ACTA ALIMENTARIA POLONICA

Vol. XIII (XXXVII), No. 3 1987

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ENERGY AND FOOD PRODUCTION

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The aim of this paper is to show the role of energy in man's life, and in food production in particular. The energy use by the food chain is evaluated and the share of agriculture and food processing industry in this consumption is investigated. A new method of ascertanining the energy intensiveness of the food production chain is proposed. Measures to lower energy use by the food processing industry based on the proposed method are described in detail.

INTRODUCTION

The consumption of energy in the world is increasing very rapidly, while the world nonrenewable energy reserves are being depleted at a rapidly accelerating rate. It is assessed that world energy consumption has increased from 2.3×10^{20} J in 1970 to 3.1×10^{20} J in 1980 and to 3.7×10^{20} J in 1985 [5.11]. It is expected that in 1990 this consumption will be close to 4.4×10^{20} J [11] (Fig. 1).

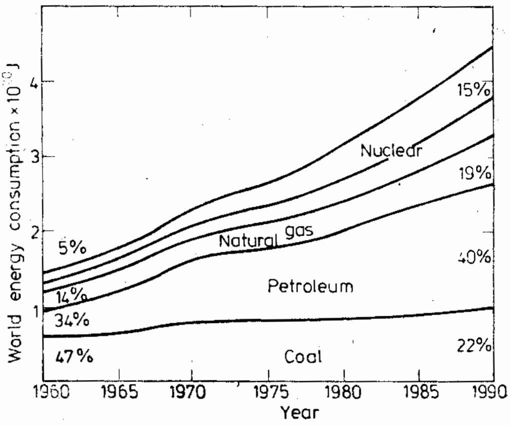

Fig. 1. Energy consumption in the world [11]

The increasing demand for energy in the world is due to two reasons. Firstly, the world population is growing at an exponential rate, and secondly, human labour is being replaced by machines, robots and computers on an ever larger scale. The drive to replace human work by machines as much as possible, and the improvement of the standard of living in developed countries leads to a rapidly increasing consumption of energy per caput (Fig. 2). Thus, the annual primary energy consumption by the statistical inhabitant of the world was equal to 37 GJ in 1950, 70 GJ in 1975 and is expected to reach 111 GJ in the year 2000 [5].

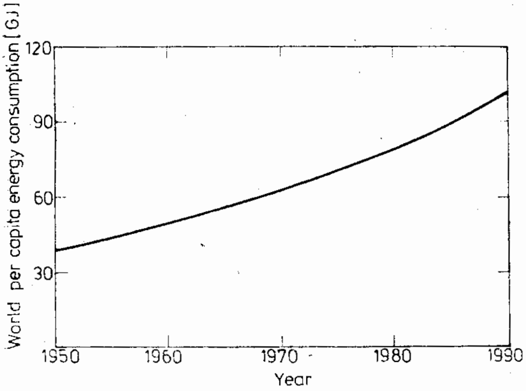

Fig. 2. Average annual per caput energy consumption

To illustrate the significance of these figures let us assume that a man is able to exert 75 W for 8 hours a day 250 days per year. He would annually produce 540 MJ of energy, i.e. slightly more than 0.5 GJ. Thus man uses annually 150 to 200 times more energy than he is capable of producing with his own muscles. Man's power capacity is, therefore, extremely limited, and the value of its work is insufficient to achieve a reasonable standard of living.

Taking that the daily food energy requirement of man is 10 MJ, the yearly food energy intake is nearly 3.7 GJ. Comparing this figure with

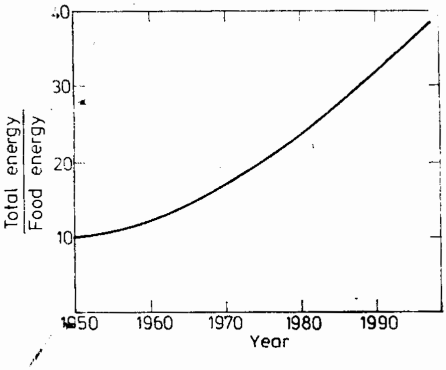

Fig. 3. Ratio of total energy used to food energy

man's power capacity we see that humans are biochemical energy converters of very low efficiency. Moreover, we see that man uses more than 25 times the energy he consumes as food (Fig. 3).

