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H. REUTER

PRESENT AND FUTURE TRENDS IN TECHNOLOGY OF MILK AND DAIRY PRODUCTS PROCESSING UNDER LIMITED ENERGY SUPPLY

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A number of engineering solutions to reduce considerably energy and production costs in food processing factories have been developed and approved in practice in recent years. Energy utilization in the factory can be improved by compined generation of power and heat, increased recovery of process heat, introduction of high efficient process equipment, application of solar energy.

INTRODUCTION

This lecture is coming 3 or 4 years to late and 10 years in advance. At the moment the very low level of energy prices does not force to save energy as it should be. With a view to the future it can be foreseen that natural fuel reserves, which we currently are using intensively will be exhausted and consequently prices will increase. Therefore we have to think about energy saving not only in the near future we have to make efforts right now. It is therefore imperative that all energy users to take practical steps to save energy by good house keeping and application of energy saving technologies. The immediate objective of the industry is not to save energy. In countries with a free market economy the primary objective is to reduce the energy costs by saving energy.

SPECIFIC ENERGY DEMAND IN FOOD PROCESSING

The specific energy consumption, that is the energy consumption per kg processed food, depends on [13].

1. The specific energy demand which is affected by the type of food (like meat, fish, milk, cereals, fruits and vegetables), the applied process (like sterilization, drying, freezing, fermentation, ...) and the type of

packaging (cans, glass jars, laminated carton package, laminated plastic or paper).

2. The degree of energy utilization, resulting from the mode in which the primary energy is utilized in the food factory.

Measures which improve the energy utilization in food processing can be devided into three stages:

— In the short term, much can be achieved without huge investments to minimize energy losses and raise the degree of energy utilization. First of all the efficiency of energy utilization within the plant should be verified and increased by measures which are known and well approved.

— In the mid term, processing equipment can be replaced with the latest designs of improved energy efficiency or be modified in ways which will reduce the energy demand, without changing technology in principle.

— In the long term, measures which bring about technological and structural changes are taken into consideration. They lead to basic changes and thus will not be mentioned as their development cannot yet be predicted and they are at present more or less objectives of speculation.

First of all the degree of energy utilization following from the way in which the primary energy (electric current, coal, gas, oil) is used in the factory has to be improved. The short and mid term measures can be realized at short sight by applying technologies which are presently known, well approved and do not require high investments.

Food processing factories differ from each other in their design and arrangement, technology applied, production programmes, output and in their energy situation. Even between factories having similar production programmes considerable differences exist. Therefore a standard overall energy saving guide line cannot be laid down. However, in numerous factories we can find similar conditions concerning particular processing operations and specify energy saving technical solutions which can be implemented individually or in combination.

A number of engineering solutions reducing considerably energy and production costs have been developed, installed and approved in practice in recent years. In the following some of these approved technologies are given which have been successfully installed mainly in dairies; but they can also be implemented in other food processing factories [14].

SHORT TERM MEASURES

The simplest and low cost way to save energy is undoubtedly given by consequently avoiding heat losses of any type in steam generation, transport and its application in the process. Short term measures to aboid heat losses include improvement of the efficiency of steam generators by reducing the temperature of exhaust gases or recovery of the waste heat from exhaust gases, careful insulation of all pipes, process equipment, workshop, houses. In many cases this can be achieved with minimum costs, by good housekeeping and training of the staff.

MID TERM MEASURES

In the mid term we can distinguish four main areas of energy saving technologies which require some investments. These are:

1. Combined generation of power and heat.
2. Recovery of process heat by increased heat exchange.
   i. Utilization of the recovered heat inside of the factory.
   ii. Utilization of the recovered heat outside of the factory.
3. Replacement of old equipment by process equipment achieving high thermal efficiency.
4. Application of solar energy.

Installation of these measures in German food factories resulted in payback times ranging from 2 to 5 years as showed later on. All payback times mentioned in this report have been calculated on the base of much higher energy prices we have had between 1979 and 1982.

COMBINED GENERATION OF POWER AND HEAT

One of the most interesting and promising developments in generating power is the combined generation of power and heat in the factory. Power and heat co-generation, as it is understood today, is the generation of electricity or mechanical driving power from primary energy and the extensive use of waste heat of the system to provide steam or hot water.

It is known that in the conventional electrical power station the primary energy (coal, oil, gas) can be utilized only up to 30-33% and the rest is lost as waste heat. The primary energy can be considerably better utilized when the power generation is coupled with heat recovery from the low temperature waste heat.

