the rate of 20 to 25% of the total ration dry matter or 3.6 to 4 kg daily per cow. Soybean hulls add bulk to finely textured rations and the high fiber content is highly digestible and low in effective fiber (14%).

3- Wheat milled feeds

The wheat mill feeds (bran, millrun, and middling) are by-products produced during the milling of wheat for flour. They consist of varying amounts of bran, germ, and flour. Wheat middling (also called midds) are a common ingredient in cattle feeds and have been very competitively priced in recent years. They have about 92% the energy value of corn and contain more protein (16%). They are a palatable feedstuff and can be included at a level of about 15 to 25% of the total ratio dry matter.

2.1.2.2 Fruit and Vegetable Residues:

The quantity of by-products from food processing has increased in last years as results of increasing of factories for processing vegetables and fruits. Therefore, recycling of these by-products for animal feed would achieve a decrease in environmental pollution, as well as a reduction of the cost of animal production.

Food processing residues may be in a solid form such as: skins, core, tissues and seeds or in liquid form **(El-Boushy and Vanderpoel, 1994).**

Heng (1996) reported that processing residues, after crops have been processed for human consumption, has a high water content, good palatability and are rich in nutrients. They also have a high fiber content, and are easily spoiled and fermented. Unless they are dried or ensiled, they must be used while they are still fresh. The most popular fruit and vegetable residues are:

1- Apple Pomace

Seymour (2003) reported that apple pomace is a source of energy concentrates, a high palatable feed, medium in energy, low in protein and can replace up to about one third of the concentrated in ration and 15-10% in complete feedlot ration.

El-Boushy and Vanderpoel (1994) reported that apple pomace is numerous, such as dried, canned, frozen and sliced apples as well as souse. Apple processing produce large quantities of residue estimated to be 7.6 5 by dry weigh of the total processed apples.

2- Citrus Pulp

Ammernan and Henry (1980) reported that the citrus pulp as a by-product is an excellent feedstuff for ruminants, and dried citrus pulp is essentially the only feedstuff currently available from the industry and approximately 600,000 t are produced annually in Florida, about 90% is pelleted and approximately 70% of total production is marketed outside the United States.

Nutrient content of citrus pulp is influenced by several factors including source of fruit and type of processing. They also stated that citrus is considered a bulky concentrate being high in energy low in protein and fiber but with some roughage replacement value. Citrus pulp is well utilized by ruminants when fed at levels, which do not exceed 30% of total DMT.

3- Grape Pomace

Seymour (2003) indicated that by-products of grape juice and wine processing consists mainly of grape seeds, stems, and skins. It has little feeding value, being very low in both energy and protein. When included in a concentrate mix, it can be considered only filler to reduce the price of the mix. With new harvesting and winery techniques, grape pomace containing few or no stems can be produced. This waste feed has been fed successfully up 15-20% level in complete feedlot rations.

4- Potato Residues

Maiga *et al.* (1999) reported that potato residues are high in energy, very palatable and low in protein. Potato residues such as culls, peeling, and other residues can be mixed with cuff, chopped hay or hay silage and preserved as silage or can be dried and preserved as meal.

Miller *et al.* (1987) indicated that several dried processed potato products are sometimes available for feeding to or other livestock. These include potato meal, potato flakes, potato slices, and potato pulp.

Potato meal is from cull potatoes that are sliced, dried, and then ground to a meal consistency. This dried raw potato meal is not well digested even when limited to 30% of the diet, there is often diarrhea and reduced performance. This product is uncooked, and both starch and protein are poorly digested. Cattle better utilize this product than other animals.

Shaver (1998) reported that potato waste is available in potato processing areas, and includes cull potatoes, french fries and potato chips. Cull fresh potatoes that are not frozen, rotten, or sprouted can be fed to cows either whole or chopped.

Potato waste straight from a processing plant may contain varying amounts of inedible or rotten potatoes. french fries or chips, skins, and fats or oils from frying operations.

Potato waste usually contains (75%) to (80%) moisture. It should be treated as a wet, starchy concentrate in ration formulation, and limited to not more than 11.5 to 16 kg as fed or 2.5to 3.5 kg of DM per cow per day.

2.1.2.3 Liquid Residues

1- Molasses

Kellems and Church (1998) reported that molasses as a major by-product of sugar production come from sugar cane, sugar beet and citrus fruits. They also stated that all types of molasses are utilized widely as a feedstuff.

Helaly (1986) reported the chemical analysis of molasses as follows:dry matter 76.9%, crude protein 10.1%, ash 8.6 % and NPN 5.82%. He also stated that molasses is used in animal ration of 5% for calves, 15% for dairy and 7% for goats.

Staples and Harris (1991) mentioned that sugar cane molasses is the most common liquid supplement fed to dairy cattle. More recently, a several of molasses products are available to livestock feeders. Among those are cane, citrus, beet molasses, and a number of products resulting from the production of alcohol.

Most of the by-products are palatable and are frequently used in concentrate mixes at the rate of 4 to 7% to control dustiness. Molasses products vary considerably in energy content with cane molasses containing about 65% TDN (as fed). Suggested levels for maximum feeding are (1) to (1.25) kg daily per cow.

2- Diary residue (whey)

Maiga (1997) reported that whey is the residue from cheese production and consists primarily of lactose, minerals and water. It can be fed dry or as a liquid. The liquid is termed sweet whey or acid whey. Sweet whey comes from the manufacture of cheddar and mozzarella cheese. Acid whey results from the production of cottage cheese and is less palatable than sweet whey.

Liquid whey contains only (6 to 7%) solids and must be fed rather soon after being produced or it will spoil. Dried whey products are considered energy feeds and contain (37 to72%) lactose. Typical dried whey contains about (13%) protein and whey can be added to the diet to increase rumen fermentation and microbial protein synthesis.

Miller *et al.* (1987) reported that fresh liquid sweet whey must be delivered daily. Up to 40% of the nutrients can be lost during a 48 h. storage period, and the acid produced will decrease intake. High quality sweet whey that has a consistent pH and temperature is important to minimize digestive upsets. Cheese press drippings that may contain up to 10% salt should not be added to liquid whey.

They also stated that liquid whey is corrosive and reduces the life of facilities and equipment, storage tanks, troughs and distribution equipment should be made of plastic, porcelain, or stainless steel. Storage tanks should be cleaned at least once a week to inhibit yeast growth that causes off flavor and reduces whey palatability product from cottage.

Acid whey nutrient composition is similar to that of sweet whey. Acid whey is not as palatable as sweet whey, and voluntary intake is not sufficient to adequately supply the lysine needed to supplement a ground corn diet with vitamins and minerals. Therefore, a 13% crude protein complete finishing feed should be fed free choice with liquid acid whey.

2.2 Utilization of Residues as Livestock Feed

Intensive efforts are being made in many countries around the world aiming to solve the problem of feeding shortage. Providing of some alternative feed ingredient from agricultural residues will lower the cost of animal feed and improves the economic efficiency of animal production.

Kajikawa (1996) indicated that most food by-products have high moisture content. A decrease in transportation costs and an improvement in preservation methods are required for these by-products to be used more widely such as whey, fruit and vegetable residue.

Crickenberger and Carawan (1996) indicated that many by-products can be fed to animals. However, by-products to be used as feedstuffs should be economical, dense in nutrients, and free of toxins or other substances that may be unhealthy for the animal.

Table (3) shows nutrient composition of some agricultural by-products.

Table (3): Nutrient content of some by-products **(Walker, 2000).**

Feedstuffs	DM (%)	Energy (Mcal/lb)	Cp %	Ether extract %	Ash %	P %	K %
Apple pomace	40	2.91	5.6	5.2	3.5	0.12	0.49
Beet pulp	91	1.22	9.7	0.6	5.4	0.1	0.26
Corn cobs	90	0.82	3.2	0.7	1.7	0.04	0.87
Grape pomace	20	0.45	13.0	7.9	10.3	0.12	0.35
Potato	53	1.43	5.3	0.4	3.4	0.18	1.38
Rice hulls	92	0.20	3.3	0.8	20.3-	0.08	0.57
Whey	7	1.55	18	4.3	8.7	0.65	2.75
Molasses	78	1.30	8.5	0.2	11.3	0.03	6.07

2.2.1 Feeding Agricultural Residues to Ruminants

Many works have been done in researching the feeding of agricultural residues to ruminants such as cattle, sheep, etc.

Various by-products from feed processing industries are available for dairy farmers to incorporate into diets fed to dairy cows and replacement heifers. Using these feeds offers at least two benefits: (1) may decrease the feed costs depending on prices of by-products and grains. (2) helps dispose of these by-products in an ecologically sound manner.

Devendra and Reddy (1988) formulated and processed more than 60 complete rations into mash or pellets using available fibrous agricultural feed ingredients. These formulations were tested in several experiments on cows, buffaloes, calves and sheep, for maintenance, milk production and growth. Results indicated that blending poor-quality agriculture residues (40-45%) with other ingredients in complete ration improved the utilization of the residues for milk and meat production.

Perry (1995) reported that wheat straw could be utilized to supply a part of energy because, it is best to use in combination with high quality roughage such as grass-legume hay. He also stated that corn cobs are used as animal feed after cobs are ground prior to feeding .A mixture of 90% ground corn cobs plus 10% of 32% protein supplement, fed at the 7-8 kg per day, will provide the protein and energy needs for lactating broad cows.

Ismail (2000) indicated that dried potato pomace is an important source used for feeding all ruminant species, because it has many nutrient component such as protein, vitamin A and B.

Kellems Richard and (1998) reported that molasses is as a sugar industry residue, utilized widely as a feedstuff, particularly for ruminants. The sweet taste of molasses makes it appealing to most animals In addition, molasses is of value in reducing dust in mash feeds, as a pellet binder, as vehicle for feeding medicines or other additives and as a liquid protein supplement. They also stated that the cost is attractive as compared with that of grains.

Church and Pond (1988) reported that molasses is an energy source because the main constituents are sugar. In commercial use, molasses is adjusted to about 25% water content, but may be dried for mixing into dry diets. Molasses is utilized widely as feedstuff for ruminants. They also indicated that whey as a dairy by product is used similar to dried skim milk. It is an excellent source of vitamin B complex.

Whey has been known for decades as a product of high nutritional value. Today, the development of markets using whey powder and fractions of whey as ingredients in foodstuffs for human and animal consumption.

Fisher and Bukley (1985) indicated that whey permeat can be successfully fed as the only source of liquid to cattle. Cattle can consume (20 to 30 %) of their total dry matter intake as liquid whey, but higher intakes of whey can be achieved with concentrated product than liquid whey.

Clapp (1990) reported that dried whey can be used as a milk replacer for calves when whole milk is not available. Milk replacers can produce comparable weight gains in calves to 4 weeks as the feeding of whole milk. A good quality milk replacer is made up mainly of high quality products (dried whey, dried skim milk and etc.) plus, in some cases a small percentage of cereal products.

They also stated that the analysis of commercial milk replacer must be at least 20% protein, 12% fat, and about 0.25% fiber. A milk replacer feeding program of Agri-Canady recommend feeding approximately 0.25 of milk replacer in one kilogram of water twice a day, this amount is fed without variation until weaned at three weeks. Lactating cows can be fed up to (4.5 kg) of dried whey daily.

2.2.2 Feeding Agricultural Residue to Poultry

Gillespie (2002) reported that the poultry feed cost is about two-thirds of total producing eggs and meat for chickens. Ration of the chicken must supply the protein, carbohydrates, minerals, vitamins, and water that poultry require.

El-Boushy and Vanderpoele (1994) stated that the use of residue products in poultry nutrition may lower poultry performance. However, these residues may be much cheaper than the traditional feedstuffs currently in use.

El-Hag *et al.* (1999) used different by-products of date with fish sardines and barley for feeding ruminants and poultry in Sultanate of Oman. They concluded that feed of date by-products supplements with sardines and barley was very economical and feasible for ruminants and poultry in Sultanate, where the fish sardines provided a cheap and excellent source of protein and minerals to the by products.

Abou Akkada *et al.* (1975) reported results of trials on laying hens of three breeds, Alexandria, Dokki and Fayomi, which were given basal diet alone or with 2,4 or 6% dried tomato residue from canning. The diets were given for a bout 6 weeks and the effect on egg production, egg weight and yolk color were recorded separately for each breed .The tomato residue used in these trials had a protein level varying from 12.5 to 22.5% and the fiber and moisture levels ranged from 18 to 26.9 % and from 8 to 10%, resp. No differences in egg production and egg weight were noticed among diets.

Yang and Choung (1988) used dried citrus peels at levels of 5,10 or 15% to replace bran in a basal diet containing 60% maize, 10% wheat bran, 16% soybean meal and 3.5% fish meal .The diet with 15% citrus peels decreased feed efficiency and gave darker egg yolk. They concluded that the optimum inclusion of dried citrus peel in diet is 10%.

Hulan *et al* (1982) investigated the use of potato waste meal in broiler diets to replace maize .Two experiments were carried out in which potato waste in practical diets of broilers fed up to 49 days old. They concluded that potato waste meal can be considered as a good substitute diet for 20% of the ground maize for broiler chickens.

El-Boushey and Vanderpoele (1994) indicated that whey product contains an unknown growth factor (UGF) especially for turkey poults. They achieved an increase in weight gain of poults by supplementing a mixture of dried whole whey or molasses.

2.3 Factors Affecting in Selecting Agricultural Residue for Feed

Many residues can be fed to animals. Generally, residue to be used as feedstuffs should be economical, dense in nutrients, and free of toxins or other substances that may be unhealthy for animals when determining whether to purchase and feed a particular by-product. Several factors should be considered. These include the following points according to **Crickenberger and Carawan (1996)**:

1-Is the by-product economical to feed

2- Will feeding this by-product reduce feed costs and/or increase milk production or growth to more than pay for the additional costs.

3- How palatable is the by-product

4- Can it be added to a grain mix that will be fed through the parlor or individually, or does the by-product need to be included in a total mixed ration or mixed with silage to maintain palatability.

5- Does the by-product provide an economical source of a nutrient, such as fat, fiber, or protein, needed to complement forages being fed.

6- What are the additional costs associated with transportation of this by-product to your farm

7-What additional costs are associated with the additional time you will need to spend locating the most economically priced commodity These costs need to be included when calculating the cost of a particular product.

8- Are special equipment or facilities needed to handle and store this by-product.

9- How long will it take you to feed a load of this by-product.

10- Can this by-product be stored for that length of time.

11- Wet by-products are limited for time they can be stored and still maintain their quality.

12- Is the by-product free of contaminants, which could be harmful to the cattle's health or milk supply.

13- Is this by-product available year-round, or is it available only seasonally.

2.4 Agricultural Residue Processing Methods

Agricultural processing may be defined as an activity which is performed to maintain or improve the quality or to change the form of material form of state to another (such as changing the whey from liquid form to the solid form) or characteristic of an agricultural product residue for preparing the material for the following process.

The processing procedures are a series of unit operations, each unit partially contributed to produce the final product such as (chopping, grinding, drying, pelleting, and extrusion).

Unit operations used for recycling of agricultural residue are various according to the type of the by-product (solid, semisolid, and liquid) the agricultural residue recycling methods include: chemical, mechanical, biological, and heating treatments.

2.4.1 Chemical Treatment

Chemical treatment is usually used to improve the quality of roughage residue and to increase the nutrient content.

Kellems and Church (1998) stated that the use of NaOH (sodium hydroxide) seems to improve utilization to the greatest improvement, especially when cost is considered. They also stated that methods have been developed to spray concentrated solution of NaOH directly on fiber residue.

They also stated that the use of anhydrous ammonia seems to be a more feasible method to improve nutrient availability. This method requires that residue be stacked and covered with plastic; then anhydrous ammonia is applied .The anhydrous ammonia changes from liquid to gas and penetrates the material being treated.

2.4.2 Drying Method (heating treatment)

One of the greatest difficulties in the use of agricultural residue such as (dairy and agricultural processing residue) lies in their dilution by large volume of water. Therefore, drying unit is an important unit used to remove moisture from wet residue or liquid residue. Drying is a process used to remove moisture from material to enhance handling, transportability, and storability and to reduce the cost of transportation or texture and to change the residue form from one state to another.

Sahy and Singh (1999) reported that the agricultural product drying methods could be broadly grouped into: sun or solar drying and artificial drying.

Aboud (2001) designed and constructed a solar drying for drying cattle wastes .He studied the performance of the solar drying system and the factors affecting the drying process such as the thickness of the drying layer, the drying temperature, the flow rate of the drying air, and the moisture content of the waste. He concluded that there is a high correlation between the studied factors and the thermal efficiency of the system, and the drying rate. He found that the effective thickness for drying such material is (3cm).

El-Boushy and Vanderpoel (1994) indicated that the drying of semi solid residue takes place in a rotary dryer .A rotary dryer type with oil or gas burning is used. Hot air enters the feed end (for citrus) .Hot air dries the peel and conveys it to the discharge end through a series of baffles and tumblers where the peel exits at approximately 116C° with 10% moisture.

They also stated that drying potato residue takes place in a single-drum dryer equipped with 4-6 applicator rolls. The material is fed into the top of the drum either at a central point or at tow points .The effect of the drum speed and sheet density is a special study.

Batty and Folkman (1983) divide the mechanical dryers into two groups: the first group includes tray, tunnel, belt and rotary dryers. These dryers are suitable for drying solid, semi solid materials such as (vegetable and fruit residues) .The second groups are spray, and drum dryers, this group is suitable for paste, slurries and concentrated liquid such as dairy product and dairy residue.

2.4.3 Mechanical Method

Mechanical treatment for agricultural residues such as, chopping, grinding, mixing, pelleting and compacting of fibrous residue are used to improve the nutritive value of residue or to decrease the density of that material to facilitate the handling process or to condition the material for the following grinding process.

2.4.3.1 Grinding Process

Sitkei (1986) reported that grinding process is one of the most important operations in fodder preparation used for recycling of roughage residue using hammer, roller and burr mills.

Sahy and Singh (1999) indicated that grinding process means that the size of the material is reduced using several ways, but mainly the following four methods are used in size reduction machines: compression, or crushing, impacting, shearing and cutting. The previous methods for size reduction use the following types of grinders:

1- Hammer mills

As shown in fig. (1), hammer mills are used for various size reduction jobs. These mills contain a high-speed rotor inside a cylindrical casing .The hammers are rotated between 1500 to 4000 r.p.m, strike and grind the material until it becomes small enough to pass through the bottom screen.

Church and Pond (1988) indicated that hammer mills will grind anything from course roughage to any type of grain, and the product size will vary from particles similar to cracked grain to fine powder.

2- Roller mills

Carl and Denny (1978) stated that roller mills are usually sized according to the diameter and length of the roller. For operating, the rollers should not be fed too rapidly. Roller speeds are 350-600 r.p.m.

3- Crushers

The crushers should be used before the milling process. Crusher is of the large corrugated roll type or of a tooth-roll type.

Sahy and Singh (1999) stated that crushers are mostly used to break large pieces of solid materials into small lumps. The crushers in use are jaw crushers, gyrator crushers, and crushing rolls.

2.4.3.2 Pelleting Process

According to **(ASAE, 2003)** Pelleting process is the agglomeration process of molding into mass of small particles by means of mechanical process in combination with moisture, heat, and pressure.

Church and Pond (1988) reported that pelleting is accomplished by grinding the feed and then forcing it though a thick die. They also stated that pellets can be made in different diameters, lengths and hardness and have been commercially available for many years.

Simmons (1963) divided cubing and pelleting machines into two types:

1- Molding machines

In this type of machines, the feed is molded or compressed through two large surfaces and revolve inversely at 7 r.p.m .This type has been superseded by the modern extrusion type due to longer compression period in the latter.

2-Extrusion Machines

The scheduler type embodies two spur-toothed gear wheels run into opposite direction, each having radial holes at the root of the teeth where the compressed meal is extruded and out off by stationary knives inside each wheel. Success in pelleting is affected by the physical and chemical characteristics of feed ingredients. Some ingredients are very difficult to agglomerate. Small quantities of binding agents such as bentonite. Clay can be added to the diet to improve the adhesion of materials in the pellet. Fig. (2) and fig. (3) show principles of pelleting and extrusion machines.

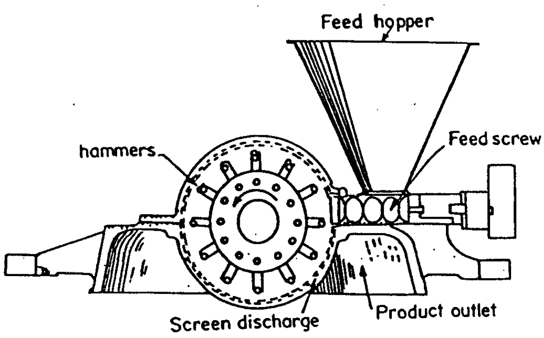


Fig. (1): Hammer mill **(Sahy and Singh, 1999)**.