The above examples clearly show the role of energy in man's life. However, the quoted numbers might be misunderstood as far as the role of energy in food production is concerned. The ratio of 25 : 1 may suggest that food production is very low energy intensive when compared with the production of other consumer goods. This would be a false understanding of the matter because 3.7 GJ of food energy man requires annually is in the form of food ready to eat. Energy is needed to produce such food, and its input is large.

THE FOOD CHAIN

The food chain begins with the sowing of seeds and ends on the consumer plate. It consists of many links, the most important of which are: agriculture, processing and storage, transport, retail and consumption. The flow of materials in the food chain is represented in Fig. 4.

The food chain plays an important role in the energy economy of a country. In the USA it consumes around 16% of the total energy used by the nation [3], in France the figure stands at 12.3% [13], and in Japan

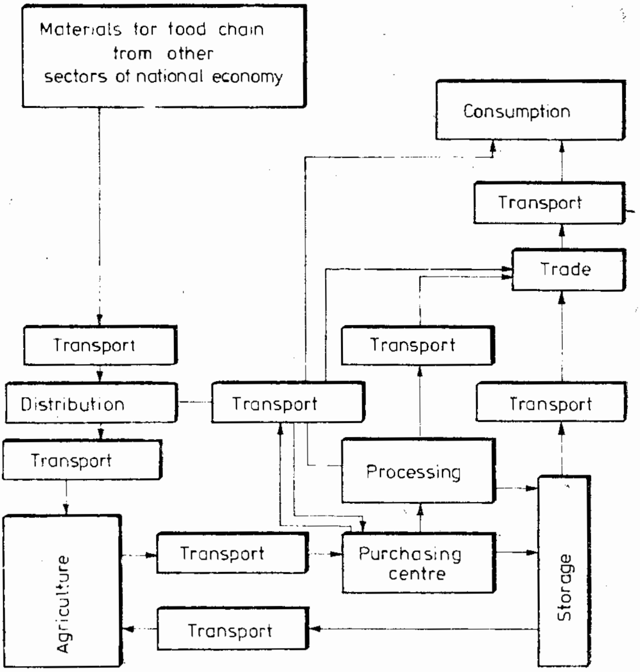

Fig. 4. Flow of materials in the food chain

at 11% [12]. The share of each link in the total energy consumption by the food chain is different and is affected by the primary energy sources, the technology and processes used, the food habits, etc. In the USA, agriculture uses 2.9% of energy, food processing industry takes up 4.8%, home food preparation 4.3% and preparation of food in restaurants, snack-bars cAC accounts for 2.8%. The share of wholesale trade is 0.5% and of the retail trade — 0.8% [3]. Agriculture consumes 2.7% of total energy in France [13], 3% in West Germany [13], 3% in Japan [12] and 5% in Poland [13] (Fig. 5).

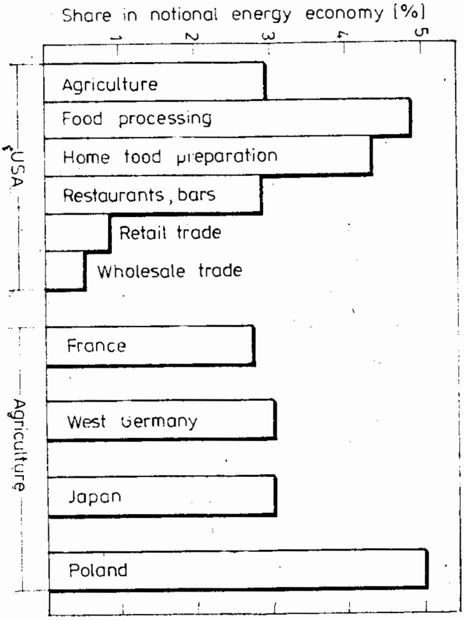

Fig. 5. The share of selected food chain links in national energy economy

As we can see the production of food raw material consumes from 20 to 30% of the energy used by the food chain. Taking that the food industry consists of processing, storage and distribution one may assess its share of energy consumption as being between 30 and 50%. Worth noting is the share of home food preparation and food services in the energy consumption by the food chain. It is between 20 and 50%, and in many countries it exceeds 30%. For example in the USA it is 30% [14] and in Japan — 38% [12].

The use of energy by the food chain is large. The comparison of energy input with the food energy obtained from the food chain shows that in many developed countries the production of 1 J of food energy requires at least several joules of primary energy. For example this ratio 1 : 10 in the USA [7] and 1 : 4 in Japan [12].