The power and heat co-generation systems used till today in the food processing plants consisted of a high pressure steam generator, a back pressure turbine coupled with a generator and utilizing the low pressure steam as process heat. For economic use of this combination a, simultaneous consumption of power and steam is a prerequisite. These conditions were till today fulfilled in drying plants producing large quantities of powdered products (i.e. milk powder) by evaporation and spraydrying.

In the recent systems of power and heat co-generation, which are preferrably used in dairy plants and in breweries, a combustion engine (diesel or gas engine) is installed to drive the power generator. The exhaust gases (by diesel engine at 300-450 °C and by gas engine at 550-750 °C) are utilized to generate steam or hot water in a boiler plant equipped with an economiser to generate steam (Fig. 1).

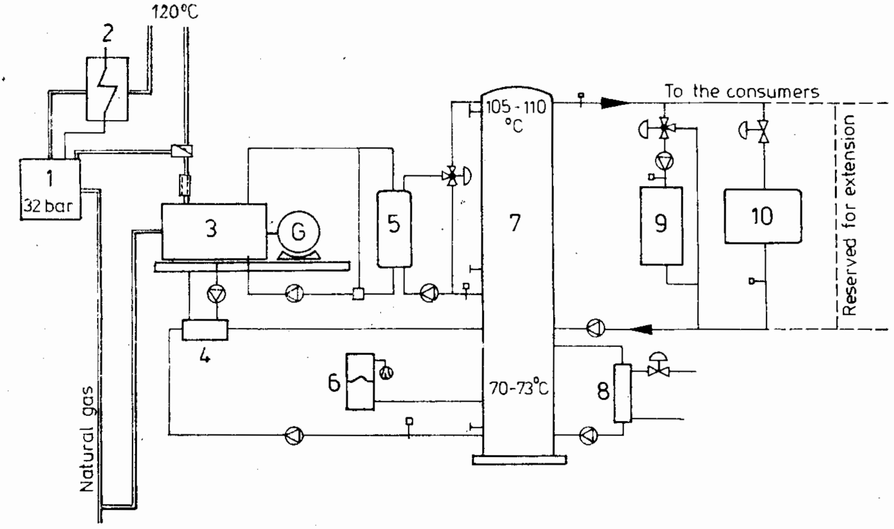

Fig. 1. Power and heat co-generation in a dairy plant; 1 — steam boiler, 2 — heat exchanger (economizer), 3 — gas, 4 — heat exchanger, 5 — heat exchanger, 6 — pressure holder, 7 — heat accumulator, 8 — emergency cooler, 9 — pasteurizer for milk, 10 — spray dryer

The difference in electricity generation compared with a power station is given in the fact that low temperature waste heat produced in a power station cannot be utilized, while utilization of exhaust heat of the combustion engine inside the factory could be possible. One more advantage is given by utilizing the heat from the cooling circuit of the combustion engine for the production of hot water at 70-73 °C. By reducing the temperature of the temperature of the exhaust gases at a little above the dew point energy losses are minimized and an efficiency of 86% and with recovery of all low temperature heat of 90% can be achieved. For conditions existing in industrialized european countries payback times of 4-5.5 years are mentioned for installed plants of this type. However, installations with a combustion engine require higher repairing and maintenance costs.

In food processing factories refrigerators are widely used to provide with ice-water or with a cooling agent of +1 °C for chilling. Refrigeneration equipments belong to the main power consumers in the factories. A feasible and economical way to reduce energy costs of chilling is also given by power and heat co-generation. The electromotor used till today to drive the compressor of the refrigeration plant can be replaced by a combustion engine, the gas engine bing the most favourable one from the energetic point of view. Usable is the heat carried off with the cooling water and a part of the caloric capacity of the exhaust gases. Assuming that the outlet temperature of the engine cooling fluid is adjusted to 120 °C and heat is exchanged in a closed water circuit hot water at 100-110 °C can be gained.

By cooling exhaust gases to 180 °C or 150 °C, in extreme cases even lower, hot water at 90 °C can be generated, stored in a heat accumulator and withdrawn when required for example to supply a milk pasteurizer (Fig. 2). The same combination is used also to drive the compressor for mechanical vapours compression. This way of power and heat co-generation enables to utilize another 50% of the energy content of the primary energy (gas, oil) in the form of hot water at 85 to 110 °C. This arrangement is economically feasible only when the heat in the form of hot water is completely utilized and an equivalent amount of energy can be saved in the boiler plant.