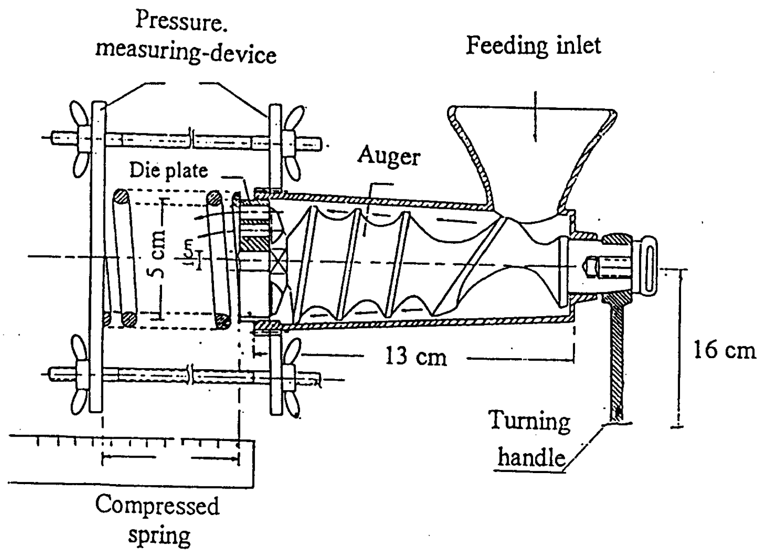
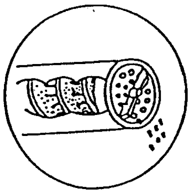
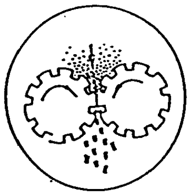


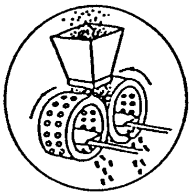
Fig. (2): Schematic of screw-manual pelletizer **(Watfa, 1999)**.



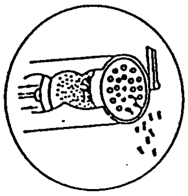
Material extruded through die by worm, then cut into pellets by rotary knife.



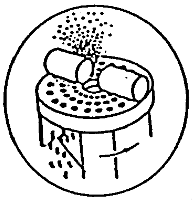
Cubes or bricquetts formed by compression between counter-rotating dies.



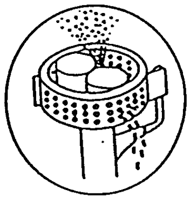
Material forced through holes in dies to inner surfaces, where it is cut into pellets by stationary knives.



Material forced through stationary die by piston. Knife speed determines pellet length.



Stationary, horizontal die. pellets extruded from under side of die, then cut by rotating knives.



Stationary die, rolls and knives rotate. Pellets extruded around outer circumference of die.

Fig.(3):Principles of pelleting machines **(Simmons,1963)**.

2.5 Factors Affecting Pelleting Process

1-Moisture content

Sitkei (1986) stated that with increasing moisture content, many agricultural material assume plastic properties, facilitating of compression.

Awady *et al.* (2002) indicated that the pelleting process for wheat sifting residue as mill by-products was directly affected by the moisture content of the mixture, where the torque required for pelleting process decreases by 10% when moisture content increases from 25 to 40% on a wet basis.

Dobie (1959) concluded that moisture content for commercial pelleting is within the range of 12-16.5%, usually by adding steam.

2- Effect of pressure and dwell time

Sitkei (1986) mentioned that the pelleting pressure ranged between 500 and 1500 bar where the compressibility of straw grit mixtures may be described by an equation of the form: $P=a.\lambda^{b}.e^{c.\lambda}$, where λ is the volumetric weight, the constants a, b and c are determined experimentally.

Watfa (2002) found that the moisture content and forming die influence the forming pressure, where the forming pressure require for forming wheat sifting decrease from 58.9 to 46.15 bar with increasing of moister content from 25to 40%. Forming pressure decreased by 64% as die hole increased from 5 to 10 mm.

3- Specific energy requirement

Awday *et al.* (2002) indicated that the specific energy is affected by moisture content, where the specific energy in sifting wheat palletizing decreased by about 21% as a moisture content was increased from 25% to 40%. They also found that the decreasing in specific energy is due to both increase in productivity and decrease in power.

4- **Effect of temperature**

Simmons (1963) stated that if cold meal is cubed, pelleting machines suffer excessive friction between the die and the rollers. Therefore, increasing in wear, replacement costs and less durable and hard.

Reece (1966) showed that the advantages of applying heat to both die and material to increase durability, especially with steamy, low moisture content hay. This increases durability compared with experiments carried out without additional heat.

5- **Effect of binding materials**

Simmons (1963) mentioned that the most suitable compositions for cubing or pelleting are those materials containing a high percentage of oil, protein, and carbohydrate, but in general it is usually difficult to handle. He also showed that molasses improves the binding properties, and the surface polish as well as the appearance of pellets or cubes.

2.6 Agricultural Residue Pelleting

Many researchers have conducted studies on compacting agricultural residue into pelleting to improve the handling characteristics of the products and to increase the bulk density to suitable density. . Therefore, recycling of agricultural residue into pelleting form will lead to the following aspects, **Behnke (2001).**

1- Decreased feed wastage.

2- Reduced selective feeding.

3- Decreased ingredient segregation, less time and energy expended for prehension.

4- Destruction of pathogenic organisms. Thermal modification of starch and protein improved palatability.

Watfa (1999) used a screw –manual pelletizer to study factors affecting the pelleting of grain chaff .He used four die plates of 4, 5, 6 and 8 mm diameter in forming of wheat dust with binding agents. He found that heat application on the process is a complementary part in making durable coherent pellets. He concluded that the specific energy for pelleting process was 29.1kJ/kg.

Awady *et al.* (2002) investigated design factors relating to auger-pelleting machine performance. For this purpose, he used two augers of different pitch to diameter ratio of 5.2/3.92 and 3.1/11 with three multi–hole forming die plates of 5, 8 and 10 mm diameter.

Result for high pitch to diameter ratio auger showed 14.1% increase in productivity from 2.21 to 2.5533 kg/h for 5 mm die over 25-40% moisture content and the result also showed that the addition of heat improved pellets durability and reduced in torque requirements, but total specific energy including heating, greatly increased.

El-Wersh *et al.* (1999) investigated the effect of the sample moisture content, compression stress and temperature and crosshead speed on the quality of wheat bran pellets. The results showed that the pellet durability depends on their mechanical properties. Therefore, the best pelleting treatments was prepared at 13% moisture content, pressing under compression of 56 MPa at temperature of 90 °C.

Devandra and Reddy (1988) formed more than 60 complete rations pellets using locally available fibrous agricultural feed ingredients, then these pelleted formulation were tested in several experiments on cross breed cows, Muhrrah ,buffaloes, cross breed calves and sheep for maintenance , milk production and growth, cost of processing, nutrient digestibility and nutritive value of these pelleting formulations . Results indicated that blending poor-quality residues (40-45%) with other ingredients in complete rations improved the utilization of the residue and insured the supply of nutrients for milk or meat production. Table (4) shows pellets palatability of various residues.

Table (4): Pellets palatability for some residues (**Kniep, 1982**).

Low	Medium	High
Beet pulp	Groundnuts	Wheat midis
Wheat bran	Fish meal	Linseed meal
Dried whey	Dehydrated alfalfa	Meat scrap

2.7 Pellets quality

2.7.1 Hardness

Hardness implies the ability of a body to resist deformation by abrasion. Hardness is not used directly in engineering design, but it is an important strength index.

Shaw (1973) classified the wide variety of hardness test procedures into: (a) static indentation tests; (b) scratch tests; (c) plowing tests; (d) rebound tests; (e) damping tests; (f) cutting tests; (g) abrasion tests; and (h) erosion tests.

Typically, measuring hardness by a static indentation test involves forcing a hard tool of known geometry on the sample. The hardness is defined as the ratio of the applied force to the size of indentation. The Brinell hardness test involves pressing a sphere against a flat surface. There are two ways in which hardness can be calculated in this test: Brinell hardness and Meyer hardness. Brinell hardness is defined as the applied force divided by the surface area of contact:

$$H_B=2F/\pi D[D-(D^2-d^2)^{1/2}]$$

$$H_M=4F/\pi .\ d^2$$

Where:

H_B = Brinell hardness, (N/mm^2).

H_M:Meyer hardness, (N/mm^2).

F = maximum applied load, (N).

D = diameter of the probe or sphere, (mm), and (d): diameter of the dent (mm).

2.7.2 Pellet Durability:

Behnke (2001) reported that the pellet durability index (PDI) (ASAE S269.3) was developed as a predictor of pellet fines produced during mechanical handling. He also reported a correlations of R=0.967 and 0.949 for hot pellets and pellets cooled for 24 h. respectively, using the tumbling can as a predictor of pellet fines. Methods which measure individual pellets resulted in the lowest correlation (Stokes, R=0.78; Shear test R=0.72).

2.8 Dairy Residue (whey)

2.8.1 Whey Definition:

Whey as a dairy by-product (the liquid residue of cheese and casein manufacture) originates from mammal milk, and is one of the biggest reservoirs of food, protein, and lactose remaining outside consumption channels.

Whey has been known for decades as a product of high nutritional value. Today, the development of markets using whey powder and fractions of whey as ingredients in foodstuffs for human and animal consumption have transformed the previously troublesome by-product whey into a valuable product for the dairy and cheese-making industries.

2.8.2 Whey Quantities

World whey output, at approximately 186 million tons in 2000 keeps increasing at a rate of about 3% per year **(FAO, 2000).**

Bylund (1995) indicated that each 120 million tons of whey contain some 0.7 million tons of relatively high value protein equal to the protein contents of almost 2 million tons of soybeans.

El-Sayed (1987) indicated that the Arab Republic of Egypt produces about 118.8 thousand tons of sweet whey and 600 thousand tons of salted whey (this is produced from Domiati

Cheese), where the most of that whey is dumped in sewers or spread on lands as a fertilizer material .

Zall (1992) reported that many types of whey are produced according to the milk manufacture, where the sweet whey results from manufacturing of products that principally use rennet type enzymes at pH 5.6 like hard cheese (cheddar cheese and Swiss cheese) .Acid whey occurs as the by-product from manufacture of dairy products, where the coagulum is formed by acidification in pH of about 5.1 to below, like cottage cheese. Salted whey is manufactured from milk with 6-12% salt added before renneting.

2.8.3 Whey Composition

Bylund (1995) reported that the whey comprises 80-90% of total volume of milk entering the process and contains about 50% of nutrients in the original milk such as protein, lactose, vitamins and minerals. Table (5) shows approximate composition figures for whey from cheese and casein manufacturing.

Table (5): Approximate composition of whey **(Bylund, 1995).**

Constituent	Cheese whey%	Casein whey%
Total solids	6.4	6.5
Water	93.6	93.5
Fat	0.05	0.04
True protein	0.55	0.55
NPN	0.18	0.18
Lactose	4.80	4.80
Ash (minerals)	0.50	0.80

2.8.4 Whey Utilization

Morr (1992) indicated that whey products have many uses where, whey is used in animal feed, which include milk replacer for calves, feeds for cattle, poultry, and for pet foods. Whey and its derivatives are also used in many food products, including dairy products, baked goods, candies, snack foods, dry mixes, processed meats, infant formulas, nutritional beverages, and in numerous other dried, frozen and prepared foods.

Whey products offer numerous functional and nutritional properties that are valued by food manufacturers. For example, in dairy products, whey can replace the fat in low-fat products. It improves slicing, spreading, and melting characteristics in processed cheeses. In baked goods, whey improves the crust color and enhances flavor. In processed meats, it improves moisture retention.

Whey offers high-quality protein, calcium, and vitamins, which can be used to improve the nutritional content of many foods. In infant formula, whey creates a formula more similar to human milk and stimulates the growth of beneficial bacteria in the intestinal tract.

Harvey and Hill (1999) indicated that both liquid and dried whey is used in human and animal feed. Whey is often used for bread -making, being very economical when employed in lieu of milk.

ZoBell and Burrell (2002) used sweet liquid whey to produce whey silage for feeding cattle. Therefore, six studies were performed involving whey silage. The objectives of studies were to determine if silage could be produced from sweet liquid cheese whey, small grain straw and wheat middling, and to determine its effect on production and digestibility when utilized in growing and finishing diets for cattle.

Results showed that whey silage was produced in those studies for less than fifty dollars a ton was priced at one hundred dollars a ton, when diets containing 55and 80 percent of silage was fed to growing steers. They were equal in digestibility to standard diets comprised of alfalfa hay, corn silage and barley grain .The cost per pound of grain was decreased in studies with growing cattle, where

55 to 98 % of the ration was comprised of whey silage. A decision to use whey silage in cattle ration would need to be made on a case by case basis after determining the cost of available feedsuffs.

Kosikouski (1979) indicated that bakeries use sweet whey powder in bread, batters, cooked fillings, and icings for cakes.

Molder *et al.* (1980) stated that both acid and sweet whey, in practice , can be fed to livestock , but the latter is preferred because of its palatability where, acid whey is high in lactic acid and ash content than sweet whey , but protein and total solids of the two products are comparable. The digestibility of whey protein is about 65% for ruminants.

Fisher and Buckley (1985) indicated that whey permeate can be successfully fed as the only source of liquid to cattle. Cattle can consume 20 to 30% of their total dry matter intakes from liquid whey, but higher intakes can be achieved with concentrated product than liquid whey.

Clapp (1990) stated that whey can be used as milk replacers when whole milk is not available, milk replacer can produce comparable weight gains in calves to 4 weeks as feeding of whey replacers. He also stated that the analysis of commercial milk replacer must be at least 20% protein, 12% fat and about 0.25% fiber.

Miller *et al.* (1987) indicated that dried whey can cause pelleting difficulty and can increase pellet hardness which reduces palatability.

2.8.5 Whey Processing

Recycling whey from liquid to solid form using dehydration process will achieve many goals:

1- The economic benefits of using dried whey products are derived from reduced transportation cost, extended storage time, flavor, texture and the ability to increase the consumption of whey solids by the animals.

2- The dried whey is used as milk replacer in calves feeding, and in pelleting manufacture to enhance some physical and chemical properties of pelletes.

3- Reducing pollution by liquid whey where, the biological oxygen demand (BOD) of whey is 32000 mg O_2/L.

Whey recycling from liquid to solid (powder) is accomplished in tow stage: The first one is concentration the permeate from 6% solid content to (40 to 50%) using the Reverse Osmosis (RO) way as the first step and using the evaporation as the second step. The second stage is the final drying using a drum dryer or a spray dryer.

2.8.5.1 Whey Concentrating

Whey concentrating may be accomplished in two stages using (RO) in the first stage and evaporation in the second stage as follows:

1-Reverse Osmosis

Pearce (1992) reported that whey permeate is concentrated in two stages, Reverse Osmosis method (RO) in the first stage. (RO) is limited to 20-22% moisture reduction.

(RO) works by passing a dilute product stream across a membrane of porosity, sufficiently low to allow the permeation of water and equivalent or small sized molecules because of the low porosity of membrane, a high pressure is required to facilitate an economic rate of water permeation.

2- Evaporation

Caric (1994) reported that evaporation is a compulsory step in powder processing for several reasons:

1- The powder produced from evaporated whey has long shelf life and larger powder produced particles with a smaller amount of occluded air.

2- For concentrating whey prior to drying a continuous multiple effect evaporator usually of the tubular type is used.

3- For roller drying, the concentration during evaporation is increased to 33-35% total solid, while for spray drying it is up to 40-50%.

He also stated that a higher concentration during drum drying would form a thick layer on the rollers, followed by inhibited drying and intensive irreversible changes in protein, lactose, and fat. However, further concentrating for spray drying would increase viscosity and cause difficulties during atomization of the whey.

In evaporation principle, whey at elevated temperature is distributed evenly over the inner surface of a long vertical tube and flows down as a thin layer under vacuum (70°C, 70mm Hg pressure). During process, water is lost from film and is removed as vapor and the concentrated product emerges at the lower end of the tube.

In principle, design of multiple tubes is used and arranged consequently. From stage of to stage, there is a decreasing boiling temperature owing to difference in vacuum product pumped from stage to stage by condensation with cooling water.

2.8.5.2 Whey Drying

The final step in production whey powder from concentrated whey should be a final dehydration process using drum dryer or spray drying.

Drying process denotes that water is removed from the product to the safe moisture content. In dried whey the water content should be in the ranged about from 3.5 to 5%.

Miller *et al.* (1987) indicated that spray drying or roller drying produces dried whey. The dried product contains 65 to 70% lactose, 13% crude protein, 0.8% lysine, 0.9% calcium, 0.7% phosphorus, and about 5% salts of sodium and potassium.

Dried whey contains high quality protein and nutrients that are readily digested by the young animal. Since dried whey is much less expensive than dried skim milk, and has many of the benefits of milk. It is an attractive substitute for milk in starter feeds.

Bylund (1995) indicated that whey is dried in the same way as milk (i.e in drum or spray dryers). Drying whey is completed through two stages: the concentration stage, where the whey permeate is concentrated from 6% to 40-50% solid content. The second stage is the final drying using a drum or a spray dryer. The final step of drying whey is dehydration process using drum or spray dryer.

1- Drum dryer

The features of the use of the drum dryers in food drying such as dairy products are:

1-Short drying time about (10 -20 seconds) and capable of continuous drying.

2-Capable of directly solidifying liquid, paste and suspense materials after drying

3- (70 -80 %) heating efficiency, low consumption of steam, about (1-2) kg of steam per kg of water.

4-Easy operation, maintenance, and long machine life.

5- No second contamination to the environment.

6- Easy to change machine functions, suitable for multiple production, but small quantity.

7- Adjustable drying time and temperature, according to processing requirement.

8- Able to dry up all materials completely.

9- Can process any quantity of material, and heat sensitive material with added vacuum device.

Rodriguez ***et al*** **(1996)$_{(a)}$** stated that drum dryer is currently used in the food industry to dry, heavy paste and thick liquids such as cooked starch, mashed potatoes, and concentrated liquids .

Bylund (1995) stated that the use of drum for drying involves a problem, to scrape off the dried layer from the surface of the drum. A filler, such as wheat or rye bran, is therefore mixed into the product before drying to make the dried product easier to scrape off.

Harvey and Hill (1999) stated that there are three methods of film drying (drum drying), each one possessing certain advantages. These are:

1- Atmospheric roller drying: with this method, the drying rolls are exposed to the air, and drying takes place at atmospheric pressure.

2- Vacuum roller drying: When this system is employed, the whole unit is in enclosed chamber either with or without the employment of vacuum.

3- Band film drying: product is dried on a continuous band by hot air in enclosed chamber either with or without the employment of a vacuum. Fig (4) shows drum dryer configurations.

McCabe ***et al.*** **(2001)** reported that the drum dryer consists of one or more heated metal rolls on the outside of which a thin layer of liquid is evaporated to dryness. Dried solid is scraped off the rolls as they slowly revolve.

They also stated that the rolls of a drum are 0.6 to 3 m in diameter and 0.6 to 4 m long, revolving at 1 to 10 r.p.m . The time that the solid is in contact with hot metal is 6 to 15 second , which is short enough to result in little decomposition even for heat –

sensitive products .The heat-transfer coefficient is high, from 1200 to 2000 W/m^2. °C under optimum conditions , although it may be only one-tenth of these values when conditions are advised.

Brennan ***et al.*** **(1990)** indicated that the factors affecting the drying rate and final moisture content of a particular material on a drum drier are: speed of rotation of a drum (controlling dwell time), steam pressure or heating temperature, and film thickness. They also stated that the advantages of drum drying are high rates of drying and economic use of heat.

Caric (1994) indicated that sharp knives skim product in the form of a thin film, this blade form an angle of 0.26 to 0.52 rad (15-30°) with the roller surface.

Rodriguez ***et al.*** **(1996)$_{(a)}$** analyzed different ways for controlling the final moisture content of a product dried on a drum dryer to reduce its unevenness in order to obtain a high–quality product and to increase dryer productivity.

They concluded that drying on a drum dryer takes place as boiling phenomena mechanism; consequently, an infrared temperature sensor can be used as a local moisture sensor for the dried product. This measurement works with a thin film, without contact, is precise and quite cheap compared to other methods .It can be used to detect moisture unevenness and location of wet zones in real time, and eventually to detect anomalies such as absence of product on the dryer.

Rodriguez ***et al.*** **(1996)$_{(b)}$** chose two variables, the drum speed and the heating steam pressure, in order to control the final moisture content produced by a drum dryer by modifying a classical method such as electric heater.

They concluded that the correction of local unevenness has been possible using a complementary heating source, (i.e an inductive heater). This configuration increases productivity by reducing the overdrying, which is the actual way to overcome unevenness in industry.

2. Spray drying

Caric (1994) indicated that predominant method of drying milk and dairy products is spray drying. Evaporated product is dispersed (atomized) into fine droplets and exposed to a hot air flow in the spray chamber.

Batty and Folkmans (1983) indicated that spray drying is a popular technique for producing dried powder from liquids such as milk and dairy wastes, and that spray drying process consists of the following steps:

1- Concentrating a product to relatively low moisture content (from 45-55%).

2- Spraying the concentrated product into hot air stream, so that very small droplets are produced.

3- Transferring heat from air stream to the liquid droplets to provide the necessary latent heat of vaporization.

4- Separation and filtration of the dried powder from air stream.

They also reported some of the advantages of spry drying as follows:

1-Heat sensitive products can be successfully spray dried.

2-Drying times are very short (usually less than one second).

3-High production rates can be obtained.

McCabe *et al.* (2001) indicated that in typical spray dryer, the drying chamber is a cylinder. Liquid feed is pumped into a spray atomizer in the roof of chamber. The spray disk is about 300mm in diameter and rotates 5,000 to 10,000 rpm. Average drop diameter in spray dryer ranges from 20μm to 180 μm. The heat transfer coefficient for the individual drops my be estimated from the following eq

$h.D/k=2.0+0.60(D.G/\mu)^{0.50}(C_{p}.\ \mu/k)^{0.333}$

Where:

D: is the diameter of the droplet.

k: thermal conductivity .

h: surface heat transfer coefficient .

C_p: specific heat at constant pressure.