This high disproportion between input and output energy illustrates the low energetic efficiency of the food chain. In developed countries the efficiency is less than 20%. The question thus arises: what causes the losses? The answer is simple. The only producer of food energy is agriculture. The remaining links of the food chain merely process, preserve and refine the agricultural products, but do not supply them with food energy. Accordingly, the energy input into agriculture profits in food energy, while the energy used by the remaining links of the food chain is lost.

AGRICULTURE

Agriculture as food energy producer is also not very efficient. In France 1 J of fossil fuel used in agriculture provides 2.8 J of food, feed and fiber [11], in the USA 1 J of fuel produces 7 J of food energy [11]. The production of cereals, potatoes, sugar beets and green forage are the only energy-efficient processes in agriculture. The ratio of food energy to primary energy (Er) for these materials is higher than 1. In growing wheat, 1 J of fossil energy gives more than 3 J of food energy (Table 1) and $Er > 3$; for potatoes $Er > 2$, for sugar beets $Er > 4$, and for green forage Er is still higher. For lucerne $Er = 6.2$, for hay $Er = 5$ and for corn silage $Er = 4$. The energy ratio for vegetable and fruit production is much lower, usualy below 1 : for tomatoes $Er = 0.6$, for carrot $Er = 1.1$, for green peas $Er = 0.94$ and for apples $Er = 0.5$. The use of geenhouses in agricultural production affecsts the energy ratio very strongly. For example, the energy ratio for lettuce cultivated in a greenhouse is 0.002.

Table 1. Energy ratio of selected agricultural products [8]

Product	Er
Barley, G.B.	2.4
Beef	0.04
Carrot, G.B.	1.1
Corn, USA	2.58
Eggs, G.B.	0.14
Green peas, G.B.	0.94
Milk, G.B.	0.374
Pork	0.20
Potato, USA	2.27
Poultry, G.B.	0.10
Rice, USA	1.29
Sheep meat	0.04
Sugar beet, G.B.	4.20
Wheat, G.B.	3.35

Substantial losses of energy occur in animal production. This is because animals, like humans, are energy bioconverters of low efficiency. Animal efficiency seldom exceeds 20%. Production of milk and eggs gives Er = 0.22, of beef and sheep meat 0.10, of pork 0.20 and of poultry 0.18 [11].

PROCESSING OF FOOD

Raw materials entering the food industry contain a certain amount of energy and their processing requires an expenditure of energy amounting to 0.2-10 J of primary energy per each joule of food energy, depending on the kind of product.

Processing, preservation, refining and storage of food products require an input of energy. The demand for energy is affected by many factors such as: the type of raw material used, applied technology, mechanization and automation of processing lines, the energy source, etc. The input of energy is relatively large, ranging from a fraction of one megajoule to tens of megajoules per one kilogram of product. For example, the production of granulated sugar from sugar beets requires from 8.3 to 18.2 MJ/kg, the production of liquid milk requires 0.6-7 MJ/kg, of tomato paste 13-30 MJ/kg, of beer 1.6-5.9 MJ/kg, and of white bread 4-14 MJ/kg (Table 2). These figures, compared with the energy intensiveness of other commercially produced products show that energy consumption by the food processing industry is substantial. According to data typical for Poland [10], mining of coal needs 0.255 MJ/kg, of crude oil 2.795 MJ/kg,

Table 2. Energy use in food processing [9]

Product		Energy use, MJ/kg
Beer		1.6-5.9
Bread		13.9
Bread and wheat milling		18.8
Canned green peas		2.3-2.6
Canned meat		2.5-2.6
Granulated sugar	(France)	10.5
	(FRG)	17.6
	(G.B.)	8.3
Dried green peas		4.1
Dried whey		23.5
Liquid milk		0.6-7.0
Frozen green peas		3.7
Margarine		13.6
Tomato paste		13.1
Wine		4.2-17.0

the production of raw iron requires 15.4 MJ/kg of rolled iron 5.5 MJ/kg and of electrolytic aluminium 61.16 MJ/kg.

Processing causes definite changes in quality of food material. The inedible parts of the material are usually removed, new forms and shapes are created, chemical composition may be altered, and new attractive sensoric attributes chieved. In some processes material is cooked or converted to form that is ready to eat. In other processes material is packed in hermetic containers and preserved. In all these processes energy is consumed and the food energy of the product changes, albeit usually to a small extent only. The relationship between energy input in food processing and the changes of Er is illustrated in the following examples.