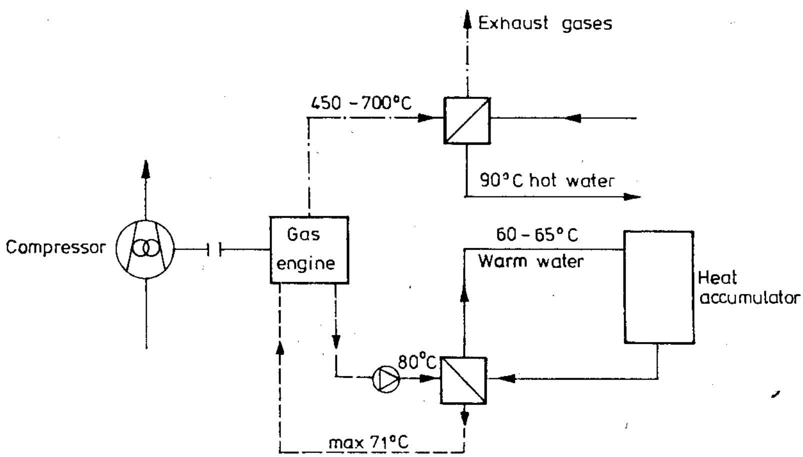

Fig. 2. Power and heat co-generation in a dairy plant to trive the compressor for refrigeration or mechanical vapours compression

Such an arrangement demands huge investments and the economy must be carefully calculated. Coupled systems of this type deliver cooling agent and hot water in a fixed relation and therefore are less flexible than separate systems, which produce only one of them according to demand. In addition to this there exists the earlier mentioned increased maintenance. Power and heat co-generation systems of this type have been installed in a greater number already and payback times of 3-5 years are mentioned for these arrangements.

RECOVERY OF PROCESS HEAT BY INCREASED HEAT EXCHANGE

Recovery of process heat by increased heat exchange is the next simple and economic way to save energy. Equipment needed (heat exchangers, pump, heat accumulators) is approved and requires low investment costs only.

When the heat recovered from low temperature waste heat exceeds the demand inside the factory (i.e. for producing hot water) then considerations should be taken to use the excess heat externally.

HEAT UTILIZATION INSIDE OF THE FACTORY

Heating of liquid foods (milk, milk products, fruits and vegetables juices) for pasteurization or UHT-treatment can economically be carried out only by a high degree of heat recovery. Compared to milk heaters in former years, which had a rate of heat recovery of 60-80% only, recent plants are installed with a minimum of 90% heat recovery. Based on energy prices of 1980 the calculated minimum of operation costs of a milk pasteurizer with plate heat exchangers was reached with a degree of heat recovery of 94-96%. With the latest pasteurizers for milk heat recovery therefore ranges to 92 or 94%. The payback time for increasing the heat exchanging surfaces to achieve from 80 to 90% heat recovery is about 1 year. An increased heat exchange also saves water for cooling or energy for refrigeneration.

At many steps in the production heat which was formerly eliminated with cooling water can be recovered by heat exchange. If the time of heat recovery does not coincide with the time of demand the heat can be stored with a water circuit in a heat accumulator. There are various possibilities for the application of this arrangement. The heat accumulator is a new type of equipment in food factories.

In a dairy, in cheese making after curd production whey is drained off with a temperature of 50 °C. The heat content of the whey can be used to heat water to 45 °C and store it in a hot water heat accumulator (Fig. 3). The hot water in the accumulator serves to warm up the cheese milk to the required cheese making temperature usually to 30-32 °C, to prepare warm water for process use and for preheating of cleaning solutions. This system also reduces the consumption of steam and cooling water. The installation consist of plate heat exchangers connected to a water circulating system and one or two tanks for the accumulation of warm water. The investments laid down in this arrangement are equivalent to the savings in energy achieved in 2 years; this results in a payback time of 2 years.

In a similar way the superheat and condensation heat of the refri-

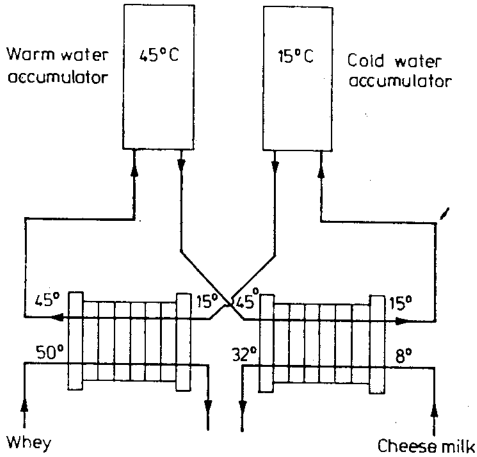

Fig. 3. Arrangement of heat recovery by heat exchangers and heat accumulators in a cheese factory

gerator system, usually eliminated by cooling water, can be recovered and utilized.