G: mass velocity.

μ: absolut viscosity.

Figs (5) and (6) shows spray dryers basic layouts.

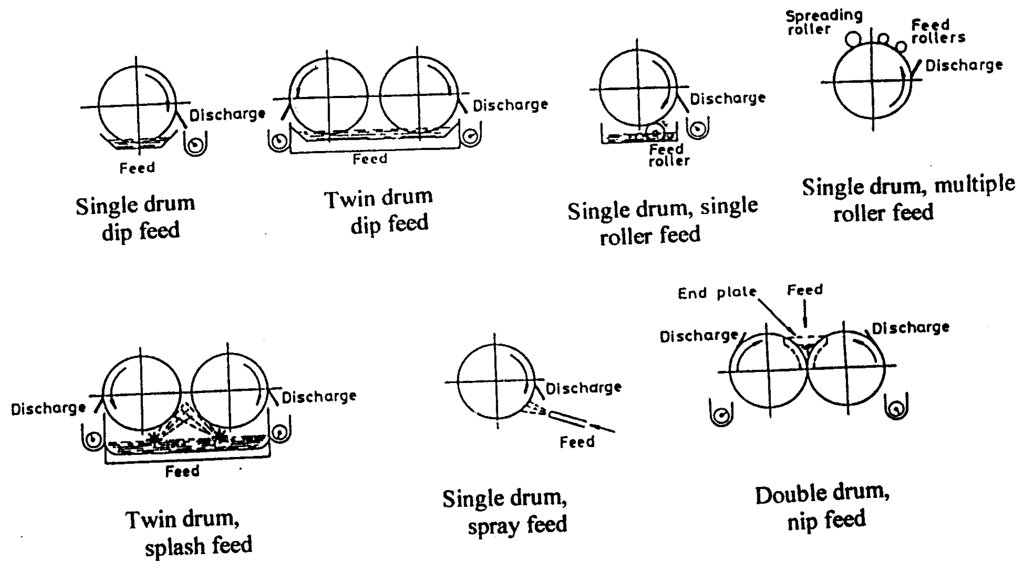


Fig.(4):Drum dryer configurations **(Masters,1997)** ·

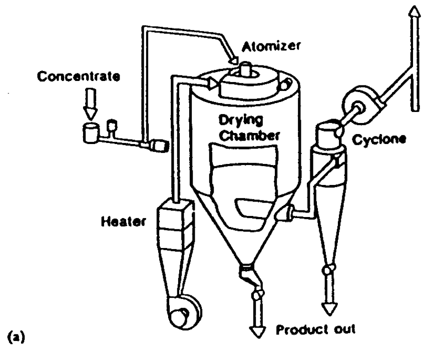


Fig. (5): Spray dryer layout **(Masters, 1997).**

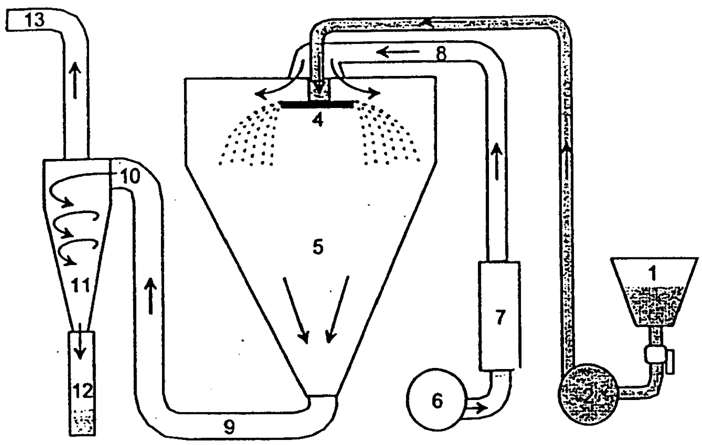


Fig. (6): Spray dryer **(Sharma *et al.*, 2000).**

1,millk reservoir; 2,feed pump;3,product feed pipeline;4,atomizer;5,drying champer;6,air fan;7,hot air duct;9, a mixture of dried product and air-carrying.

III- MATERIALS AND MEHTODS

3.1 Experiment of the Drying Unit

3.1.1 Treatment Design

Treatment design includes the following points:

1 - Objective

Experiments were carried out to design and construct an engineering unit (Drum Dryer) for dairy residue recycling (whey) from liquid form to solid form to be used in latter time (during storing) as supplements in food industry and in animal feed, and to study some processing parameters such as: drum speed (N), drying temperature (T_d), and the whey properties such as the initial moisture content , (M_{ci}) and the feeding rate (m_p) on the performance of the drum dryer and the product quality of the dried product, such as: bulk density (ρ) and final moisture content (M_{cf})

2 - Factors

The processing variables are initial solids content or initial moisture content (M_{ci}), drum speed (N) and the drying temperature (T_d).

3 - Treatments

The levels of the processing variables are:

M_{ci}: (50, 55, 60, 65 %).

N: (1, 2, 4, 6 and 7 r.p.m)

T_d: (120, 130, 140,150 °C)

4 - Experimental Design

Fig. (7) Shows both input and output variables used in this study.

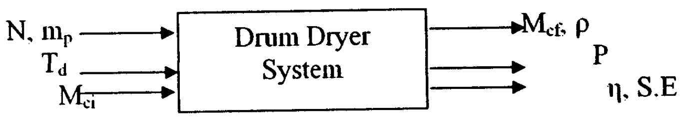


Fig. (7): Schematic representation of the influence of variables (input) on objective (output) variables.

3.1.2 Experimental Procedures

The following steps are achieved during the drying procedures.

1 - Concentrating liquid whey by evaporating process before being applied to the drum surface to the required solid content.

2 - Heating the feed to the suitable temperature to reduce its viscosity during the process.

3 - Adjusting the drum speed to control the residence time.

4 - Adjusting the temperature of the drum surface.

5 - Adjusting the blade (scraping knife) to fit securely against the drum.

3.1.3 Drum Dryer Operation

Prior to starting up, all components of the unit must be clean, dry, and the powder bucket is in its place. The running operations include:

A - Place the concentrated whey in the pan of the system.

B – Adjust the gap position between the drum surface and the feeding roller.

C - Turn on the heater.

D - Attach loosely the scraping knife.

E - Start the drum and regulate it to the desired speed and direction.

F - Place the collection pan for dried powder.

G - Start to record reading.

H - Clean up when finished drying.

3.2. Design of the Drying Unit

The drying unit used in this research was designed and constructed in the Agric. Eng. Dept., Fac. of Agric., Ain Shams Univ.

It consisted of the following components as shown in figs. (8) and (9).

3.2.1 The Drying Unit System

This unit consisted of the following main components:

1 - The Drum

A hollow stainless steel drum fabricated from a stainless steel tube of 5 mm thickness, 170 mm diameter, 300 mm in length, and (0.16 m^2) drying surface .The two sides of the drum were covered with iron and glass wool. The drum rotates slowly (1 to 10 r.p.m) about its horizontal axis using two roller bearings.

2 - Electrical Heater

The heater was a spiral resistance of 250 mm in length and 50 mm diameter to fit with the dimensions of the drum. The heater was fixed inside the drum using a screwed flange. The heater power was 2 kW.

3 - Scraping Knife

This device was fixed on the drum surface to scrape the dried material after of 0.9 of revolution from the point of application of the feed, where the angle decline of the knife was 15^{o} with the vertical.

3.2.2 Feeding System

The function of the feeding system is to introduce the wet material to the drum surface in a uniform thickness. This system consisted of a reservoir for the raw material and a stainless steel roller of 50 mm diameter.

3.2.3 Power Transmission System

The function of this system is to transmit the motion from the power unit (motor) to the drying unit, and the feeding system, and to control the drum revolution. This system consisted of the following components:

1 - Electrical Motor

0.35 kW, 1480 r.p.m, shaft diameter of 15 mm working voltage of 220 / 110 v, and working current: 3/6 Amps

2 - Speed Reduction

20:1 reducer ratio, input shaft of 10 mm and output shaft of 12 mm.

3.2.4 Accessories

Accessories include pulleys of motor and speed reduction, 5 sprockets with different diameters, two pairs of spur gears, V belt to transmit the motion from the motor to the speed reduction, and a chain to transmit the motion from the speed reduction to the drum shaft.

3.3 Measuring Instrumentation

3.3.1 Temperature measurement

For heat and mass balance, two types of thermometer were used as follows:

A - Infrared thermometer

Manufacture country is Germany, Model: 860T305608603, Power requirement: 3V DC current, temperature range: -30 to 900°C, emssivety: 0.4-1, target distance: 20 mm, response time: 1 second.

B - Thermocouple

Source of manufacture: USA, model: Bri-5050, useful range:-50 to 750C°, power requirement: 9 volt, DC.

3.3.2 Electrical Balance:

For measuring mass samples used for bulk density and moisture content, an electrical balance was used. It had the following data: source of manufacture: USA, Capacity: 200 g, readability: 0.01g, power requirement: 9 volt, DC.

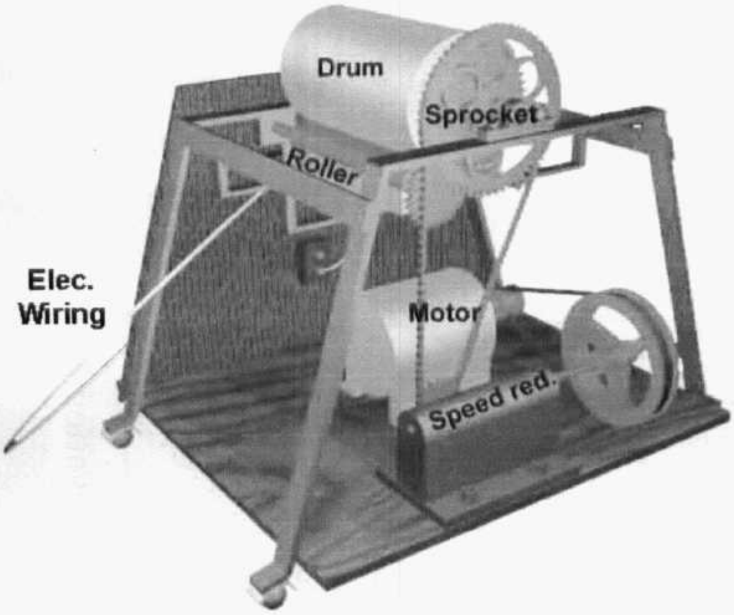


Fig. (8): Perspective of the drum dryer unit.

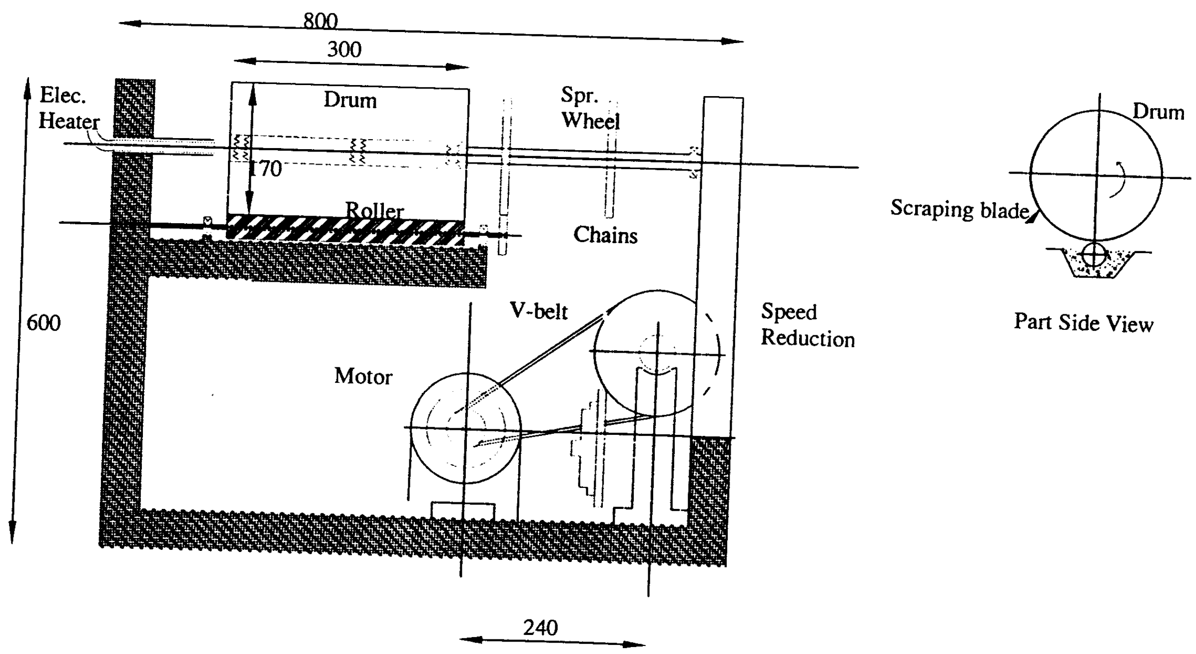


Fig.(9):Drum dryer elevation.
Dims are in mm.

3.3.3 Electrical Gages

These instruments were used to measure electrical current intensity and voltage of the electrical heater using the following gages:

1 - Ammeter

Used to measure the electrical current passing through the heater resistance .It has the following specification: source of manufacture: China, model: NR-72, range: 0 to 15 A.

2 - Voltmeter

Used for measuring the voltage applied to the heater .The specifications of the voltmeter are Source of manufacture: China, model: Sf 72x72, Range: 0 to 500V.

3.4 Methods

3.4.1 Moisture Content Determination

For both the wet and dried materials, a sample of 25 g was used according to **AOAC (1990)**, and then the moisture content was determined using the following equations, according to **(Henderson and Perry, 1975)** as follows:

$$m_{wb} = \frac{m_b - m_a}{m_b} \times 100\% \qquad \text{on wet basis} \quad \ldots\ldots\ldots\ldots\ldots (3\text{-}1)$$

$$m_{db} = \frac{m_b - m_a}{m_a} \times 100\% \qquad \text{on dry basis} \quad \ldots\ldots\ldots\ldots\ldots (3\text{-}2)$$

Where, m_b, m_a are the mass of the product before and after drying resp.

m_{wb} ,m_{db} are the moisture contents on wet and dry bases, resp.

3.4.2 Bulk Density

Bulk density was measured according **Sharma *et al.* (2000)** by filling a graduated cylinder with the product and settling it in a standard manner, then measuring both its volume and weight. The density is computed using the normal formula: ρ=m/v.Where: m, v are the mass and volume respectively.

3.4.3 Heat Balance

Heat balance as shown in fig.(10),was accomplished to estimate the thermal efficiency, overall heat transfer, and heat losses. These items were estimated for drying energy requirement. For heat and mass balance applied on the drying unit, some assumptions were considered as follows:

1 - The surface temperature of the drum is distributed uniformly axially and radially.

2 - The thickness of the film is uniform during the drying process along the drum.

3 - The thermal resistance between the heater and the inner surface is negligible.

4 - Averages of the thermal properties of the product were used for heat and mass transfer.

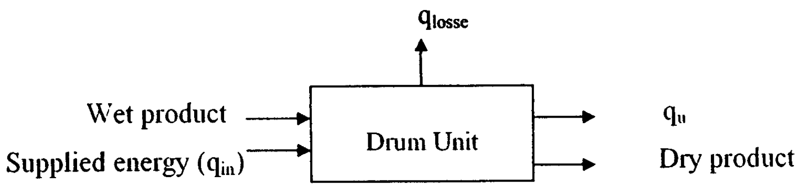


Fig. (10): Schematic diagram of mass and energy balance.

An energy balance on the system gives:

$q_{in}= q_u + q_{loss} = q_s + q_l + q_{loss}$ .... (3-3)

Where:

q_{in}: The total supplied energy to the system, (W)

q_u: The useful energy which divides into terms , q_s and q_l, (W).

q_s: The required sensible heat to raise the raw material temperature to the evaporation temperature, (W).

q_l: The latent (the required energy to remove the water from the material at the boiling point), (W).

The terms of the equation (3-3) are given by the following equations:

q_{in} =V.I .... (3-4)

$q_s = m'_p . C_p . (T_f - T_{pi})$ .... (3-5)

$q_l = m'_w . h_{fv}$ .... (3-6)

Where:

V: The voltage between the mains of the heater, (volt).

I: The current intensity passing through the heater resistance, Amp.

m'_p: The feeding rate to the drum surface, (kg/s).

C_p: The specific heat of the product, (kJ/kg. °C).

T_f, T_{pi}: The temperatures of the film and the fed product resp., (°C).

m'_w: Water evaporating rate during the drying process, (kg).

h_{fv}: The latent heat of vaporization of water.

3.4.4 Thermal Efficiency:

The thermal efficiency was calculated by the following equation:

$\eta = q_u/q_{in} = (q_s + q_l) / q_{in} = [\, m'_p . C_p . (T_f - T_i) + (m'_w . h_{fv})] / VI.$ (3-7)

3.4.5. Overall Heat Transfer Coefficient Determination

The overall heat transfer coefficient is an important parameter used in heat transfer calculations .The overall heat transfer can be calculated as follows:

1- Theoretically

By this way, the overall heat transfer coefficient includes the combined effects of connective and conductive heat transfer between energy source and the product according the following equation according to **Sharma *et al.* (2000)**:

$$U = \frac{1}{x/k + x_p/k_p + 1/h_p + 1/h_a} \quad \text{.............................(3-8)}$$

Where:

U: The overall heat transfer coefficient, ($W/m^2.{}^\circ C$)

X, X_p: Thicknesses of the drum surface and the dried film resp., (mm).

k, k_p: Thermal conductivities of drum wall and the dried material respectively, (W/m. °C).The thermal conductivities for mild stainless steel was (9.5 W /m. °C), and the product thermal conductivity was computed according to eq.(3-33).

h_p: The convective heat transfer of the material, the h_p can be calculated by the following equation according (**McCabe *et al.*, 2001**):

h_a: The convctive heat transfer of air, ($W/m^2.{}^\circ C$)

$q_{ev} = h_p.A(T_s-T_f)$ ....(3-9).

Where:

q_{ev}: The latent heat of evaporation required to evaporated the water present in wet material at the drying temperature, (kJ/kg).

A: The drying surface area, (m^2).

T_s, T_f: Drum surface temperature and the film temperature resp, (°C).

2- Experimentally:

The total useful energy supplied is given by the following equation according to (**Masters, 1997**):

$q_u = A.U(T_s-T_a)$ ....(3-10)

Thus the overall heat transfer coefficient is given by the following equation:

$U = q_u/A.(T_p-T_a)$ ....(3-11)

Where:

q_u: Useful energy, may be estimated from the mass balance, (W).

A: The drying surface area, (m^2).

T_s, T_a: The drum surface and the ambient temperatures resp., °C).

3.4.6 Heat Losses Determination

Heat losses were determined experimentally using heat balance, then determined theoretically using the thermal net work as shown in fig. (11) as follows:

1 - Experimentally

$q_{in} = q_{loss}+q_u$ .... (3-12)

Then:

$q_{loss} = q_{in}- q_u$ .... (3-13)

2 - Theoretically

$q_{loss}= q_p+q_{s1}+q_{s2}+q_k$ .... (3-14)

Where:

q_p: The heat losses from the dried product, (W).

q_{s1}, q_{s2}: The heat losses from the two sides of the drum, (W).

q_k: The heat loss from unused surface (the surface between the scraped point to the feeding point), (W).

The previous terms were determined according the following equation:

$q_{pow}= m^{\cdot}.C_p.(T_f -T_a)$ .... (3-15)

$q_{s1}=U_1.A_1(T_s-T_a)$ .... (3-16)

$q_{s2}=U_2A_2(T_s-T_a)$ .... (3-17)

The top loss was determined according to **(Arora, 1989)** by the following eq.

$q_k= \varepsilon.\sigma.A_3 (Ts^4-T_a^4)$ .... (3-18)

Where:

$m^{\cdot}$: The drying rate, (kg H_2O/h).

C_p: The specific heat of the dried material, (kJ/kg. °C), computed from eq.(3-30).

T_{pi}, T_a, T_s : The temperatures of the wet product , the ambient air and the drum surface resp., (°C).

$A_{1,2,3}$: Surface area of the heat losses , (m^2).

$U_{1,2}$: The heat transfer coefficients, (W/m^2 °C), The U values were determined using the following equations:

$U_1 = [x_1/k_1+x_2/k_2+x_3/k_3+(1/h_a)]^{-1}$ ....(3-19)

$U_2 = [x_1/k_1+ 1/h_a]^{-1}$..(3-20)

Where:

x_1, x_2, x_3: The thicknesses of the drum side , the glass wool ,and the second layer of the drum side ,mm.

k_1, k_2, k_3: The thermal conductivities of the drum side metal and the glass wool, (W/m. °C), thermal conductivities for the wool glass was 0.043(W/m. °C), and for rough iron was 31 (W/m. °C).

h_a : The convective heat of the air, (W/m^2. °C).

The convective heat transfer coefficient of the air was determined as a function of Nusselts Number (N_u) using the following equations:

$h_a = N_u.k/D$..(3-21)

Where:

N_u: The Nusselt number, dimensionless.

D: The characteristic length, (m).

K: The conductivity of air at (t_m), (kJ/kg °C).

The average temperature (t_m) was determined using the following equation:

$T_m=T_f+T_a/2$...(3-22)

ε: The emissivity of the drum surface (0.95).

σ: Stefan and Boltzmant Constant ($5.672x10^{-8} W/m^2K^4$).

For free convection the Nusselt number depends on the Prandtl number (P_r) and the Grashof number .The Grashof number and the Prandtl were given according to **(Batty and Folkmans, 1983)**:

$G_r = g.\beta.(T_s-T_a).\rho^2.l^3/\mu^2$..(3-23)

$P_r = \mu.C_p/k$.. (3-24)

For the vertical plates, the Nusselt number was given by an empirical equation according **(Incopera and Dewitt, 1996)** by the following equation:

$N_u = 0.68+0.671.R_a^{0.25}/[1+(0.492/P_r)^{9/16}]^{4/9}$ .... (3-25)

$R_a = G_r.P_r$.. (3-26)

Where:

R_a: The Ralyes number

Where:

C_p, k, ρ, μ, β: The heat capacity, the thermal conductivity, the density, the viscosity , the volume coefficient of expansion , respectively for the air .

T_a: The ambient temperature, (°C).
T_{fin}: The film temperature, (°C).
T_s : The drum surface temperature, (°C).
T_{is}: The inner drum surface, (°C).
T_{fin}: The average film temperature, (°C).
T_f: The film temperature, (°C).
h_p: Convective heat transfer between the fluid and the drum surface, (W/m^2 °C).
k, k_p: The thermal conductivities of the drum material and the fluid resp., (W/m °C).
x,x_p: The drum and dried material thickness resp., (m).
q_{in}.q_u: The heater capacity and the useful energy resp., (W)
q_{s1}.q_{s2}, q_k, q_{pow}: the heat losses from two sides of the drum ,between finishing drying cycles and beginning cycle, and with the dried material resp., (W).

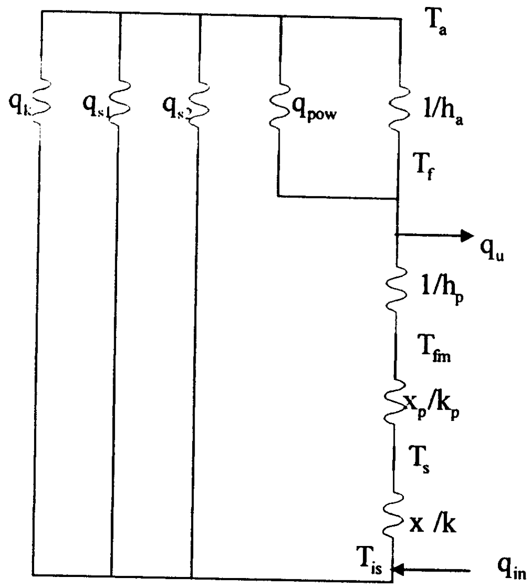


Fig. (11): Thermal network for heat transfer.

3.4.7 Mass Balance

The mass balance was made for the determination of the amount of water that evaporated from the product during the drying process , then to calculated the drying rate from mass balance .The mass balance was performed as shown in fig. (12).

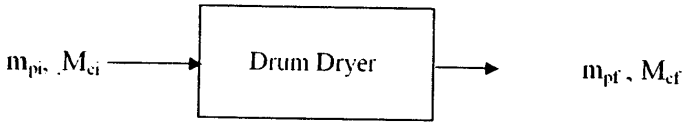


Fig. (12): Schematic diagram of the mass balance concept.

From the mass balance:

$m_{pi}\,[(1-M_{ci})] = m_{pf}\,[(1-M_{cf})]$ .... (3-27).

$m_{wi} = m_{pi} * M_{ci}$ .... (3-28).

$m_{wf} = m_{pf} * M_{cf}$ .... (3-29.

$m_w = m_{wi} - m_{wf}$ .... (3-30).

Where:

m_{pi}, m_{pf} : The average mass of the product before and after the drying process resp., (kg).

M_{ci}, M_{cf} : The inatial moisture content and final moisture content resp.,(kg).

m_w: The mass lost of water from the product, (kg/h).

3.4.8 The Drying Rate Determination

The drying rate is the major indictor of the performance of the unit. The drying rate is proportional to drying surface, temperature, heat transfer rate, and the moisture content. Therefore, the drying rate may be calculated according to mass transfer or to heat transfer as follows:

$dw/dt = U.A.\Delta.T/h_{fv} = m^{\cdot}_{w}/t_d$ .... (3-31).

Where:

U: The overall heat transfer coefficient, ($W/m^{2o}C$)

ΔT: Difference temperature between the inner drum surface and the dried film , (°C)

h_{fv}: The latent heat of vaporization , (kJ/kg).

$m^{\cdot}_{w}$: The evaporating water rate of , (kg/s).

t_d: The residence time, (s).

3.4.9 Thermal Properties

The thermal properties, heat capacity, and conductivity, were determined according to **(Sing and Heldman, 2001)**, and **(Riziv and Rao, 1995)** resp. as follows:

$C_p = 1.42X_c+1.590X_p+1.67X_f+0.837X_a+4.18X$..... (3-32)

$K = 0.25X_c+0.155X_p+0.16X_f+0.135X_a+0.58X_w$... (3-33)

Where: X_c, X_p, X_f ,X_a, and X_w are the contents of the carbohydrate , protein, fat, ash , and water in the product resp.

3.4.10 Fresh Whey Source

Fresh-sweet whey for all experiments was collected from the cheese-making unit of the Dairy Dept., Fac. Agric., Ain Shams Univ.

3.4.11 Concentrated Whey

For all experiments, liquid whey was concentrated to the required solid content using an ordinary vessel and an electrical heater of (1000 Watt) of power.

3.4.12 Chemical Analysis

The chemical analysis for all samples (fresh and dried) was carried out at the Central Lab. of the College of Agriculture, Ain Shams Univ. according to the **AOAC (1990).**

3.5 Pelleting Processes, Materials and Methods

Pelleting experiments were carried out to study recycling whey as a binder material in pelleting process. The effect of the whey percent concentrates on the quality of dried pellets and on the productivity of the pelleting unit was studied.

3.5.1 Auger-Pelleting Machine

This machine was designed by **(Watfa, 2002)** as shown in fig. (13). It consists of an auger, housing with integrated feeding bin, a set of multi-hole forming die plates and an iron base for mounting all the components, an electrical motor of 1hp (0.75 kW), speed reduction of 20:1 and accessories including v-belt, and a set of pulleys for changing the speed of auger.

Table (6) shows technical specifications of the all components of the pellting unit.

Table (6): Pelleting unit technical specification **(Watfa, 2002).**

Item	Value
Electrical Motor	
Power, hp/kW	1/0.75
Speed, r.p.m	1400
Voltage, v	220
Speed reducer	20:1
Auger	
Shaft dia / length, cm	1.92 / 16.5 resp.
Shell inside/ outside, dia.	3.9 / 3,5
Die holes / hole land, mm	5, 8, 10/22

3.5.2 Test Mixture

Pelleting mixture comprised of ground corn (40%), soybeans (20%), and variable moisture content concentrated whey (40%). All the test mixture materials were purchased from the local market.

3.5.3 Procedure

A mixture is adjusted to the required percents of (whey, moisture content, corn, and soybeans), and then fed into the housing through the inlet hoper. The revolving auger pushes mixture axially towards the forming die then it protrudes as a pellet form.

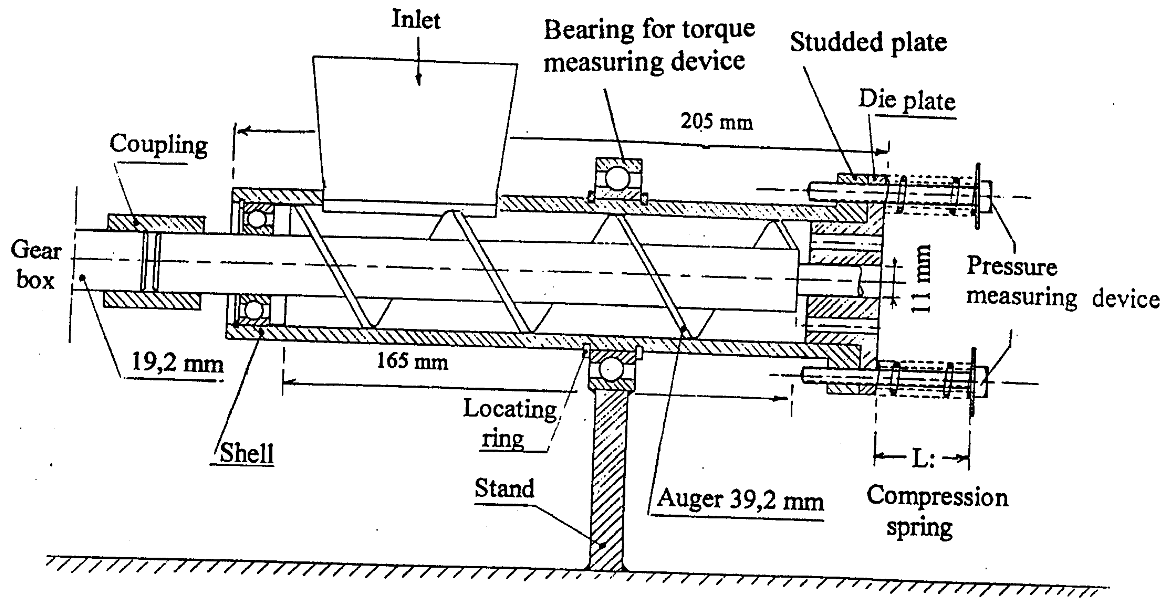


Fig.(13): Pelleting machine after (**Watfa, 2002**).

3.5.4 Hardness Measurement Gage

The hardness gage used to measure the pellet hardness has the following specification:

Manufacture country: Japan.
Name and Type: Shimpo Digital Force Gage, Modlel: FGC50.
Measuring Range: 50.00 kg.f, 500 N, 100 lb.f.
Accuracy: 35 times/sec.
Power: DC 9 v, 200 mA.

3.5.5 Pellets Bulk Density

Bulk densities for the sun-dried pellets were determined according to **ASAE (2003).** The densities for all the experiments ere determined at loose fill condition by measuring the volume of a bulk of a certain mass 200 g.

3.5.6 Pellets Density

Unit-density was determined by measuring the dimension of pellets for volume determination then dividing of the pellet mass by its volume.

3.5.7 Pellet Durability Test

The pellet durability index (PDI) (ASAE S269.3) was developed as predictor of pellet fines produced during mechanical handling before feeding time. This is accomplished using a specially designed device by **ASAS (2003).** The device is rotated about an axis perpendicular to and centered in 300 mm sides. A 230 mm long baffle is affixed. A 500g sieved sample of pellets are placed in box device and tumbled for 10 min at 50 r/min. Pellet length to diameter ratio ranges from 2.5 up to 3, then the durability Index (PDI) is defined as:

$$DPI = \frac{\text{undamaged pellets mass}}{\text{Pellets mass before tumbling}} x100 \ldots\ldots\ldots\ldots (3\text{-}34)$$

The (DPI) is accomplished by the following steps:

1 . Secure a representative sample.
2. Remove broken pellets from sample with appropriate hand sieve.
3. Weigh out 500 g of screened sample.
4. Tumble 500 g of screened pellets for 10 minutes.
5. Re-screen and weigh the whole pellet sample.
6. Compute Pellet Durability Index by dividing the weight of the whole pellets by 500 and multiplying by 100.

3.5.8 Machine Productivity

The productivity of the pelleting machine was determined with the help of a digital stopwatch and a balance of 0.1-sec. accuracy and an electrical balance of 0.01g accuracy.

3.5.9 Pellets Hardness

Pellet hardness was determined as Meyer hardness according to **Doyle and. Walker (1985)** using the following equation:

$H_m = 4F/\pi.d^2$ .... (3-35).

Where:

H_m: Meyer hardness, N/mm^2.

F: Maximum applied load, (N).

d: Diameter of the dent, (mm).

IV- RESULTS AND DISCUSSION

4.1 Thermal Efficiency of the Drying Unit

The thermal efficiency is an important indictor of the design appropriateness of drying unit, where the thermal efficiency expresses energy utilization. The thermal efficiency of the present study was performed according to heat and mass transfer, and also according to heat balance.

In heat and mass balance method, drying temperature (the temperature of drum surface), film temperature, initial moisture content and the feeding rate were measured as mentioned in material and methods chapter (III).

The mass and heat balances were performed. Sensible heat (energy required to raise the temperature of the wet material from the initial temperature to evaporation), and latent heat (energy required to evaporate the moisture at constant temperature) were computed, then thermal efficiency was determined according to equation (3-7).

Table (7) shows the thermal efficiency as a function of the drum speed and the initial moisture content.

4.1.1 Thermal Efficiency as a Function of the Drum Speed

As shown in fig. (14), regression analysis showed that there is a strong relationship between the thermal efficiency and the drum speed, this relationship followed a polynomial equation as follows:

$$\eta = -1.564N^2 + 20.587N - 8.3066 \qquad \text{(4-1)}$$

Where:

η: The thermal efficiency, (%)
N: The drum speed, (r.p.m)

Table (7): The thermal efficiency of the drying unit [1]

M_c	50%					55%				
M_{cf}	10	15	18	24	33	14	16	25	28	33
N	1	2	4	6	7	1	2	4	6	7
q_l	138	259	491	646	606	148	290	499	702	672
q_s	13	26	51	85	90	14	27	55	81	96
q_t	151	285	542	731	696	162	317	550	783	768
η	10.2	19	36	49	47	11.7	21.5	37.	53	51.5

M_{ci}	60%					65%				
M_{cf}	21	24	27	30	39	23	27	36	38	43
N.	1	2	4	6	7	1	2	4	6	7
q_l	159	310	564	809	734	172	327	680	822	801
q_s	13.8	28	42	63	73	11.5	22.5	45	67	79
q_t	172	338	606	872	807	183	350	725	889	880
η	11.	22.5	41.2	59	54	12.5	23.7	49	60.4	58

[1] Keywords of table.

N: The drum speed, (r.p.m).
M_{ci}: The initial moisture content, (%).
M_{cf}: The final moisture content, (%).
q_l: The latent heat, (W).
q_s: The sensible heat, (W).
q_t: The total useful energy, (W).

From the fitting curve as shown in fig. (14), the thermal efficiency increased with the drum speed until reaching a peak (M_c= 56%, and drum speed 6.5 r.p.m), then the thermal efficiency began to fall down.

The previous result, in the range of (1 to 6.5 r.p.m), is due to increasing of the feeding rate with the drum speed. However, when the drum speed passed the peak value (6.5 r.p.m), the feeding rate increased, where the heater capacity cannot remove the additional water. Therefore, the thermal efficiency began to fall down.

Peak values were calculated by differentiating equation (4-1) and equating to zero.

Table (8) shows comparison between calculated and predicted thermal efficiencies according to eq. (4-1) at (M_{ci}=65%). Fig. (15) shows the thermal efficiency at different moisture contents.

Table (8): Comparison between calculated and predicted thermal efficiencies at constant moisture content.

Drum speed	Calculated (%)	Predicted (%)	$\Delta\eta$	Error (%)
1	12.5	10.7	1.8	14.4
2	23.7	26.6	2.9	12.3
4	49.8	49.0	0.7	1.5
6	60.4	59.7	0.7	1.2
7	58	59.2	1.1	1.98

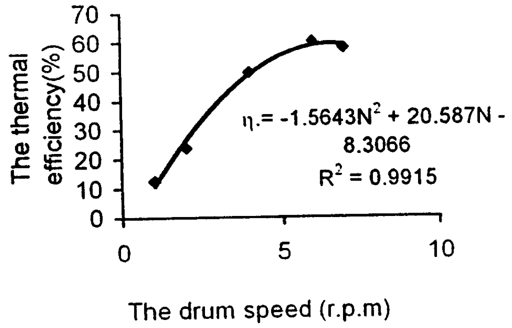


Fig. (14): Thermal efficiency as a function of the drum speed at (M_{ci}= 65%).

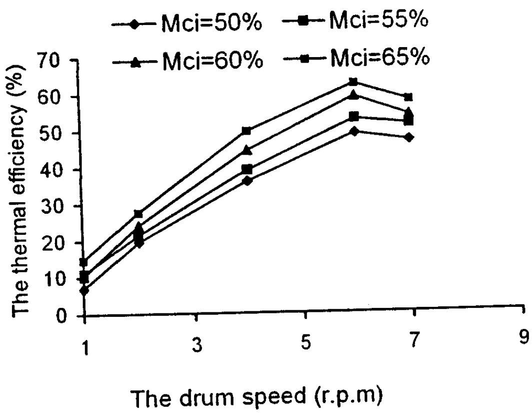


Fig. (15): The thermal efficiency as a function of the drum speed at different moisture contents.

4.1.2 Thermal Efficiency as a Function of the Moisture Content

The initial moisture content affects significantly the thermal efficiency as shown from regression analysis. The thermal efficiency increased with the initial moisture content. This change followed a polynomial relationship as shown in fig. (16), where the correlation coefficient was (0.99). The fitting curve gave a prediction equation as follows:

η=0.076M_{ci}^2-7.82M_{ci}+237 .... (4-2)

The previous result is due to the increasing of evaporated water with the moisture content, which leads to excessive evaporated rate. Fig (17) shows the relationship between the thermal efficiency and the moisture content at different drum speeds, while table (9) shows calculated and predicted thermal efficiencies according to equation (4-2).

Table (9): Comparison between calculated and predicted thermal at a constant drum speed.

Moisture	Calculated	Predicted	$\Delta\eta$	Error(%)
50	36	36.14	0.14	0.388
55	37.5	37.12	0.373	0.999
60	41.2	41.6	0.4	0.970
65	49.8	49.55	0.24	0.48

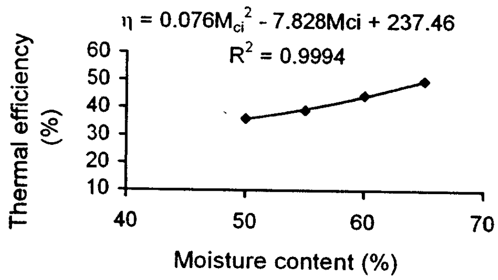


Fig. (16): Thermal efficiency as a function of the moisture content (at drum speed of 4 r.p.m)

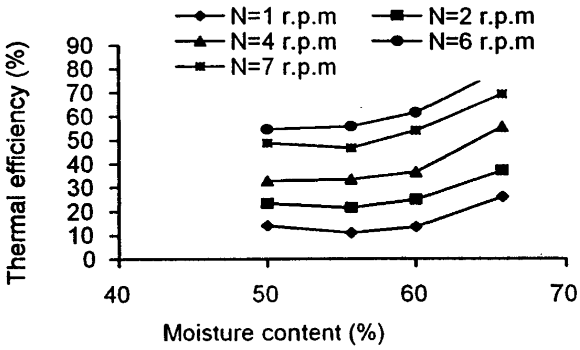


Fig. (17): Thermal efficiency as function to the moisture content at different drum speeds.

4.2 Heat Balance of the Drying System

Heat balance was carried out to determine thermal efficiency, and heat losses of the system to evaluate the performance of the system and to determine the energy required for drying. The following items were determined:

4.2.1 Overall Heat Transfer Coefficient

Overall heat transfer coefficient between the heat source (electrical heater) and the product was determined using eqs (3-8 to 3-11), then the heat transfer rate form heat source (useful energy) to the drying product was calculated.

Results showed that the overall heat transfer varies linearly with the convective heat transfer of the product as shown in fig. (18). In general, the overall heat transfer for the drum dryer system was (20-140W/m^2.°C), this results is in agreement with **(McCabe *et al.* (2001).**

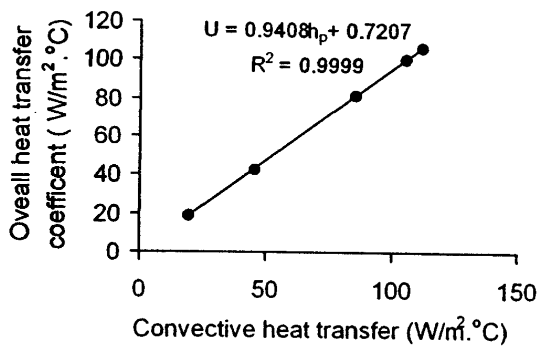


Fig. (18): Influence of product convective heat transfer over overall heat transfer.

4.2.2 Thermal Efficiency of the System

The thermal efficiency was determined according to heat balance by computing useful energy as function of the drum speed, and whey moisture content; then the thermal efficiency was computed from eq. (4-2). Table (10) shows heat transfer items used with heat balance.

Table (10): Thermal efficiency based on heat transfer [1].

Initial moisture content (50%)						Initial moisture content (65%)					
N	h_p	U	q_u	Δt	η	N	h_p	U	q_u	Δt	η
1	19	18	163	60	11	1	29	29	211	50	14.4
2	44	42	367	60	25	2	56	55	316	50	21.5
4	85	80	584	60	39	4	118	113	650	50	44.2
6	112	106	763	60	51	6	142	139	800	50	54.4
7	105	99.9	719	60	48	7	139	136	783	50	53.2

[1] **Table key words:**

N: The drum speed (r.p.m)

h_p: The convective heat transfer coefficient of the product , ($W/m^{2o}C$).

U: Overall heat transfer coefficient, ($W/m^{2o}C$).

4.2.3 Heat losses

Heat losses of each component was determined as mentioned in materials and methods using eqs. [(3-14) to (3-27)].Average losses for whole system was (50-52%).The losses source were from: the drum sides, top surface drum surface (from the scraping point to the feeding point), and with the dried product .

Results showed that the greatest loss was from the insolated drum side, then with the dried product, then from top drum surface as shown in table (11).

Table (11): Heat losses of the drum dryer (T_d=150°C, M_{ci}=50%).