In dairies evaporating and spray drying installations have a high heat consumption. Here there exist good possibilities for heat recovery. The following measures lead to a reduction of energy consumption [3].

— Preheating of the drying air with vapours condensate of the evaporator. The drying air can be preheated with a ribbed tube heat exchanger to about 40-45 °C. Savings amount to 8-10% of the drying cost.

— A far better possibility is given by preheating the fresh air by heat exchange with the outgoing air. Problems arise by the dust load of the outgoing air which deposits on the heat exchanging surface and block the heat transfer. Heat exchangers of special design are needed. In any case the dust particles of the exhaust air have to be separated by cyclones or airfilters. The heat exchanger has to be cleaned periodically on the side of the outgoing air depending on the design features and the materials used, with an unfavourable design every 8 hours. The degree of heat recovery reaches 20-30%. According to the huminity of the outgoing air the fresh air is preheated to about 60-70 °C.

Different alternatives for the heat exchange can be used. The outgoing air is cooled in an outgoing air heat exchanger by a circulating heat carrier medium (water or water/glycol mixture); which in return heats fresh-air in a fresh-air heat exchanger (Fig. 4). In both heat exchangers a temperature difference is needed to keep a heat transfer. The heat between the two air currents can also be exchanged only in one heat exchanger. Since in this case merely one temperature difference is involved the heat recovery is about 10% higher. For the air to air

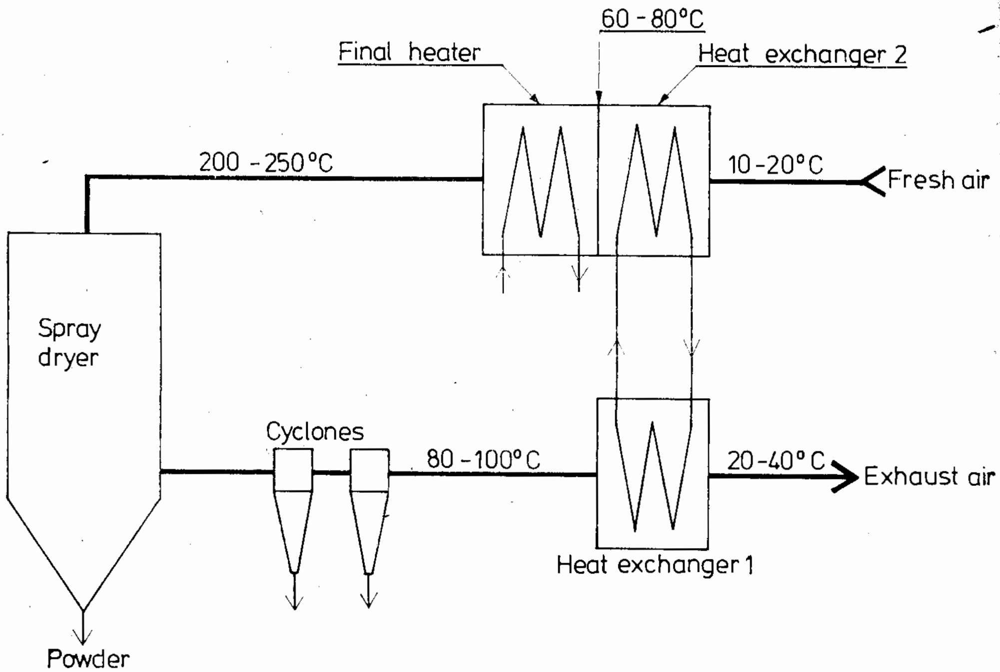

Fig. 4. Heat recovery from a spray-drying tower by two air heat exchangers and a heat carrier medium

heat exchanger plane smooth plate heat exchangers and tabular heat exchangers equipped with stainless steel or glass tubes are installed. The latter require higher investments cost but gather less dust and show longer operating times till cleaning becomes necessary.

In large evaporators a huge quantity of vapours condensate is produced. With a multiple effect evaporator the condensate of the first effect having a higher temperature is used economically as boiler feed water. The energy from vapours of the last effect can be utilized for preparing warm water or other applications inside the factory.