Component	A (m^2)	Δtm (°C)	U_l(W/m°C)	Qloss (W)	Qloss (%)
Isolated side	0.022	127	2.5	8.5	4.5
Insolated side	0.003	127	128	48.7	25.5
Top surface	0.010	127	-	22.5	11.5
With product	-	57	-	119	58.5

4.3 Unit Productivity

Unit productivity expresses capacity to produce a dried product within a limited time. Therefore, studying factors affecting the unit productivity is necessary for good design with high productivity, and best quality of the final product.

Many factors affect the productivity including film thickness, the drying area, drum speed and the initial moisture content. In this study, the drum speed and the initial moisture content were considered. Table (12) shows the drum productivity at different operation parameters.

Table (12): The productivity of the drying unit.

M_{ci}	50%					55%				
M_{cf}	10	15	18	24	33	14	16	25	28	33
N	1	2	4	6	7	1	2	4	6	7
P(g/h)	277	666	1219	1973	2611	261	535	1100	1800	2350
M_{ci}	60%					65%				
M_{cf}	21	24	27	30	39	23	27	36	38	43
N	1	2	4	6	7	1	2	4	6	7
P(g/h)	253	526	1100	1735	2296	227	485	1090	1693	2149

4.3.1 Drum Speed Effect on Unit Productivity

A regression analysis showed high correlation (R^2=0.98) between the two parameters as shown in table (13).

As shown in fig (19), productivity increased linearly with the drum speed, due to the increasing of the feeding as a result of increasing the drum speed. Prediction of the productivity as a function of the drum speed followed linear equation as follows:

$$P=369.8N-129.85 \quad (4\text{-}3).$$

Where:

P: The productivity (g/h).

N: The drum speed (r.p.m).

Table (14) shows a compassion between predicted and calculated productivity according to eq.(4-3), and fig. (20) shows the productivity as a function of the drum speed at different moisture contents.

Table (13): Regression analysis of the drum productivity as a function of the drum speed.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.991911
R Square	0.983887
Adjusted R	0.978516
Standard	139.3162
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3555464	3555464	183.1863	0.000872
Residual	3	58227.04	19409.01		
Total	4	3613691			

	Coefficie	*Standard*	*t Stat*	*P-value*	*Lower*	*Upper*
Intercept	-129.85	125.8007	-1.03218	0.377907	-530.204	270.504
P Variable	369.7954	27.32216	13.53463	0.000872	282.844	456.746

Table (14): Comparison between a predicted and calculated productivity.

Drum speed (r.p.m)	Calculated	Predicted	ΔP	Error(%)
1	277	239.95	37.05	13.3
2	666.66	609.75	56.91	8.53
4	1219	1349.35	130.35	10.69
6	1973	2088.95	115.95	5.87
7	2611	2458.75	152.25	5.83

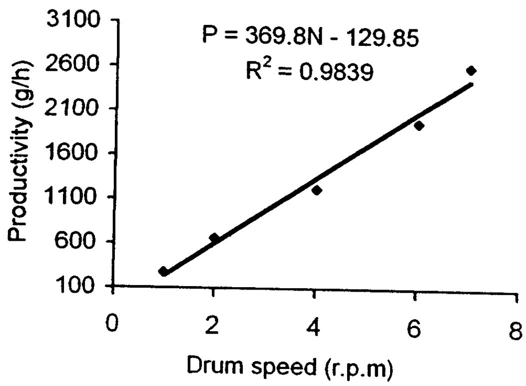


Fig. (19): Influence of the drum speed over the productivity at (M_{ci}= 50%)

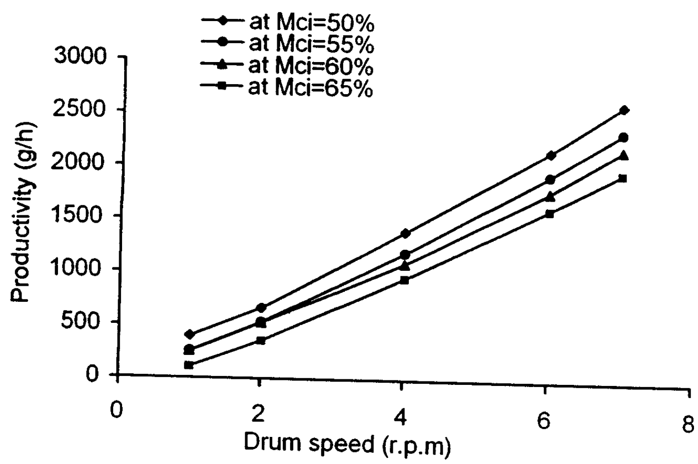


Fig. (20): Influence of the drum speed over the productivity at different moisture contents

4.3.2 Initial Moisture- Content Effect on Unit Productivity

As shown in fig. (21), productivity decreased with the initial moisture content. This relationship follows a power function at a constant drum speed (6 r.p.m). The prediction equation for the previous relationship are as follows:

$P=19159M_{ci}^{-0.5805}$ .... (4-4)

Also, fig. (22) shows the productivity as a function of the moisture content at a different drum speeds.

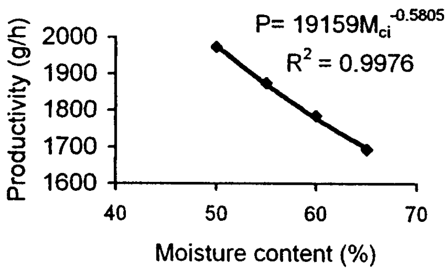


Fig. (21): The effect of the moisture content on the productivity.

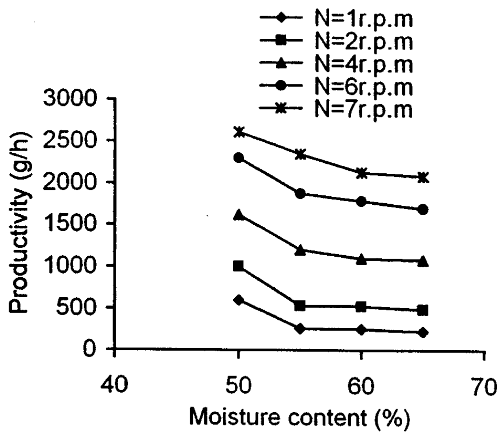


Fig. (22): The effect of the moisture content on the productivity at a different drum speeds.

4.3.3 Unit Productivity as a Function of Drum Speed and the Initial Moisture Content

As shown in fig. (19), the unit productivity as a function of the drum speed could be fitted by linear function at different moisture content as follows:

$P=a_i N+b_i$...................... (4-5), at M_{ci}=50, 55, 60, 65%.

Where:

a_i ,b_i are coefficients of regression as shown in the following table

M_{ci}	a	b
50	369.8	-129
55	344.04	-131.85
60	332.55	-138.15
65	314.69	-131.97

By drawing a_i as a function of M_{ci} as shown in fig. (23), then eq.(4-5) could be generalized:

$P= (-3.5364M_{ci}+543.61)\ N -132.74$..................... (4-6)

Table (15) shows a comparison between calculated and predicted productivities according to eq. (4-6).

Table (15): A comparison between calculated and predicted productivities.

Drum	M_{ci}	Calculated(g/h)	Predicted(g/h)	Δp	Error(%)
1	50	277	234.04	42.9	15.50
2	50	666.66	600.84	65.8	9.87
4	55	1200	1263.692	63.6	5.307
6	55	1875	1962.04	87.0	4.642
7	65	2146	2063	82.5	3.845

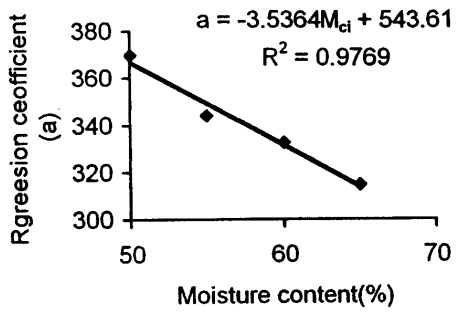


Fig. (23): Regression coefficient (a_i) as a function of M_{ci}.

4.4 Specific Energy (S.E) Requirements

Specific energy is an economical indicator expressing costs production of dried whey. Specific energy is affected by many variables such as the initial temperature of the wet material, the drum speed, and the initial moisture content of the wet material.

4.4.1 S.E as a Function of the Raw Material Temperature

As shown in fig. (24), specific energy decreased significantly linearly with the feeding temperature of the raw material, where specific energy at 40 °C was (0.75 kW.h/kg) and deceased to (0.31 kW.h/kg at 70°C).

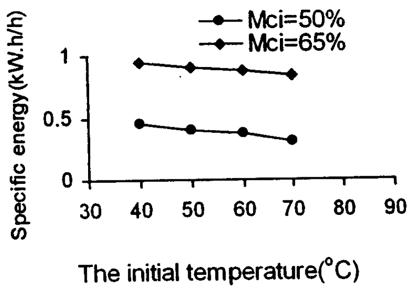


Fig. (24): Influence of the feed temperature on specific energy

4.4.2 Drum Speed Effect on S.E. Requirements

Drum speed also significantly affects the specific energy requirement, where the regression analysis showed that there is a high correlation between the two parameters (R^2=0.93).

As shown in fig. (25), specific energy decreased linearly with the drum speed, due to increasing the productivity with the drum speed, where S.E was (0.55kW.h/kg) at (1 r.p.m) then decreased to (0.266 kW.h/kg) at (7 r.p.m at M_{ci}=50). Decreasing in the specific energy is due to the increasing of productivity with the drum speed.

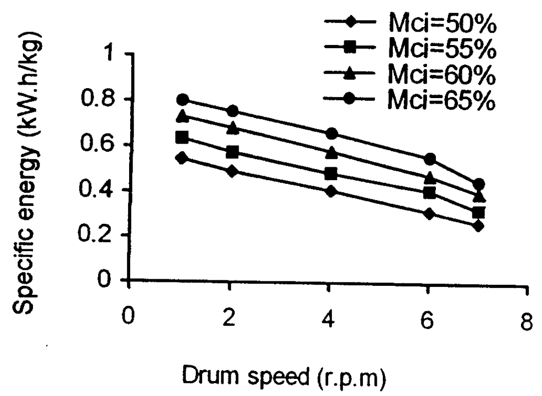


Fig. (25): The specific energy as a function of the drum speed

4.4.3 Effect Initial Moisture Content on S.E Requirements

The initial moisture content affects the specific energy, where it increased linearly with the moisture content. This is due to increasing of moisture which leads to decreasing productivity, then specific energy decreased as a result of decreasing productivity as shown in fig (26) and (27).

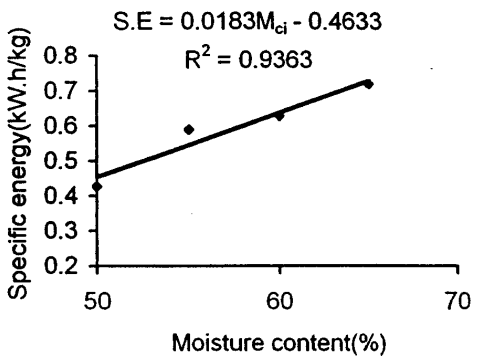


Fig. (26): Specific energy as a function of the moisture content at (N= 2 r.p.m)

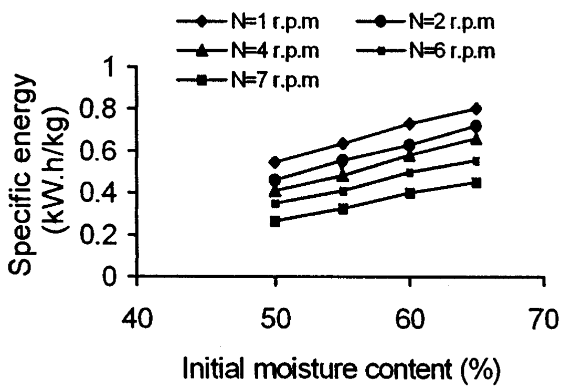


Fig. (27): Specific energy as a function of the moisture content at different drum speeds.

4.5 Drying Rate

Drying rate is affected by many processing factors such as: drying temperature, drum speed, the initial moisture content, the film thickness, and the drying surface.

4.5.1 Effect of the Drying Temperature

The drying temperature affects the drying rate through supply the required latent heat of vaporization. The drying rate increased linearly with the drying temperature as shown in fig. (28). This is due to increasing heat energy transfer rate to the product film temperature.

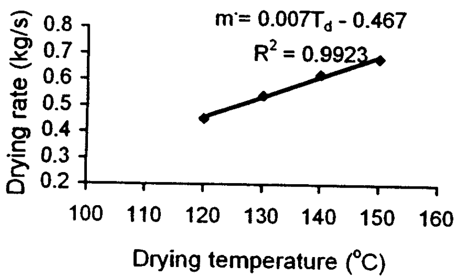


Fig. (28): The drying rate as a function of the drying temperature

4.5.2 Drum Speed Effect on the Drying Rate

The drum speed affects the drying rate, where it increased with the drum speed in the range of (1 to 6 r.p.m), then the drying rate started to fall down as shown in fig. (29). The previous results are due to increasing of the drying rate. Beyond this range, if [(N>7r.p.m) = (0.062 m/s)], the drying feed becomes large, where the heater capacity cannot remove the additional water.

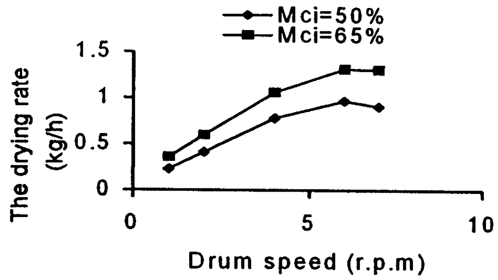


Fig. (29): The effect of the drum speed on the drying rate.

4.5.3 Initial Moisture Content Effect on Drying Rate

The initial moisture content affected the drying rate, where the drying rate increased from (0.46 kg water/kg.DM at M_{ci}=50%) to (0.76 water/kg.DM at M_{ci}=65%). This increase is due to increasing the amount of water present in the raw material as shown in fig. (30).

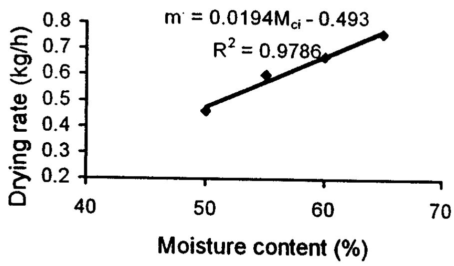


Fig. (30): the effect of the initial moisture content (M_{ci}) on the drying rate.

4.6 Final Product Quality

Specification of the final product includes: moisture content, density, and the chemical analysis, as follows:

4.6.1 Final Moisture Content

The final moisture content of the dried product is an important property of the dried material, especially with a high hygroscopic property.

Dried whey contains (40 to 70%) lactose; this property requires reducing the final moisture content of the dried material to the moisture content storage for of (3 to 10%). The final moisture contents of the dried material depend on many factors such as: drying temperature, the drum speed, and the initial moisture content of the raw material. Table (16) shows the final product moisture content at different operation parameters.

Table (16): The final moisture content (%).

M_{ci}	50%					55%				
M_{cf}	10	15	18	24	33	14	16	25	28	33
N	1	2	4	6	7	1	2	4	6	7
M_{ci}	60%					65%				
M_{cf}	21	24	27	30	39	23	27	36	38	43
N	1	2	4	6	7	1	2	4	6	7

4.6.1.1 Effect of Drum Speed on Final Moisture Content

Fig. (31) shows the relationship between the final moisture content of the product and the drum speed .As expected, the final moisture product increased linearly with drum speed due to decreasing the residence time with the drum speed. Fig (32) shows the final moisture content of the product as function of the drum speed at different conditions of the initial moisture content.

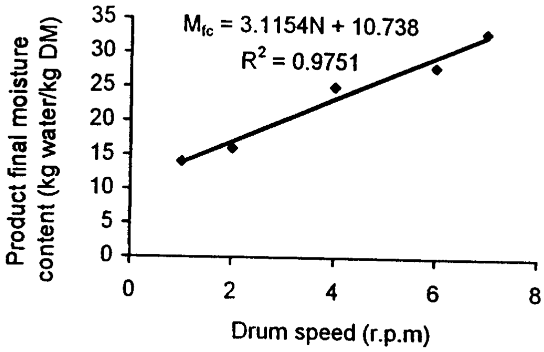


Fig. (31): Influence of the drum speed on M_{cf} content at M_{ci}=55%.

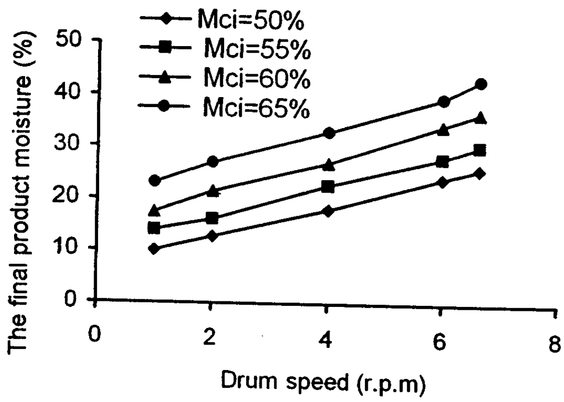


Fig. (32): Influence of the drum speed on M_{cf} at different M_{ci} at a constant drying temperature (T_d=150°C).

4.6.1.2 Relation of Initial to Final Moisture Contents

There is a linear relationship between of the product final moisture content and the initial moisture, where the product final moisture content decreased with the initial moisture content as shown in fig. (33).

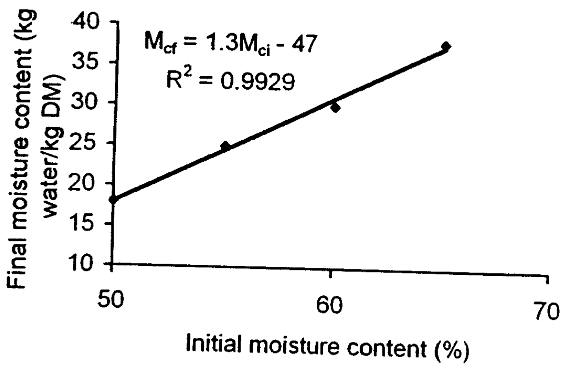


Fig. (33) Influence of M_{ci} over M_{cf}.

4.6.1 3 Effect of the Drying Temperature on the Final Moisture Content

The final moisture content decreased with increasing the drying temperature as shown in fig. (34).

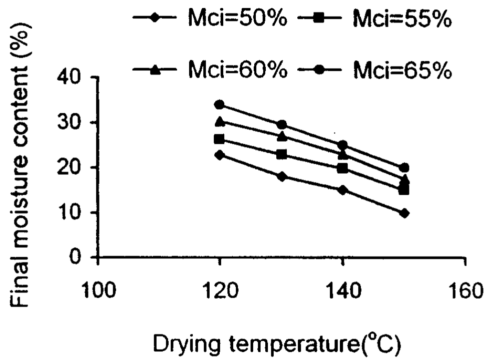


Fig. (34): Influence of the drying temperature over the final moisture content.

4.6.1.4 Influence of the Initial Moisture Content and Drum Speed on M_{cf}.

As shown in fig. (32) the relationship between the final moisture content and the drum speed at a different value of the initial moisture content could be fitted as a linear function as follows:

$M_{cf} = a_i N + b_i$, at M_{cf} =50, 55, 60, 65%

Where :

a_i ,b_i are coefficients of regression as shown in the following table:

M_{ci}	a	b
50	3.4381	6.495
55	3.2356	10.491
60	3.0343	15.561
65	3.2804	20.515

By drawing a_i as a function of M_{ci} as shown in fig .(35) then the eq. could be generalized:

M_{cf}=(0.00045M^2_{ci}-0.5299M_{ci}+18.729) N+13.2655 ....(4-7)

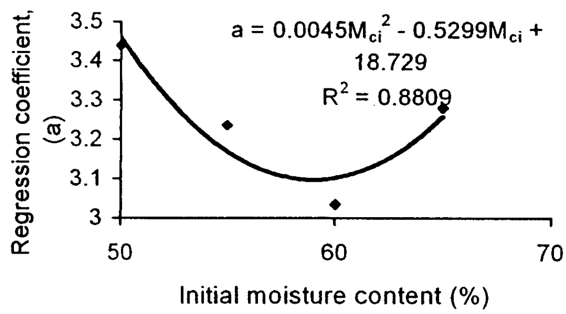


Fig. (35): Regression coefficient, (a_i) as a function of the M_{ci}.

4.6.1.5 Estimating of M_{cf} from Measuring the Final Product Temperature .

As reported by **Rodriguez and Coutois (1996)$_{(b)}$** we could predict the final moisture content as a function of the product temperature as shown in fig. (36).

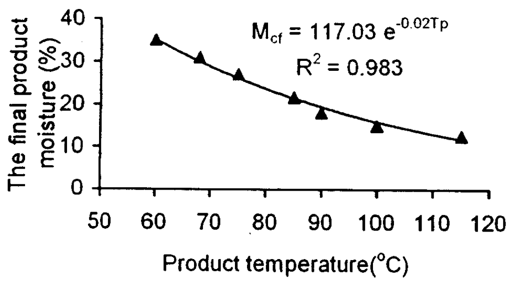


Fig. (36): Relationship between the product temperature and final moisture content.

4.6.2 Product Final Density

Density of the dried product is an important physical property affecting storage capacity, and is important in feeding of calves as milk replacer where the whey should in a suspension form.

Results showed that there is a strong relation between the product density and the drying temperature as shown in fig. (37), where the product density decreased with increasing of the drying temperature. Product density was in the ranged (0.469 to 0.498g/cm^3), where values of density are correspond with the international standard of granular whey. Fig. (38) shows the relationship between the final solid content and the product density.

4.6.3 Chemical Analysis

Chemical analyses were carried out according to **AOAC (1990)** in the Central Lab. of the Fac.of Agric. Ains –Shams Univ. Results analysis are shown in table (17).

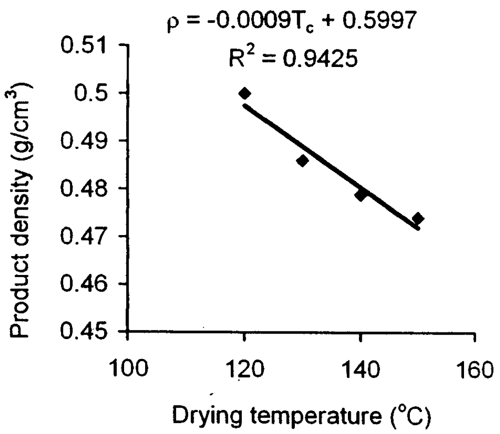


Fig. (37): Product density as function of the drying temperature.

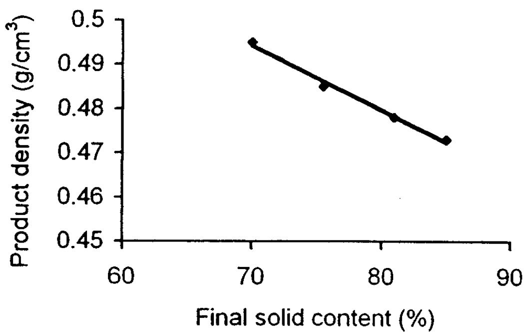


Fig. (38): Influence of final solid content over the product density.

Table (17): Chemical analysis of dried product with the addition of 10% ground soybeans to the concentrated whey.

Total solids(T.S %)	M_{cf}%	Protein %	Lactose %	Ash %
75	25	12.5	58.29	5
80	20	13.5	62.17	6.06
82	18	14.3	63.5	6.20
88	12	16.3	68.39	6.65
90	10	16.7	70.2	6.90

4.7 Economical Costs

Economical costs were evaluated at optimum operation after drawing operation curves. They included productivity, drum speed, and final moisture content as shown in fig.(39). Optimum operation was determined by choosing the point achieving practical operation the productivity, thermal efficiency, and the quality of the final product.

Parameters according to the chosen operation point were (M_{ci}= 50% , P = 1100g/h, M_{cf}= 18% and η = 41.5%). Then the cost of dried-unit mass was determined according **(Awady, 1978).**

Costs analysis showed that the cost of dried unit-mass was (5.5LE/kg dried material). This cost doesn't include grinding, packing and flavors additive. It is very low compared with the international prices (12.5$/kg). Table (18) shows a summary of the machine construction costs.

Table (18): Machine construction costs of the drum dryer.

Material	Cost (LE)	Quantity	Total
Stainless steel drum of(170 mm Dia. x300 Length)	110	1	110
Feeding roller of 50 mm Dia.	50	1	50
Motor of 220V, 0.35kW.	200	1	200
Speed reduction 1:20	250	1	250
Heater	110	1	110
Temperature regulator	30	1	30
Elec. instrumentation	20	2	40
Accessories (gears, pulleys, belts ,chains , sprockets			280
Labor workmanship			150

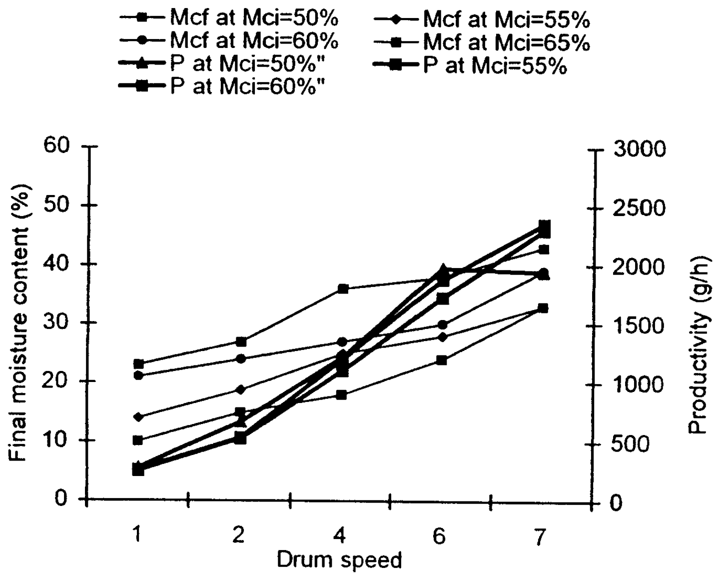


Fig. (39): The operation curves of the drum drier.

4.8. Sensitivity Analysis of Whey Drying Costs

A sensitivity analysis was performed to identify whey drying cost parameter that have the greatest effect on model drying costs prediction. A prediction model of total costs as a function of productivity and the initial moisture content separately were derived from experimental data as shown in figs. (40) and (41). Absolute and relative sensitivity coefficients were defined as follows:

$S_a = dTC/dP$.

$S_r = S_a.P/TC$

Where:

S_a: Absolute sensitive (output units/ input units).

S_r: Relative sensitivity (dimensionless).

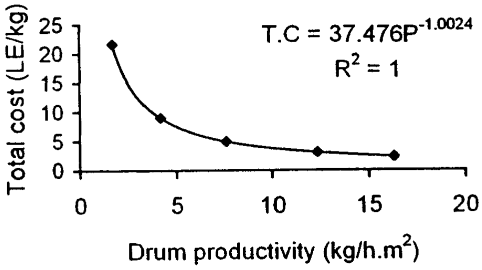


Fig. (40): Total costs of the drum dryer as function of the drum productivity.

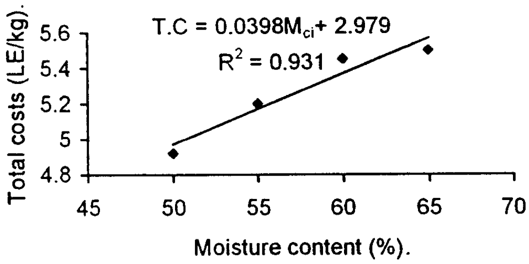


Fig. (41): Total costs of the drum dryer as function of the initial moisture content.

Sensitivity analysis as shown in table (19), showed that productivity, had highest relative coefficient of (–1.15) compared with of (0.36) for moisture content.

Table (19): Sensitivity coefficients

Parameter	Average value	Units	S_a	S_r
Productivity	0.309	kg/h	-3.72	-1.15
Moisture content	60	%	0.036	0.36

4.9 General Theory of Drum Dryer Unit Design and Operation

Dimensional analysis is a useful tool for developing a predictive model of design and operating a drum dryer unit.

The first step in dimensional analysis is to identify physical quantities that are pertinent to the system that is to be studied

According to Buckinghams'pi-Theorem, **(White,1986)** the number of physical quantities is reduced by the number of basic dimensions involved among the physical quantities ,then the physical quantities are combined into groups where ,the number of groups are:

(π = m-n) where, **(m)** is the number of physical quantities and(**n**)is number of basic dimensions pertinent of the drum dryer unit operation, which is a function of: design variables, operation variables, and material variables.

For dimensional analyses, the pertinent quantities with basic dimensions in terms of mass (M), length (L), time (τ); energy (Q) and temperature (θ) are listed in table (20).

Table (20): Pertinent quantities in the drum dryer unit dimensional analysis.

Symbol	Description of quantity	Units
	Geometry	
A	Drying area =.(πd).L	L^2
	Material	
ρ	Initial density	M/L^3
M_r	Moisture ratio	(-)
C_p	Specific heat of raw material	Q/ M.θ
	Operation	
P	Productivity	M/ τ
q	Energy requirements	Q/ τ
N	Rotational speed	1/ τ
U	Overall heat transfer coefficient	Q/L^2 θ
h	Latent heat	Q/ kg

1- Productivity groups

Drum productivity is function of the following functional relationship:

$$P = f(A, \rho, M_r, h, q, N)$$

Application of Buckingham (Pi) theorem **(White, 1986)** in dimensional analysis resulted the following dimensional variable Pi groups:

$\pi_1 = q / (p.h)$
$\pi_2 = p / (A^{1.5} .\rho.N)$
$\pi_3 = M_r$

$\pi_1 = f(\pi_2, \pi_3)$

As shown in fig. (42) productivity as a function of the drum speed could be fitted by a liner function as follows:

$\pi_1 = a_i \pi_2 + b_i$., For [π_3 = 0.33, 0.36, 0.44, 0.47 %]
Where: a_i, bi coefficient regression.
or:
$[q/(p.h)] = a_i[p/(A^{1.5} .\rho.N)] + b_i$, for [$M_r$=0.33, 0.36, 0.44 , 0.47] (4-8).

Coefficients regression as shown in the following table.

Moisture content (%)	a_i	b_i
0.33	-0.0023	0.0010
0.36	-0.0023	0.0009
0.44	-0.0020	0.0008
0.47	-0.0018	0.0005

Assuming coefficient regression (b_i) varies linearly with M_r ,then eq.(4-8) could be generalized as:

$q/ph = [-(0.002).(P)./(A^{1.5}.\rho.N)] + [0.0019M_r + 8E\text{-}5]$ .... (4-9)

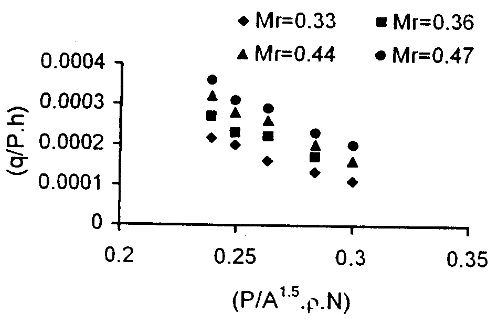


Fig. (42): Productivity as a function of drum speed for different initial moisture content.

2- Energy group

Drying energy requirements is function of the following functional relationship:

$q = f(A, \rho, m^{\cdot}, M_r, U, h, C_p)$

The dimensional analysis resulted the following dimensional variable Pi groups:

$\pi_1 = q/(m^{\cdot}.h)$
$\pi_2 = (U.A)/(m^{\cdot}h)$
$\pi_3 = M_r$
$\pi_2 = f(\pi_1, \pi_3)$

As shown in fig (43) drying energy requirements a function of heat and mass transfer properties could be fitted by a liner function as follows:

$\pi_2 = a_i\,\pi_2 + b_i$., For $\pi_3 = Mr = [0.33, 0.36, 0.44, 0.47]$ ....(4-10)

Assuming coefficient regression a_i, b_i varies linearly with M_r, then, eq.(4-10) could be generalized as:

$[(U.A)/(m^{\cdot}C_p)] = [q/(m^{\cdot}.h)].[-83.3M_r+80] - [8.625]$. (4-11)..

Coefficients regression as shown in the following table:

M_r (%)	a_i	b_i
0.33	52.17	-7.26
0.36	50.41	-9.947
0.44	44.7	-9.088
0.47	40.19	-8.6809

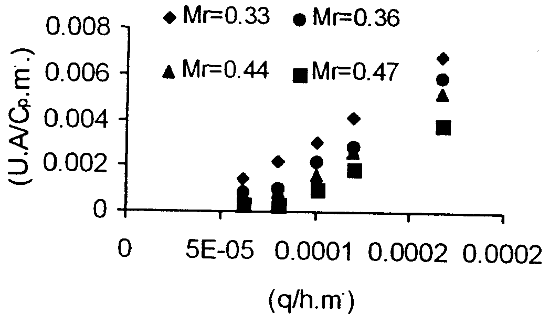


Fig. (43): Drying energy requirements as function of the heat and mass properties.

4.10 Pelleting Unit Results

This study was carried out to investigate the possibility recycling of concentrated whey as a binder material to produce durable and hard pellets, and to study the effect of whey percent in pellet mixture on the quality of pellets and on the machine productivity.

4.10.1 Concentrated Whey as Binder in Pelleting Manufacture

Pellet binders offer a viable solution to have hard and durable pellets that guarantee uniform products, better-feed conversion and reduction of feed losses.

Results showed the concentrated whey might be used as binder in pelleting manufacture, where it improved the mechanical and chemical properties of pellets.

4.10.2 Pellet Quality

Factors that influence pellet quality can be divided into several categories. It is generally agreed that the formulation is, by far, the most important factor affecting pellet quality. Therefore, this study was carried out to evaluated the effect of concentrated whey as a binder on pellets quality produced from (soybeans and corn), and on the pelleting machine productivity.

Pellet quality can be evaluated by measuring the bulk and unit of dried pellets densities; durability index (PDI) and the hardness under some processing conditions such as: the percent of a binder (concentrated whey), the forming dies and auger speed, where physical pellets-quality plays the main role in storage, and handling of pellets.

4.10.2.1Bulk Density

Bulk densities of all experiments on corn mixture were determined at loose-fill condition as according to **ASAE (2003).**

Results showed that bulk densities were between (715 to 790 kg/m^3), where the highest density was at (5 mm), then (8 mm) and (10 mm) of pellets diameter Fig. (44) shows a bulk density as a function of whey percent

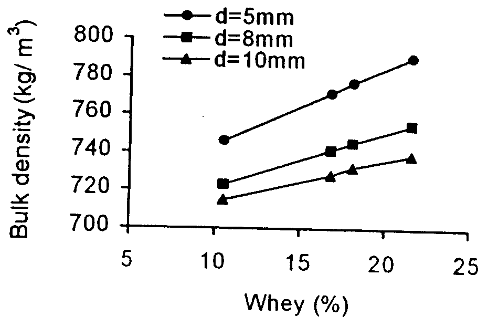


Fig (44): Bulk density at a different pellet diameter.

4.10.2.2 Pellet Unit-Density

As shown in fig. (45), pellet unit density behaves like bulk density as a function of concentrated whey, where pellet unit density increased with increasing of whey percent for all forming dies used in the experiments.

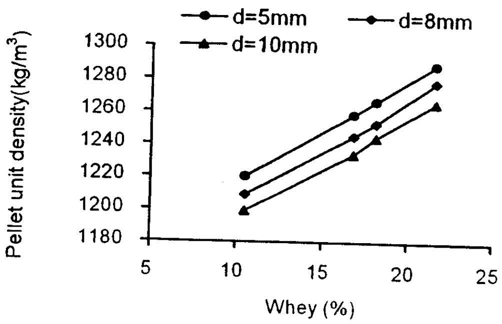


Fig. (45): Pellet unit density as a function of whey percent at different die diameters.

4.10.2.3 Pellet Durability Index (PDI)

Durability test was carried out to predict the amount of fines produced during handling pellets before feeding time.

As shown in fig. (46), pellet durability increased with increasing concentrated whey due to increasing the cohesion between mixture particles, as a result of increasing the lactose percent in whey concentrate .Durability Index was 76% at whey percent=10.5%, then increased to 89% at whey percent=21.2%for d=10mm .

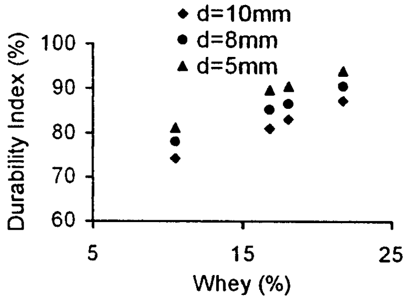


Fig. (46): Pellet durability index at different forming pellet diameters.

4.10.2.4 Effect of Whey Percent and Forming Diameter on PDI

As shown in fig. (46), durability as a function of whey percent at different forming die diameters could be fitted by a linear relationship as follows:

$PDI= a_i w_p+b_i$ at d=[5, 8,10mm] .... (4-11)

Where:

a_i, b_i are regression coefficients, values of a_i, b_i as a function of forming dies diameters are shown in the following table.

Coefficients regression for eq. (4-11).

Dies diameter (mm)	a_i	b_i
5	1.28	63
8	1.15	65
10	1.18	65

By drawing a_i as a function of pellets diameter as shown in fig. (47), then eq. (4-11) could be generalized as follows:

PDI= $[0.0109d^2-0.1833d+1.9288]$ w+64.54% ....(4-12)

where: the diameter range is [5 to 10 mm], and the whey percent [w=10 to 25%]. Table (21) shows comparison between calculated and predicted of DIP according to eq.(4-12)

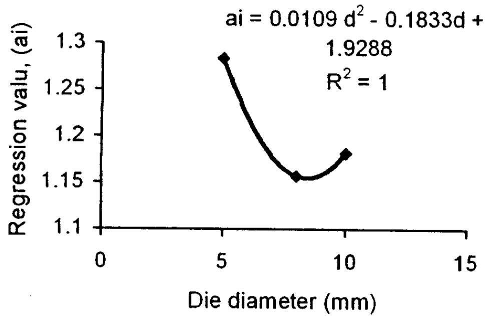


Fig. (47): coefficient regression of eq (4-11). as function of d.

Table (21): Comparison between calculated and predicted (DPI) according to eq.(4-12).

D (mm)	W (%)	DIP (%)	DIP (predicted)	ΔDIP	Error %
5	10.2	79	77.64	1.35	1.71
8	10.2	78	76.37	1.62	2
10	10.2	76	76.6	0.61	0.8
5	21.2	92.5	91.7	0.72	0.78
8	21.2	90.5	89.13	1.36	1.51
10	21.2	89	89.67	0.67	0.76

4.10.2.5 PDI as a Function of Pellets Moisture Content

As shown in fig. (48), pellet durability is affected by the degree of drying where, the durability increased with decreasing of final moisture content. This relationship followed a linear decreasing model.

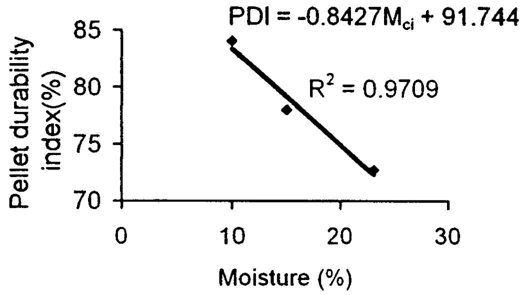


Fig. (48): Pellet durability as a function of the final moisture content.

4.10.2.6 Hardness of Pellets

Hardness implies the ability of a body to resist abrasive deformation. The hardness degree of food material may be described as soft, firm, or hard to touch or eating.

As shown in fig (49), pellet hardness increased linearly with the percent whey, where in the range of (w=10.5 to 21.2%), the hardness was 1.52 at w=10.5 increased to 2.6 at w= 21.2%, where the increase reached to 40% at a constant forming pellet diameter (d= 5mm).

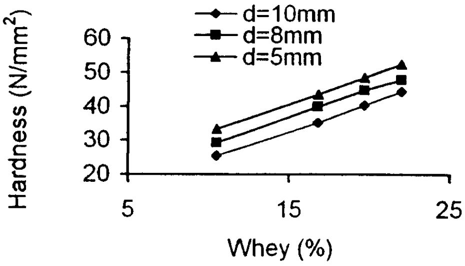


Fig. (49): Influence of whey percent over the pellet hardness.

4.2.2.7 Effect of Whey Percent and Forming Diameter on Hardness

As shown in fig. (49), the pellet hardness as function of whey percent at a different pellet forming dies could be fitted by linear function as follows:

$H_M = a_i w + b_i$, at d=[5,8,10mm]..(4-13)
Where: a_i, b_i are regression coefficients. Values of a_i, b_i as a function of forming dies diameter are give in the following table:

Coefficient regression of eq.(4-13).

Dies diameter(mm)	a_i	b_i
5	0.106	0.451
8	0.101	0.36
10	0.096	0.32

By drawing of ai as a function of forming diameter as shown in figs. (50) and (51), eq.(4-13) could be generalized as follows:

H_M= [-0.0023d+0.1184] w-0.0242d+0.5669.......................(4-14)

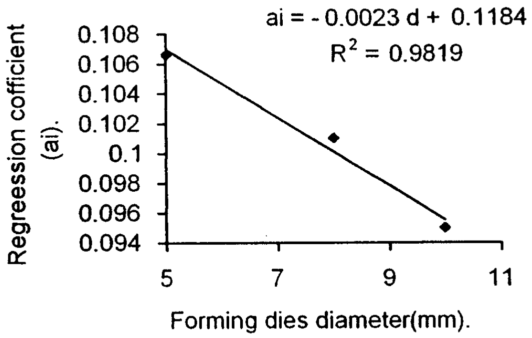


Fig. (50):Regression coefficient (a_i) as a function of forming dies dia. for eq.(4-13).

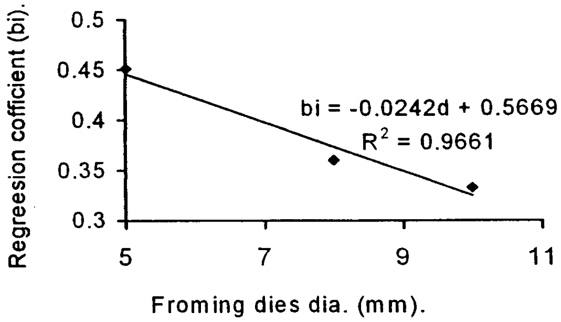


Fig. (51): Regression coefficient (bi) as a function of forming dies for eq.(4-13).

4.10.3 Machine Productivity as a Function of Whey Percent

Experiments were carried out to show the effects of adhesion and cohesion because of binding extend on machine productivity.