Improved heat exchange has its limits given by the costs of the additional heat exchanging surfaces and other equipment (pumps, heat accumulators). The minimum of costs has to be calculated by summing up the investment costs and the operating costs (mainly energy costs) (Fig. 5).

HEAT UTILIZATION OUTSIDE OF THE FACTORY

With maximum heat recovery from all waste heat currents within a factory the situation may arise that a heat potential of a low temperature level of 70 °C or lower exists which cannot be utilized inside the factory. In such a case it is obvious to look for applications outside the factory. From the airy industry some examples are known, which may be of value also for other branches of the food industry.

In a drying plant surplus condensate of the evaporator at 75 °C, surplus vapours at 48 °C and cooling water from the condenser at 35 °C are available. A heat pump driven by a gas engine produces from all the waste heat currents warm water at 70 °C, which is used to heat

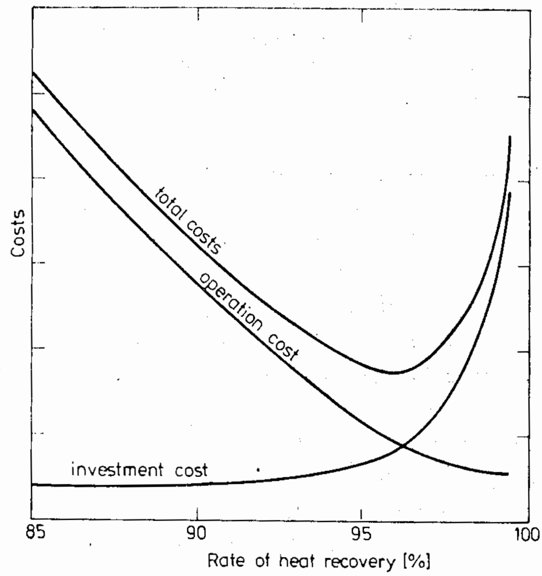

Fig. 5. Calculated minimum of total costs of a milk pasteurizer with plate heat exchangers. Investment and energy costs are based on prices of 1979-82

a public outdoor and indoor swimming pool, a hospital and the glass houses of a large market garden [1, 2]. In a dairy producing mainly fresh products the exhaust gases from a heavy oil burning boiler are cooled down to 90 °C with water in a flue gas cooler. For this temperature below the dew-point the chimney is equipped with a protective coating of stainless steel. With this form of heat recovery spring water is heated to 12-15 °C and utilized in an indoor trout breeding plant connected with the dairy. With this water temperature optimum breeding conditions for trouts can be established and 2 millions trouts are produced per year.

In another dairy the waste heat from milk cooling after pasteurization and the waste heat from the cooling water of the compressors of the refrigerating equipment is used to heat spring water to 17-18 °C. With this warmed water an inside trout hatching plant is operated [6].

INSTALLATION OF HIGH EFFICIENCY PROCESS EQUIPMENT

In the mid term the processing equipment can be replaced with latest types of improved energetic efficiency or be modified to consume less energy. An appropriate example is evaporation of milk and whey prior to drying. In former years according to lower energy prices the economical optimum was attained with a triple effect evaporator and thermal vapour compression. At the time being and with significant higher prices for energy 5 to 6 effects are required. Evaporators with 7 effects have already been installed in recent years.

With an increasing number of effects the residence time of the product rises and thereby causes greater protein denaturation. Therefore evaporators with a high number of effects are not appropriate for every product.

A more product protecting and energetically more favourable solution is the evaporation with mechanical vapour compression Kessler [7]. Compression of the vaopurs can be accomplished by a single or multiple stage axial or radial-flow compressor. The evaporators with mechanical vapour compression installed in daries up to now have a triple effect and are driven by electro-motors or combustion engines with power and heat co-generation. In Table 1, according to data given by Kessler [8], is shown to what extent energy savings are possible. The measured data consider the energy demand of the compressor, product and vacuum pumps and product preheating.

Evaporators with mechanical vapour compression exhibit lower ope-sently in Europe most of the high capacity spraydrying plants have installed high efficiency evaporation equipment.