Results showed that unit productivity was affected significantly by whey percent, where productivity decreased with whey percent for all forming dies .It decreased by (61%) when whey increased by (60%) at the same diameter.

The pervious results are due to increasing of cohesion between particles whey, and for increasing of adhesion between mixture and shell of extruder.

The increasing of cohesion and adhesion with the whey percent is due to increasing of lactose in whey .The increasing of cohesion and adhesion cause many problems during pelleting process such as: friction and difficulty of flow of mixture. Productivity decreased by whey percent as shown in fig.(52).

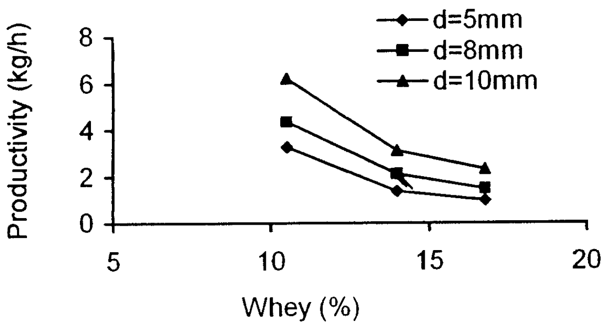


Fig. (52): Productivity of pelleting machine.

4.11 Economical Comparison between Whey Recycling into Powder and Pelleting

Drying results showed that for producing one kilogram of whey powder of (5%) final moisture content needs (20 kg) fresh whey of (6%) solid content.

Cost analysis showed that the whey powder might sell in local market by (12 LE/kg) compared with international prices (80 LE/kg). The local price gives a net return of (0.6 LE) per kg of waste whey.

Pelleting results showed that in order to produce one kilogram pellets of (40%) corn, (20%) soybeans, and (40%) whey of (60%) moisture content need to (3.5) kg fresh whey .By assuming the pellet price in local market is (2.5LE/kg), this leads to a net return of (0.33LE/kg) per kg of waste whey.

From the above analysis, it is found that recycling of whey into powder is more economically feasible than recycling it in pelleting for feed. The drying process needs special technology and capital cost compared with pelleting.

V - SUMMARY AND CONCLUSION

This research was carried out to study the possibility of recycling of dairy residue (whey) in food and feed industry using two agricultural engineering unit operations: the drying unit and the pelleting unit as follows:

Drying Unit

This unit was specifically designed, constructed, and evaluated at Fac.of Agric, Ain-Shams Univ. This unit was used to study factors affecting recycling whey from liquid to solid form by the drying to facilitate transportability, handling; and storage process in suitable conditions for subsequent use, since whey liquid requires specific storage and transport; which are uneconomical .

The performance of the drying unit (productivity, thermal efficiency, specific energy, drying rate, and cost), and the quality of the final product (final moisture, density, and chemical analysis) were evaluated as functions of the drum speed, the drying temperature and properties of the concentrated whey (initial moisture content, density, and thermal properties).

Results showed that there is a significant relation between operation parameters and the performance of the drum dryer unit and product quality as follows:

Thermal Efficiency

Thermal efficiency increased with the drum speed until reaching peak point (η = 53%) at (M_{ci} = 55%, N = 6. r.p.m), then began to fall down. Thermal efficiency also changed significantly with the initial moisture as shown from the regression analysis. This changing followed a polynomial relationship. The thermal efficiency corresponded with the optimal working conditions [(M_{ci} = 50 to 55%, drying temperature of (140 to 150°C)] and the drum speed of (4 r.p.m)] was (41.5%).

Productivity

Productivity increased linearly with the drum speed, due to the increasing of the feeding rate, while it decreased with the initial moisture content. This relationship followed a power function.

Productivity relation to drum speed and initial moisture content is as follows:

$P = (-3.5364M_{ci}+543.61)\ N-132.74.$

In general, optimal productivity corresponded with working conditions [(M_{ci} = 50 to 55%, drying temperature of (140 to 150°C) and the drum speed of (4 r.p.m)] was (1100g/h).

Drying Rate

The drying rate increased linearly with the drying temperature. This is due to increasing the energy rate to transferred the product bed. Also, the drum speed affected the drying rate, where it increased with the drum speed in the range of (1 to 6 r.p.m), then started to fall down.

Beyond (N>7r.p.m), the drying feed becomes too large, where the heater capacity cannot remove the additional water.

Also, the initial moisture content affected the drying rate, where it increased from (0.46kg water /kg.DM at M_{ci} = 50%) to (0.76 water /kg.DM at M_{ci} = 65%). This is due to the amount of water present in the raw material.

Specific Energy

The specific energy decreased linearly with the drum speed, where the specific energy was (0.55 kW.h/kg at 1 r.p.m) then decreased to (0.266 kW.h/kg at 7r.p.m), and increased with the feeding temperature, where at 40°C a specific energy was (0.75kW.h/kg) then decreased to (0.31 kWh/kg) at 70°C.The specific energy decreased linearly with he initial moisture content.

Product Quality

Product quality includes (density, final moisture content, and the final chemical analysis). Product density was in the range of (0.469 to 0.498g/cm^3), in agreement with the international standard of granular whey. It decreased with increasing of the drying temperature.

The final moisture content decreased with the drying temperature and increased with the drum speed. The final moisture content, as a function of the drum speed and the initial moisture content at a constant drying temperature (140 to 150 ^{o}C) is as follows:

$$M_{cf} = (0.00045M^2_{ci} - 0.5299M_{ci} + 18.729)\, N + 13.2655.$$

Economical Cost

Costs analysis were carried out according **Awady to (1978)** at optimum operation of (M_{ci}= 50%, P= 1100g/h, M_{cf} =18% and η= 41.5%).

Costs analysis showed that the cost of dried unit mass was (5.5LE/kg dried material), where the costs don't include grinding costs, packing costs and flavors additives. This costs are too low compared with the international prices (12.5$/kg dried).

Also, analysis sensitivity showed that productivity, had highest relative coefficient of (–1.15) compared with of (0.39) for moisture content.

General Theory for Design and Operation Drum Dryer Unit

Variables affecting the drum dryer unit performance were combined into dimensionless groups to establish a general theory for design and operates such as these units, the general equations for design and operates the drum dryer as follows:

$$q/ph = [-(0.002).(P)./(A^{1.5}.\rho.N)]+[0.0019M_r+8E\text{-}5].$$

$$[(U.A)/(\dot{m}C_p)] = [q/(\dot{m}.h)].[-83.3M_r+80]-[8.625].$$

Pelleting Unit

This unit was used to study the possibility of recycling of whey in animal feed as a binder in pellet manufacturing. The effects of whey percent as binder material, and the forming dies on the mechanical handling and storage properties such as (durability, hardness, density), and the productivity of the pelleting were studied as follows:

Pellet Durability

Pellets produced were durable enough for marketing .Pellet durability index (PDI) was (76 to 92.5%) in all forming conditions.

Durability increased with whey percent due to increasing of particle cohesion and lactose percent and protein presence. Also, durability decreased with increasing of pellets diameter, due to the decreased of forming pressure with large diameters.

Durability increased with the final moisture content. It increased by 15% when the final moisture content decreased from 23% to 10%.

Pellet Hardness

Hardness increased with whey percent, but decreased with the pellet diameter .Pellets hardness was (1.26 to 2.65N/mm^2), which is considered a medium hardness.

Pellet density

Results showed that bulk density was between (715 to 790 kg/m^3), where the highest density was at 5 mm, then 8, and 10 mm pellet diameter. Bulk density increased with the whey percent.

Unit density behaves like bulk density, as a function of concentrated whey, where the pellet unit density increased with the whey percent for all forming conditions.

Pellet- Unit Productivity:

Productivity is affected by the whey percent and the diameter of the pellets, where the forming diameter effect productivity, where productivity was (3.27kg/h) at [d= 5 mm and w= 10.5%] increased to (6.2kg/h) at [d= 10 mm and W= 10.5%]. However, productivity decreased with the whey percent, from (3.27kg/h) at [d=5mm and w= 10.5] d to (1.34kg/h) at [w= 14%. and d= 5 mm].

Economical Comparison between Whey Recycling into Powder and Pelleting

Costs analysis of drying process and pelleting manufacturing results showed that recycling of whey into powder is more economically feasible than recycling it in pelleting for feed, the drying process needs special technology and capital cost compared with pelleting, where a net return from drying was (0.60 LE/kg) per kg of waste whey, and a net return from pelleting was (0.33 LE/kg) per kg of waste

Recommendations

1- The drum dryer is suitable unit for recycling of whey from liquid form to solid form

2- The drum dryer unit may be scaled up for industry production, according the following condition

A- the drying temperature (140 to 150°C).

B- the drum speed for 4r.p.m is (0.035 m/s).

C- the initial moisture content (50 to 55%).

D- time reduction until scraping not more than13.5 second.

3- Concentrating whey is a good binder; may be used in pelleting manufacture.

4- The optimum whey percent as binder gives durable pellets and high productivity in the range (10 to 15%) as solid content.

5- Recycling of whey into powder is more economically feasible than recycling it in pelleting for feed.

New scientific contributions

A- Establishing a general theory for design, operating factors, and product quality of whey drum-drying. The final results are given in given in dimensional form in the following:

1- $q/ph = [-(0.002.(P)./(A^{1.5}.\rho.N)]+[(0.0019M_r)+(8E\text{-}5)]$

2- $[(U.A)/(m^{\cdot}C_p)]= [q/(m^{\cdot}.h)]. [-83.3M_r+80] - [8.625]$

B- Indging the comparative feasibility for whey recycling between addition as binder in pelleting manufacture and drying

Results showed that recycling of whey into powder is more economically feasible than recycling it in pelleting for feed, where a net return from whey drying was (0.6 LE) per kg of waste whey compared with net return of (0.33 LE/kg) per kg of waste whey from pelleting manufacture.

VI - REFERENCES

Awady, M.N. (1978). Engineering of tractors and agricultural machinery, Txt. Bk., in Arabic, Col. Agric., Ain–Shams Univ.: 164-167.

Awady, M.N. (2002). Pollution and its economical effects, (In Arabic), Misr J. of Ag.Eng.19 (1): 1-3.

Awady, M.N, El-Sahrigi, A.F., and Watfa, Y.A. (2002). A study on design factors related to plant residues forming machines, Misr J.of Agri.Eng.Vol.19 (4): 1-15.

Abou Akkada, A.R., Khalil, A., Kosba, M.A. and Kalifah, M.M. (1975) Effect of feeding residues of tomato canning on the performance of laying hens. Alex., J.Agric.Res.23(1):9-14.

Aboud, A.J. (2001). A study on some engineering factors affecting the design of an animal feed processing system, M.Sc.Th., Fac.of Agric.Ain Shams Univ.: 74-75.

Ammernan, C.B. and Henry, P.R. (1980). Citrus and vegetable products for ruminants animals, Dept.of Animal Sci. Univ. of Florida, (unpublished).

AOAC. (1990). Official methods of analysis of the Association of Official Analysis Chemists, 5^{th}, ed. by Kennen Helrich, Ames.: 69-91.

AOAD. (1997) Study of technical and economical, Evaluation for agricultural residues crops. (Arab Organization for Agricultural Development), Sudan-Khartoum: 1-31.

Arora, C.P. (1989). Heat and mass transfer,3^{rd} ed., Khanna pub.Delhi:245-246.

ASAE. (2003). Standard engineering practices data .ISBNO 54-14360 library of Congress by the American Society of Ag. Eng.: 567-569.

Batty, J. C., and Folkmans, S. (1983) Food engineering fundamentals, John Wiley & Sons-Inc, Ames.: 235-250.

Behnke, K., C. (2001). Processing factors influencing pellet quality, Feed Tech, vol.5, Nr4, South Africa: 1-15.

El-Boushy, A.R.y., and Vanderpoel, A.F .B. (1994). Poultry feed from wastes, processing and use. Champan & Hall, UK. : 1-30,125,188-340.

Brennan, J.G., Butters, J.R., Cowcll, N.D., and Lilly, A.E.V. (1990). Food engineering operation, Elsevir. Applied Sci., England: 391-401.

Bylund, G. (1995) Tetra Park Processing System (Hand Book) Ch15, Ch,17.AB, S-22186 Lund, Sweden:331-350,361-373.

Caric, M. (1994). Concentrated and dried dairy products, Ch5 ,V.C.H. Pub.,Inc.:57-163.

Carl, w. and hall,P.E. (1980) Drying and storage of agriculture crops, AVI Pb.Co.Inc.:258-289.

Church, D.C. and Pond, W.G.(1988). Basic animal nutrition and feeding, 3rd, John Wiley &Sons.Ch21.

Clapp, H.J. (1990). Starting the dairy calf, Division of Agricultural and Rural , MOA. and Food, Canada.

Crickenberger, R.G. and Carawan, R.E. (1996) Using food processing by-roduct for animal feed .North Carolina Coope. Exte., Pub.

Deleeuw, P.N. (1997). Crop residues in tropical trend in supply, demand and use (Ch3) .In crop residues in stainable mixed crop livestock farming systems, ed. Renard, C., CAB Inter. ,Wash..:41-63.

Devendra, C., and Reddy, M.R. (1988). Complete ration based on fibrous agricultural residues for ruminants .Proc .of non –

conventional feed resources and agricultural residues. corn in Llisar,India,21-29 March: 94-111.

Dobie, J.B. (1959). Engineering appraised of hay pelleting. Agric.Eng.: 40,76-93.

Doyle, J. and J.C.F. Walker. (1985). Indentation hardness of Wood and Fiber Sci.17(3): 369-376.

.FAO (2000). Production Yearbook, UN-FAO, Rome. Vol.54, P: 245.

Fisher, L.J, and Buckley, W.T. (1985). Effect of feeding a concentrating whey-canola meal mixture as the major component of starter ration for calves ,Can.,J.Anim.Sci.:65-683.

Gillespie, J. R. (2002). Modern livestock and poultry production, 6th ed., Ch36 , Delmar Thomson Learning, Ame.:738-823.

El-Hag, M.G., El-Shagi, K.M., Khangeri, H. H. (1999). Utilization of date by products and fish sardines as feed for ruminants and poultry.J.of Arab Ag. Res., ed, AOAD, vol(3) : 151-171

Harvey, W. C., and Hill, H. (1999). Milk production ، pb .Biotech Books, 2nd , India, ChV. : 282-319

Helally, E.A. (1986). Feeding materials and preparation, Txt., Bk., in Arabic, El-Anglow El-Massrea Lib. Egypt.:139-140

Henderson, S.M., and Perry, R.L. (1975) Agricultural process engineering, John Whiley & Sons, INC, NY.: 302-339.

Heng, K .A. (1996) Utilization of agricultural by-products in Taiwan ,Chun Station, Taiwan Livestock ,Res. Ins., Taiwan, (unpublished.).

Hulan, H.W. Proudfoot, F.G., and Zarkadas, C.G. (1982). Potato waste meal. The nutritive value and quality for broiler chicken, Can.J.Anim.Sci.62, 1171-80.

Ismail, S.H. (2000). Nonconventional feedsuffs in feeding of animals and poultry, Txt. Bk., in Arabic, Int. Cairo, Egypt. :36-65.

Incopera, F. P., and Dewitt, D.P. (1996). Introduction to heat transfer, 3rd ed., John Wiley & Sons, Inc. Ames.: 446-497.

Kajikawa, H. (1996). Utilization of by-products from food processing as livestock feed in Japan, Dep. of Animal Nutrition Institute of Animal Industry, Tsukuba 305, Japan. (unp.) .

Kosikouski, F.V. (1979). Whey utilization and whey products, J. Dai. Sci.vol.62, No.7:1149-1160.

Kellems, O.R., and Church, D.C. (1998). 4th ed. Livestock feeds and feeding .Prentice Hall, Inc. USA.: 99-103,191-213.

Kniep (1982) Pellet Mill Operator Manuel, American Feed Manufacturers Association: 25-32.

Maiga, H.A., (1997). Alternative feeds for dairy cattle in Northwest Minnesoto. Univ. of Minnesota.

Maiga, H.A., Schingoethe, D.J.and Henson, J. E. (1996). Ruminal degradation, amino acids composition, and intestinal digestibility of the residual component of five protein supplements. J. Dairy Sic. 79:1647.

Masters, k. (1997). Spray dryers, Ch5. Industrial drying of foods, ed. by Barker, C.G.J., Chapman & Hall, London.:91-133.

McCabe, W., Smith, J.C., and Harriott, P. (2001) Unit operations of chemical engineering,6th .ed., McGraw-Hill Book Co.:804-806.

Miller, E.R., Holden, P.J. and Leibbrandt, V.D. (1987). By-products in swine diets, Cooperative Extension Work in agricultural and home economics, State of Indiana, Prude Univ.19-30.

Modler, H. W., Mulleer, P.G., Elliot, J.T., and Emnons, D.B. (1980). Economic and technical aspects of feeding whey to livestock. Dai. Sci.: 838-855.

Morr, C.V. (1992) Whey utilization. In whey and lactose processing ed. By Zadow, J.G., Elsevier Applied Science, NY.: 134-135.

Pearce, R.J (1992) .Whey processing, Ch2.In whey and lactose processing, ed. Zadow, J.G., Elsevier, NY. :77-80.

Perry, T.W. (1995) The effect of processing on the nutritive of feeds stuffs for Beef Cattle, Ch.6.In Beef Cattle feeding and nutrition, Academic Press, eds. Perru, T.W and Ceecava, M.J. , UK.:73-85.

Reece, F.N. (1966). Temperature, pressure and time relationships in forming dense hay wafers, Trans. ASAE, 9(6):749-751.

Riziv, S. S., Hand Rao, M.A. (1995). Engineering properties of foods 2^{nd}, Pb. Marcel Dekeer , NY.:132.

Rodriguez, G., Vasseur, J. and Courtois, F. (1996)$_a$. Design and control of drum dryers for the food industry. Part1. Set-up of a moisture sensor and inductive heater, J.of Food Eng. Elsevier Science LTd., vol. (28): 271-282.

Rodriguez, G., Vasseur, J., and Courtois, F. (1996)$_b$. Design and control of drum dryers for the food industry. Part2. Automatic Control, J. of Food Eng. Elsevier Sci. LTd., vol. (30):171-183.

Sahay, K. M., and Singh, K.K. (1992). 2^{nd} Ed .Unit operation of agricultural processing, Vikas Pub. House PVT LTD, Delhi: 103-162, 224, 321-328.

El-Sayed, M.M.A. (1987). The use of ultrafiltration technique for the utilization of cheese whey, .Ph.D Th., Ain Shams Univ.: 1-3.

Sharma, S.K., Mulvaney, S.J., and Rizvi,S. S. H. (2000) Food processing and laboratory experiments , John Wiley& Sons, Inc.Ames.:202-223. .

Shaw, M.C. (1973). The fundamental basis of the hardness test (c.f. from Tabil *et al.* ,2002).

Shaver, R.D. (2002). By –products feedstuff in dairy cattle diets in the upper Midwest, Dept.of Dair., Sci., Univ. of Wisconsin-Madison.

Singh, P., and Heldman, D.R. (2001).Introduction of food engineering ,3rd ed., Acad. Press, GB:217-219.

Simmons, N.Q. (1963). Feed milling ,1st ed. Leonard Hill LTD.:73-77, 182-185, 208-214.

Sitkei, G. (1986). Mechanics of agricultural materials , Elsevier Sci., NY,459-473.

Staples, C.R., and Harris, B (1991). Energy and milling by-products feedstuffs for dairy cattle, Florida Coop. Ext. Serv./Inst. Food and Agric.Sci, Univ. of Florida.111-125.

Seymour, J. C. (2003). The feed value of unusual feedstuff, Dep. of Nat. Resor. and Env., Victoria, Australia.

Tabil, L.G., Sokhansanj, W.J., Crera, R.T., Patil, M.H., Khoshtaghaza, M.H., and Opoku, A. (2002). Physical characterization of alfalfa cubes: 1Hardness, Canadian Biosystemes Eng., vol.(44).3.55-3.63.

Walker, P. (2000). The use of food waste as feedstuff for ruminants, Ch11,I n Food waste to animal feed ,ed. by Westendorf, W., Iowa State Univ. Press, Ames.:185-225.

El-Werch, E.M., Soliman, N .S., and Shoukr, A. Z. (1999). Mechanical proprties of wheat bran pellets related to pelleting factors,7th Conf. Mis Soc., Ag.Eng. 27-28 Oct.:113-138.

Watfa, Y.A (1999). A study on machinery used in forming of chaff by pressing and bonding. M.Sc. Th., Fac. of Agrc., Ain Shams Univ.:26

Watfa, Y.A. (2002). A study on design factors related to plant residues forming machines, Ph.D., Th.Fac.of Agrc., Ain Shams Univ.:31,50.

White, F.M., (1986). Fluid mechanics, s^{nd} ed. McGraw-Hill Book Co.: 253-255.

Yang, S. J. and Choung, C.C. (1988). Studies on the utilization of citrus by-products as livestock feed, Korean J.Anim.Sci.27 (4), 239-45.

Zall, R. R. (1992). Sources and composition of whey and permeated, Ch1.In Whey and lactose processing .Ed.Zadow, J.G., Elsevier Applied Science, NY.: 2,43-45.

Zobell, D. R. and Burrell ,W.C. (2002). Producing whey silage for growing and finishing cattle. Utah State Univesity.:1-6.

VII - APPENDIX

Determination of Dimensionless Groups Involving the Drum Dryer Performance:

1 - Drum production

Drum production is function of the following parameters:

$P = f(A, \rho, N, M_r, h, q)$

Where:

A: The drying area, (m^2).