Table 1. Energy demand of different evaporating systems

		Evaporation with a 3-effect evaporator		
		with thermal vapors compression	with mechanical vapors compression and external electricity	with mechanical vapor compression and own electricity, power and heat cogeneration
		kJ/kg inlet product		
Process energy	steam	898	28	28
	current	22	72	72
Efficiency	steam	0.77	0.77	0.77
	current	0.33	0.33	0.8
Primary energy	steam	1166	36	36
	current	67	218	90
Total		1233	254	126

Sterilizers and pasteurizers have a high heat consumption. For low and middle viscous fluid and mainly homogeneous foods — such as milk, ration costs but require higher investments and maintenance costs. The amortization times known till today range between 3-4 years only. Pre-cream, juice, puddings, desserts, soups, sauces, mashes — the continuous ultra-high-temperature heating offers the possibility to accomplish a higher heat recovery. The UHT-process combined with an aseptic packaging in appropriate and energy saving containers — such as plastic flexible pouches, blown plastic bottles, semirigid carton containers — can save a considerable amount of energy compared with in container sterilization in glass jars or cans [13].

When sprawy drying foodstuffs, the aim is to achieve the desired powder quality with lowest operation costs. These requirements are often in conflict. The operation costs of a sprawy dryer are mainly determined by energy costs of steam consumption. The steam consumption can be reduced by

— increasing the powder residual moisture content,
— increasing the dry matter content of the feed,
— increasing the inlet temperature of the fresh air.

An increase of the dry matter content of the feed normally creates technological problems. An increase of the residual moisture of the powder needs final drying by an attached after-dryer, usually a fluidized bed-dryer. In a one stage spray dryer any increase of the fresh air temperature results in an increase in temperature of the particles leaving the tower. The particle temperature influences product deterioration by heat degradation due to excessive heat exposure.

In a normal single-stage spray dryer the conditions are generally fixed to achieve the maximum permissible particle temperature to meet the quality standards of the powder. With dairy products and other foods any increase of the inlet temperature or dry matter content of the feed deteriorates the product quality. Recognition of these principles created the bases for two-stage drying. In a two-stage dryer all three factors can be combined to improve both energy consumption and product quality.

In a two-stage drying process the moist product leaving the spray drying tower with a higher moisture content is after-dried in a fluidized bed dryer. Figure 6 illustrates a two-stage spray drying system. A fluidized bed 2 is integrated in the drying chamber 1. The stationary fluidized bed has a shape of a ring placed at the bottom of the chamber round the outlet duct. A vibrated fluidized bed 3 is attached for final drying and cooling. Fines collected from the cyclones 4 are recyceld to the atomizer cloud for further agglomeration if required [9]. After-drying takes place under much gentler conditions, i.e. the particle temperature is much lower than it would be if the same amount of moisture would

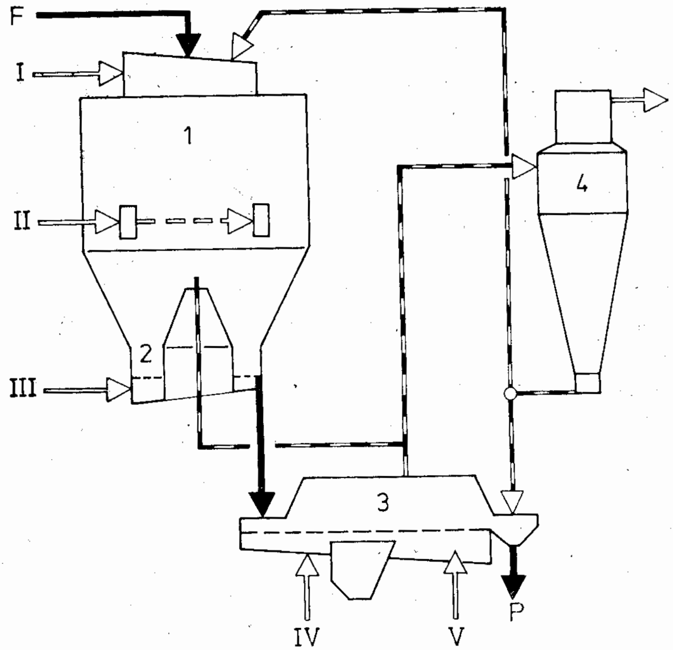

Fig. 6. Two-stage spray drying system; 1 — drying chamber, 2 — integrated fluidized bed, 3 — vibrated fluidized bed, 4 — cyclone, F — feed, p — product, I — fresh air, II — wall-sweep air, III — fluidized bed drying air, IV — fluidized bed drying air, V — fluidized bed cooling air

be removed in a single-stage drying process because heat and mass transfer coefficients are much better in a fluidized bed.

Removal of the last part of moisture by fluidized bed drying requires considerably less thermal energy than removal of the same moisture in a spray dryer. Table 2 shows that the specific heat consumption of a two-stage drying unit is about 20% lower than the corresponding value of a single-stage dryer, and product quality is also upgraded [5].

APPLICATION OF SOLAR ENERGY

Primary energy from fossil fuels can be saved by changing to other sources. Food processing plants need process heat in the form of steam or hot water in the lower and middle temperature range. Process heat of these temperature ranges can be generated today without risk by solar energy.

For temperatures around 70 °C (eventually up to 100 °C) flat collector systems without concentrating the radiation are suitable. Technology of solar systems is today well developed and they are installed in many areas (e.g. for room heating warm water provision). Flat collector systems

Table 2. Energy demand of single- and two-stage spray drying systems

		1-stage drying and pneumatic cooling	2-stage drying and post drying in a fluidized bed from 6 to 3.5% moisture	2-stage drying and post drying in a fluidized bed, with high air inlet temperature
Drying tower				
Hot air temperature	°C	200	200	250
Milk powder 3,5% (6%) moisture	kg/h	1295	(1565)	(2087)
Energy consumption per kg powder	kJ	5199	4300	4019
2-stage (fluid, bed)				
Hot air temperature	°C	—	130	130
Milk powder 3,5% moisture	kg/h	—	1525	2033
Energy consumption per kg powder in the 2 stage	kJ	—	225	214
Total energy consumption per kg powder	kJ	5199	4525	4233
Increase of powder production	kg/h	—	230	738
Energy saving per kg powder	%	—	13	19

are able to collect even diffuse solar radiation (up. to 50%) when the sky is overcasted. If higher temperatures are required (e.g. for food sterilization) it is necessary to concentrate or focus the solar radiation. In the concentrating systems incident direct solar radiation is reflected by mirrors and focused on a smaller area, which is smaller by the factor C (concentrations factor) than the reflecting area. In the focal point an absorber is situated, on which the density of energy is larger by factor C than the density of energy of direct solar radiation. Thereby in the focal point considerably higher temperatures can be generated. With concentration factors ranging from 30-50 temperatures up to 400 °C can be achieved. As a disadvantage of these systems it should be taken into account, that only direct and parallel incident solar radiation can be focused. Diffused solar radiation during overcasted skies cannot be used in the concentrating systems. Therefore such systems are intended only for countries having longer sunshine periods. These conditions are fulfilled for example in South Europe, neighbouring mediteranean countries and other similar regions.

These systems however deliver heat at the required temperature only as long as the sun shines and also only if a definite irradiations energy is achieved. Therefore parallel to a solar system a conventional heat producing system should always be available.

Two factories in Spain, a dairy and a canning factory, represent good examples of solar energy application in the food industry [10, 11, 12]. Solar irradiation is collected with cylindrical parabolic mirror collectors and focused on a tubular absorber, which is situated in the focal line of the mirror (Fig. 7). The mirrors are regulated with a sensor and are automatically adjusted with the position of the sun, so that the incident is circulated in a closed circuit and at the outlet of the collector field

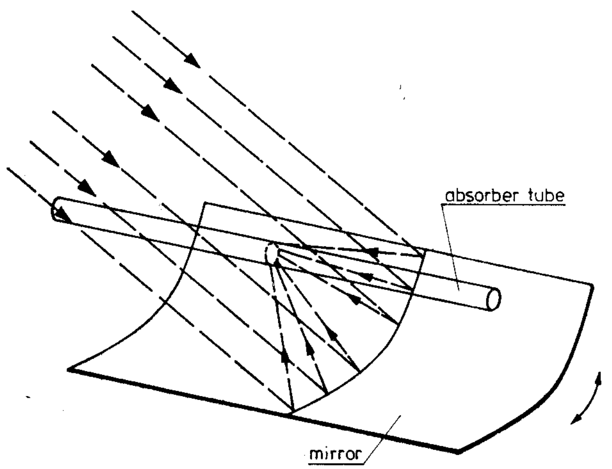

Fig. 7. Solar energy concentration system with reflecting mirror and absorbed tube filled with heat carrier medium