N: The drum speed, (r.p.m).

ρ: Density of whey, (kg/m^3).

M_r: The moisture ratio, (%).

h: Latent heat of evaporation, (kJ/kg).

q: Drying energy requirements, (W).

Number of variables, n=7

Number of basic units, m=4

Therefore, the number of dimensionless groups:

$P = m\text{-}n = 7\text{-}4 = 3$

Choosing A, ρ, h, and N as repeating variables, then:

$\pi_1 = (P.A^a.\ \rho^{\ b}.\ h^c.N^d\ )$.

$\pi_2 = (q.\ A^a.\ \rho^{\ b}.\ h^c.N^d)$

$\pi_3 = M_r$

Substituting basic units per variables to (p_1) results:

$1 = Q^oM^o.\tau^o.L^o = (M/.\tau.)(L^2)^a.(M/L^3).^b(Q/M)^c.(1/\tau)^d$.

Matching the exponents results:

Q: c = 0

M: 1+b-c = 0

τ: -1-d = 0

L: 2a-3b = 0

From the previous eqs.

A = -1.5, b=-1, c = 0, d = -1

Substituting a, b, c and d to p_1

$\pi_1 = (P/A^{1.5}. \rho. N)$.

Also substituting basic units per variables to (p_2) results:

$1 = (Q/.\tau). (L^2)^a. (M/L^3)^b.(Q/M)^c.(1/\tau)^d$.

Matching the exponents results:

Q: 1+c = 0

M: b-c = 0

τ: -1-d = 0

L: 2a+-3b = 0

Substituting a, b, c to and d p_2

A = 1.5, b = -1, c = -1, d =-1

$\pi_2 = (q/ A^{1.5}. \rho. h.N)$.

$\pi_3 = M_r$

Then:

$\pi_2 = f(\pi_2/ \pi_1, \pi_3)$, or (q/h.p) = f [(P/A$^{1.5}$. ρ. N.), ($M_r$)]

2 - Drying energy requirements:

Drying energy requirements is function of the following parameters:

$q = (A, m^{\cdot}, U, C_p, h, \rho, M_r)$

Where:

q: Drying energy requirements for the drying process, (W).

A: The drying area, (m^2).

C_p: Specific heat of the whey, (kJ/kg.°C).

M_r: The drying rate, %).

$m^{\cdot}$: The feeding rate, (kg/s).

h: Latent heat of evaporation, (kJ/kg).

ρ: Density of whey, (kg/m^3).

U: Overall heat transfer coefficient, (W/m^2 °C).

Number of variables, n = 8

Number of basic units, m = 5

Therefore, the number of dimensionless groups:

P = m-n = 8-5 = 3

Choosing A, ρ, m˙, Cp, and h as repeating variables, then:

$\pi_1 = q.A^a.\ m^{\cdot b}\ \rho^c..C_p{}^d\ .h^e$

$\pi_2 = U\ A^a.\ m^{\cdot b}\ \rho^c..C_p{}^d\ .h^e$

$.\pi_3 = M_r$

Substituting basic units per variables to (p_1) results:

$1 = Q^oM^o.\tau^o.L^o\theta^o = (Q.\ /\tau).(L^2)^a.(M/\tau\ )^b.(M/L^3)^c.(Q/M.\theta\ )^d.(Q/M)^e$

Matching the exponents results:

θ: -d = 0

τ: -1-b = 0

M: b+c-d-e = 0

L: 2a-3c = 0

Q: 1+d+e = 0

From the previous eqs.

A = 0, b=-1, c = 0, d = 0, e =-1

Substituting a, b, c to p_1

$\pi_1 = (q/m^{\cdot}.h$

Also

Substituting basic units per variables to (p_2) results:

$1 = Q^oM^o.\tau^o.L^o\theta^o = (Q.\ /L^2\ \theta).(L^2)^a.(M/\tau\ )^b.(M/L^3)^c.(Q/M.\theta\ )^d.(Q/M)^e$

Matching the exponents results:

Q: 1+d+e = 0

θ: -1-d = 0

M: b+c-d-e = 0

τ: -1-b = 0

L: -2+2a-3c = 0

Substituting a, b ,c ,d , and e to p_2

A = 1,b = -1,c =, 0, d = -1, e = 0

$\pi_2 = U.A/ m^{\cdot}.C_p$

$\pi_3 = M_r$

then :

$\pi_2 = f(\pi_{1,},\pi_3)$, or $(q/m^{\cdot}.h) = f[(U.A/ m^{\cdot}.C_p),(M_r)]$.

Table (1): Standard size drum dryer in constant production[1]

Dim. Model	Drum Dia. (mm)	Drum length (mm)	Heating surface (m^2)	Power (hp)	Working pressure (kg/cm^2)	Approx. Size (cm)
LK3050D	300	500	0.9	1	6	125x72x100
LK5060D	300	600	1.8	1	6	135x92x111
LK7605D	760	500	2.3	2	6	150x190x175
LK7660D	760	1000	4.7	2	6	200x190x175
LK7615D	760	1500	7.1	2	6	250x190x175
LK7620D	760	2000	9.5	4	6	300x190x195
LK9310D	930	1000	5.8	4	6	205x210x195
LK9315D	930	1500	8.7	4	6	255x210x195
LK9320D	930	2000	11.6	5	6	303x210x195
LK1520SD	1500	2000	9.4	3	6	305x180x195

Table (2): Screen sizes for pellet durability tests **(ASAS, 2003).**

Dia. of Pellet (mm)	Size	Dia. (mm)
2.4	N_o.10	2.0
3.2	N_o.7	2.8
3.6	N_o.6	3.4
4.0	N_o.6	3.4
4.8	N_o.5	4.0
5.2	N_o.4	4.8
6.4	N_o.3 1/2	5.7

[1] Lisky Industrial Co.,LTD,Taipei Hsien,Taiwan

الملخص العربي

يهدف البحث إلى دراسة إمكانية إعادة تدوير مخلفات تصنيـــع الألبـــان (الشـــرش-Whey أو ما يسمى مصل الجبن) في شكلين مختلفين وذلك لإعادة استخدامه مرة أخرى فـــي مجال الصناعات الغذائية أو في مجال الإنتاج الحيواني كبدائل للألبان بعد التجفيف أو إضافتـــه في عمليات تصنيع المصبعات العلفية كمادة رابطة، وذلك لتحسين خواص المنتج الميكانيكيـــة والكيميائية.

ومن أجل تحقيق الأهداف السابقة، تم في هذا البحث استخدام وحدتي تصنيع بحثيتيـــن لإعادة تدوير الشرش (وهما وحدة تحويل الشرش من الحالة الســـائلة إلـــى الحالـــة الصلبـــة بالتجفيف والأخرى وحدة لإنتاج المصبعات الحيوانية) كما يلي:

وحدة التشغيل بالتجفيف: (Drying unit operation)

تم في هذا البحث تصميم، وتنفيذ ، وتقييم أداء وحدة تصنيع هند ســـية (مجفـــف ذي الإسطوانة) وذلك لإعادة تدوير مخلفات تصنيع الألبان (مصل الجبن) من الحالة الســـائلة إلـــى الحالة الصلبة، لإعادة استخدام المادة بعد التجفيف في عمليات التصنيع المختلفـــة (الغذائـــي، الحيواني) وبحيث تساهم هذه العملية في تسهيل عملية تخزين و تداول الشـــرش بعـــد عمليـــة التجفيف تلك، حيث يتطلب تخزينه وهو في الحالة السائلة إلى عمليات تبريد وبســـترة والـــى مساحات ضخمة للتخزين، وبالتالي تصبح عملية التخزين غير اقتصادية مما يضطـــر المنتـــج التخلص من هذه المادة في المصارف المختلفة مسببا في ذلك تلوثا شديدا للبيئة وفقدا في قيمته الاقتصادية.

لذلك تم في هذا البحث تقييم أداء وحدة التشغيل المصممة لحل المشكلة الســـابقة مـــن خلال دراسة تأثير عوامل التصميم و التشغيل المختلفة من أبعاد، وطاقـــة، و ســـرعة دوران، درجة حرارة التجفيف، وخواص المادة مثل: محتوى المادة من المواد الصلبة، وكثافة المـــادة على أداء الوحدة والتي تشمل:

١-وحدة التجفيف: (Drying unit)

وتتألف هذه الوحدة من اسطوانة التجفيف، وهي مصنعة من مادة غير قابلـــة للصـــدأ (stainless steel) وبطول300 mm وقطـــر170 mm وبحيـــث تشـــكل مســـاحة تجفيـــف قدرها($0.16\ m^2$) تدور اسطوانة التجفيف حول محورها الأفقي بسرعة(1-7 r.p.m). وفـــي

مركز الاسطوانة تم إدخال السخان الكهربائي والذي هو مصدر الطاقة اللازم لعملية التجفيف بقدرة (2 kW) من مقاومة كهربائية طول(2 m) وقطر(8 mm) ليصبح بطول(250 mm) وقطر(50 mm) ليتناسب مع أبعاد الاسطوانة، ويتم التحكم بدرجة الحرارة بواسطة منظم (temperature regulator) ذي مجال (0-300°C).

٢-وحدة التغذية: (Feeding unit)

وتشمل هذه الوحدة اسطوانة التغذية (feeding roller) والتي تقوم بإمداد اسطوانة التجفيف بالمادة المراد تجفيفها، وهي بطول (300 mm) وقطر(50 mm) وتتلقى الحركة من عمود إدارة المجفف بواسطة تروس ، يتم تغذية اسطوانة التجفيف من خلال انغماسها بحوض الشرش.

٣-وحدة القدرة: (Power unit)

ويحوي هذا الجزء على المحرك الكهربائي قدرة (0.35kW) وسرعة دوران (1440r.pm) ويعمل على جهد(220v)، وتحوي على مخفض للسرعة بنسبة (20:1).

٤-الأجهزة المساعدة: (Accessories)

وتشمل هذه الوحدة الأجزاء المساعدة اللازمة لتشغيل الوحدات السابقة ومنها: التروس، العجلات المسننة(sprockets)، سيور نقل الحركة بين المخفض والمحرك، وسلسلة (chain) نقل الحركة بين المخفض ومحور المجفف، سكين القشط(scraper knife) و حوض تجميع المادة الجافة.

وحدة تصنيع المصبعات: (Pellet processing unit)

تم استخدام هذه الوحدة المتوفرة في قسم هـ.ز-ك.ز-ج.عين شمس **(Watfa,2002)** والمعدلة من قبل الباحث لدراسة الخواص الميكانيكية للمصبعات و الخاصة بتداول الأعلاف وذلك عند استخدام الشرش (المصل) كمادة رابطة، وكذلك دراسة تأثير ذلك على إنتاجية الوحدة التي تتألف مما يلي:

بريمة التشغيل: (Extruder)

وهي عبارة عن بريمة تستخدم لدفع المادة عبر قوالب التشكيل ،حيث نسبة الخطوة إلـى القطر(5.2/3.92) وبطول(16.5cm) وغلاف (shell) بطول (20cm) ، ويتبع هذا الجـزء مجموعة قوالب التشكيل ذات الأقطار(5,8,10 mm).

٢-وحدة القدرة: (Power unit)

وتحوي هذه الوحدة المحرك الكهربائي قدرة (1hp, 0.75 kW) وسـرعة دوران ، (1440r.p.m) و مخفض سرعة، بنسبة التخفيض (1:20).

٣-الأجهزة المساعدة: (Accessories)

وتشمل هذه الوحدة الأجزاء المساعدة اللازمة لتشغيل الوحدات السابقة ومنـها:سـيور نقل الحركة، الطارات، وهيكل الآلة ، ومجموعة كراسي المحاور.

وأظهرت نتائج البحث مايلي:

١-وحدة التجفيف: تم دراسة تأثير كل من السرعة، درجة حرارة التجفيف، وخواص المـادة على أداء وحدة التجفيف وخواص المنتج بعد التجفيف كما يلي:

الإنتاجية: (Productivity)

تأثرت الإنتاجية بسرعة دوران المجفف ،حيث زادت الإنتاجية مـع زيـادة سـرعة الدوران بشكل خطي، حيث بلغت الزيادة (84%) عند زيادة السرعة من (1 to7 r.p.m)وذلك عند ثبات بقية عوامل الدراسة.

انخفضت الإنتاجية مع زيادة المحتوى الرطوبي وتبع هذا الانخفاض شكل معادلة قـوة، حيث انخفضت الإنتاجية بنسبة(14%) وذلك عند زيادة المحتوى الطوبي بنسب(15%) . وتم التوصل إلى معادلة للتنبؤ بالإنتاجية كتابع للسرعة والمحتوى الرطوبي:

$P=(-3.536M_c+543.61)N-132.74$ Where (R^2=97%)

الكفاءة الحرارية: (Thermal efficiency)

تغيرت الكفاءة الحرارية مع سرعة الدوران ، و تبع هذا التغير منحني مـن الدرجـة الثانية، حيث وصلت الكفاءة إلى أعلى قيمها عند سرعة دوران(4to 6 r.p.m).وتأثرت الكفاءة

الحرارية بالمحتوي الرطوبي الابتدائي حيث زادت وفقاً لمنحني من الدرجـــة الثانيــة، حيــث وصلت إلى أعلى قيمة لها عند محتوى رطوبي (50 to 55%).

الطاقة النوعية: (The specific energy)

تأثرت الطاقة النوعية بدرجة حرارة تسحين المادة قبل التجفيـــف، حيــث انخفضــت الطاقة النوعية مع زيادة التسخين، حيث انخفضت بنسبة (15%)عند زيادة التسخين من درجـة حرارة من (40 to70 °C).وانخفضت الطاقية النوعية بشكل كبير مع زيادة السرعة وبلغـــت قيمة الانخفاض (51%) عند زيادة السرعة من (1 to7 r.p.m) و.زادت الطاقــة النوعيــة النوعية مع زيادة المحتوى الرطوبي وذلك بشكل خطي.

معدل التجفيف: (Drying rate)

زاد معدل التجفيف مع زيادة درجة حرارة التجفيف، حيث بلغت نسبة الزيــادة (48%) عند زيادة درجة الحرارة من (120 to150 °C) . وكذلك زاد معدل التجفيـــف مـــع زيـــادة السرعة حتى سرعة(6 r.p.m) وبعدها بدأ بالانخفاض بعد هذه السرعة. هـــذا وكـــان تـــأثير المحتوى الرطوبي على معدل التجفيف قليلا.

تقدير التكاليف: (Costs estimating)

تم تقدير تكلفة إنتاج وحدة الكتلة وفقا لمعادلة **(Awady, 1978)** حيث بلغت التكلفـــة (5.5LE/kg) ، وهذه التكلفة اقل بكثير من الأسعار العالمية،.وكما تم إجراء اختبار الحساسـية لتكلفة وحدة الكتلة كتابع للانتاجية و محتوى الرطوبة الابتدائي، حيث بينت نتائج التحليـــل أن التكلفة هي أكثر حساسية للانتاجية منها للمحتوى الرطوبي.

مواصفات المنتج النهائي: (Properties of final product)

يعتبر المحتوى الرطوبي النهائي والكثافة من مواصفات الجودة للمنج النهائي ، حيــث يوثر المحتوى الرطوبي على جودة عملية التخزين من حيث امتصاصية الرطوبة من الوســـط الخارجي أو من حيث تعرض المادة المخزنة للبكتيريا والجراثيم. وتلعب الكثافة دورا هاما فـي عمليات التداول والتخزين وكذلك في عملية استخدام الشرش المجفف كبدائل للألبان.

وتبين من نتائج البحث، انخفاض محتوى الرطوبة النهائي مع زيادة درجـــة حـــرارة التجفيف ،حيث بلغت هذه النسبة(46 %) عند زيادة درجـــة الحـــرارة مـــن (140-150°C)

وانخفضت الكثافة بنسبة (5.3%). وتأثر محتوى المنتج النهائي من البروتين بنسبة المواد الصلبة في المنتج حيث زادت النسبة مع زيادة نسبة المواد الصلبة في المنتج النهائي.

نظرية تصميم وتشغيل المجفف ذي الإسطوانة:

تم استخدام نظرية التحليل البعدي لاستنباط معادلات عامة تربط بين عوامل التشغيل المختلفة وبحيث يمكن استخدام هذه المعادلات في تشغيل وتصميم مثل هذا النوع من وحدات التشغيل وكانت المعادلات كما يلي:

$$(q/ph) = [-(0.002).(P)./(A^{1.5}.\rho.N)] + [0.0019M_r + 8E\text{-}5]$$

$$[(U.A)/(m^{\cdot}C_p)] = [q/(m^{\cdot}.h)].[-83.3M_r + 80] - [8.625]$$

٢- وحدة تصنيع المصبعات: (Pelleting unit)

االكثافة:(Density)

تلعب الكثافة دورا رئيسيا في عمليات تداول وتخزين الأعلاف ، بلغت الكثافة الظاهرية للمصبعات المصنعة من الذرة وفول الصويا واستخدام الشرش السائل المركز كمادة رابطة(715 to $790 kg/m^3$) وهذه الكثافة تتوافق مع ما هو موجود في الأسواق، وتأثرت الكثافة بنسبة المادة الرابطة حيث ازدادت مع زيادة نسبة المادة الرابطة، حيث بلغت الزيادة بحدود6% عند زياة نسبة الشرش بمقدار (50%) وزادت نسبة الكثافة الظاهرية (5%) عند خفض قطر المصبعات من (10mm to5mm) وكذلك سلكت الكثافة الحقيقية نفس سلوك الكثافة الظاهرية حيث بلغت مدى يتراوح(1220 to $1288 kg/m^3$).

درجة التحمل: (Durability Index)

تعتبر درجة التحمل من أهم مواصفات المصبعات العلفية إذ تعبر عن درجة تماسك جزيئات المخلوط العلفي وعدم انفصالها عن بعضها البعض، حيث يسبب تفكك الجزيئات انخفاض في جودة المادة العلفية وخسارة لبعض المكونات الهامة وخصوصا العناصر الصغرى (micro ingredient).

أظهرت نتائج البحث أن درجة التحمل كانت مرتفعة حيث وصل مؤشر درجة التحمل بحدود(PDI = (76 to 92.5% وتأثرت درجة التحمل بنسبة المادة الرابطة وقطر المصبعات، حيث زادت مع زيادة نسبة المادة الرابطة وقلت مع زيادة اقطار المصبعات.

الصلابة: (Hardness)

تعبر الصلابة عن مقاومة تشوه المادة تحت تأثير الأحمـــال الخـــاد شـــة المختلفـــة، وأظهرت التجارب زيادة الصلابة مع زيادة نسبة الشرش كمادة رابطة، حيـــث بلغـــت نســـبة الزيادة (35%) وذلك عند زيادة نسبة الشرش من (40% to 30 %) وكذلك كـــانت أعلـــى صلابة عند قطر مصبعات (5mm).

الإنتاجية: (Productivity)

تعتبر الإنتاجية هدفا رئيسا في عملية الإنتاج، حيث تؤثر على تكلفة المنتـــج النـــهائي فبزيادة الإنتاجية تنخفض التكلفة. وهذا ينعكس بشكل رئيسي على أسعار المنتجات الحيوانيـــة. وأظهرت نتائج البحث انخفاض في انتاجية الة تشكيل المصبعات مـــع زيـــادة نســـبة المـــادة الرابطة، حيث بلغت نسبة الانخفاض (160%) عند زيادة نسبة المادة الرابطة الـــى (40%)، وتأثرت الإنتاجية بقطر تشكيل المصبعات حيث زادت مع زيادة قطر .

٣- مقارنة العائد من إعادة تدوير الشرش بالتجفيف أو استخدامه في تصنيع المصبعات:

تم إجراء مقارنة العائد الاقتصادي من اعادة تدوير الشرش بـــالتجفيف أو اســـتخدامه كمادة رابطة في تصنيع الاعلاف. أظهرت النتائج إن إعادة تدوير الشرش بـــالتجفيف يحقـــق عائد اكبر، حيث بلغت قيمة العائد لوحدة الكتلة للشـــرش الطـــازج (0.6LE) مقارنـــة مـــع (0.33LE)عند استخدامه في تصنيع الأعلاف.

جامعة عين شمس

كلية الزراعة

قسم الهندســة الزراعية

رسالة دكتوراه

اسم الطالب: **أحمد جاد الله عبود**

عنوان الرسالة: **دراســة عوامل تصميمية لإعادة تدوير مخلفات تصنيع الألبان**

اسم الدرجة: **دكتوراه الفلسفة**

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تاريخ البحث: ٢٠٠١/٩/١٧

الدراسات العليا

ختم الإجازة

/ /٢٠٠٤

أجيزت الرسالة بتاريخ

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موافقة مجلس الكلية

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موافقة مجلس الجامعة

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صفحة الموافقة على الرسالة

دراسة عوامل تصميمية لإعادة تدوير مخلفات تصنيع الألبان

رسالة مقدمة من

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ماجستير في العلوم الزراعية ، (ميكنة زراعية)، جامعة عين شمس،٢٠٠١

للحصول على

درجة دكتور فلسفة في العلوم الزراعية (ميكنة زراعية)

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تاريخ المناقشة: / /٢٠٠٤

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إجازة في الهندســـة الميكانيكية، (قوى)، جامعة دمشق,١٩٩١

ماجستير في العلوم الزراعية، (ميكنة زراعية)، جامعة عين شمس،٢٠٠١

للحصول على

درجة دكتور فلسفة في العلوم الزراعية

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قسم الهندســـة الزراعية

كلية الزراعة-جامعة عين شمس

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