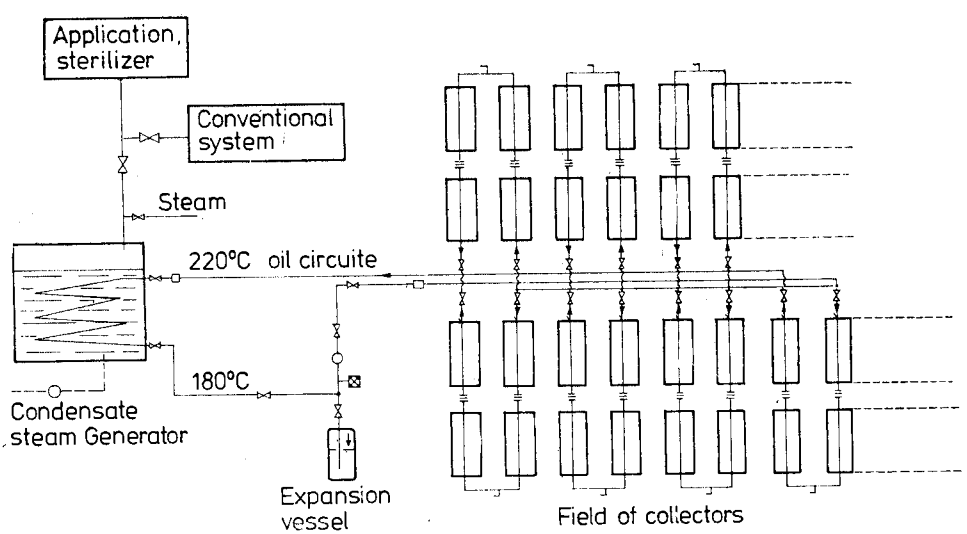

Fig. 8. Arrangement of a solar energy system in a Spanish dairy factory

is heated up to 220 °C. The oil discharges its heat in a steam generator, which generates saturated steam at 6 bar/cm^2 pressure. In the dairy radiation is always focused on the absorber. In the absorber tube oil plant a collecting field of 580 m^2 area installed on the roof generates a maximum of 400 kg/h saturated steam at a pressure of 6 bar/cm^2 (Fig. 8). In the canning factory a collecting area of 1120 m^2 produces steam at a pressure of 9 bar/cm^2.

SUMMARY

Today there exists a large number of approved technical solutions applicable without risk to save energy and costs in food processing plants. With all measures our aim should be to reduce our dependence on fossil primary energy and change to other locally available and cheaper energy carriers.

With almost all these measures, which reduce the steam or hot water demand in plants, we have, however, to consider that they lead to an increase of electric energy consumption. Changes of technology which are brought about at present or in future in all branches of the industry will lead to an increment of electric power consumption.

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WSPÓŁCZESNE I PRZYSZŁOŚCIOWE TRENDY W PRZETWÓRSTWIE MLEKA W WARUNKACH OGRANICZONYCH ZASOBÓW ENERGETYCZNYCH

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Streszczenie

Zużycie energii w przetwórstwie żywności zależy od zapotrzebowania energii i stopnia jej wykorzystania. Przede wszystkim należy polepszyć stopień wykorzystania energii.

Zakłady przetwarzające żywność różnią się między sobą pod względem zaprojektowania, technologii, programów produkcyjnych, wielkości przerobu i ich sytuacji energetycznej. Nie jest możliwe podanie ogólnej koncepcji dotyczącej oszczędności energii. Jednakże można zasugerować rozwiązania inżynieryjne dotyczące oszczędności energii dla poszczególnych operacji technologicznych. Mogą być one wdrażane indywidualnie lub w połączeniu z innymi rozwiązaniami. W ostatnich latach wdrożono do praktyki przemysłowej wiele takich rozwiązań.

Najprostszym i najtańszym sposobem oszczędzania energii jest bez wątpienia unikanie jej strat. Natomiast jednym z najbardziej interesujących i obiecujących rozwiązań technicznych dotyczących oszczędności energii jest wykorzystanie pierwotnych źródeł energii do jednoczesnego wytwarzania energii elektrycznej i ciepła w samym zakładzie, z szerokim wykorzystaniem ciepła odpadowego tego systemu do otrzymywania pary i gorącej wody. Regeneracja ciepła w procesach technologicznych jest najprostszym sposobem oszczędzania energii. Może być ona realizowana w sprawdzonych pod względem inżynieryjnym urządzeniach i z niewielkim nakładem kosztów inwestycyjnych. Jeśli odzyskane ciepło nie może być zużyte w samym zakładzie należy szukać możliwości jego wykorzystania poza jego obrębem. Należy przeprowadzać modyfikację urządzeń w celu mniejszego zużycia energii lub wprowadzać nowe, o lepszej efektywności wykorzystanie energii. Możliwa jest oszczędność energii pierwotnej, pochodzącej z kopalin przez sięganie do nowych źródeł energii. Na przykład energia słoneczna może być wykorzystana do wytwarzania pary i gorącej wody niezbędnej do przetwórstwa żywności.