White bread is an essential food product. The toal energy input for white bread production is, according to different sources, up to 20 MJ/kg. The energy requirement is divided as follows (Fig. 6): production of raw materials — 19.5%, milling wheat — 12.9%, processing, packaging and transport — 64.3%, retail stores — 3.3%. As for the energy ratios in white bread production wheat has Er = 3, after milling the Er for flour is 1.8, after confection Er = 0.52, and white bread on the table of a consumer has Er = 0.50. The cycle of white bread production changes Er by 83%.

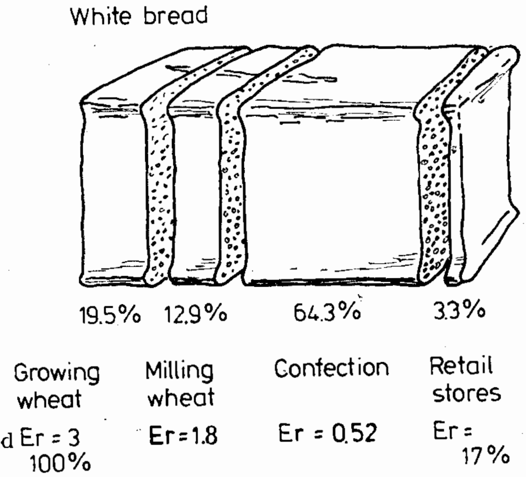

Fig. 6. Total energy use in white bread production [6]

Canned green peas. Cultivation of peas requires an energy input of 2.5 MJ/kg [8]. Processing takes 1.4 MJ/kg [1] while transportation and retail trade require as much as 2.3 MJ/kg [1]. The package (tin can) is an energy-intensive product and its energy equivalent is equal to 7.8 MJ per unit [1]. The total energy input is 14 MJ/kg. In this process the energy ratio changes from 1 to 0.07. If the energy equivalent of the can is not included in the calculations, the energy ratio changes from 1 to 0.16. Again, an 84% decrease of Er is due to processing, distribution and retail. This example is worthy of notice, because it shows that more than 50% of the energy input in canned green peas production goes to the packaging material. It shows, moreover, the way in which energy intensiveness of food production can be affected by energy intensiveness of other branches of national economy.

Milk production requires, on the average, 8 MJ/kg [8]. Processing of liquid milk takes up 2.1 MJ/kg [2]. The package contributes large amounts of energy to the total energy consumption in the production of liquid milk. The production of glass bottles or cardboard containers requires around 1.8 MJ a piece. The energy ratio changes from 0.30 to 0.25 if the energy expenditure to produce the package is not taken into account. Hence the change in Er is only 17%.

Canned meat produced on the basis of pork represents a still different situation. The production of one kilogram of pork meat requires 48.5 MJ [8]. Processing uses 2.5 MJ/kg and the metal can adds another 7.8 MJ. The total figure is 60 MJ/kg. Energy ratio changes from 0.20 to 0.16, i.e. by about 20%. If the metal can is not included in the calculations, the Er of the produce is 0.19 and the change is less than 5%.

The above examples show clearly that the change of energy ratio is greater when the energy ratio for the raw material is higher (Fig. 7). This course of the curve is also theoretically justifiable. If the energy input to produce a raw material is very small, Er tends to infinity. Hence, any input of energy due to processing and distribution decreases Er substantially, and the change of Er approaches asymptotically 100%. On the other hand, when the energy input to produce a raw material

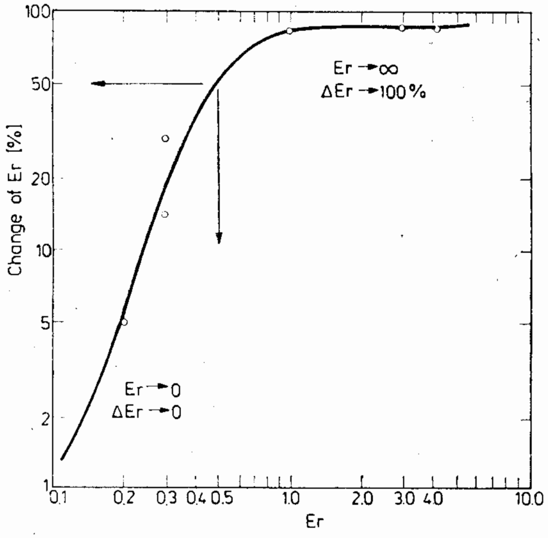

Fig. 7. Relationship between the change of Er due to processing and Er of raw material

is very large then Er approaches zero. Thus, the energy input in food processing is here relatively small and the change of Er is close to zero.

Taking the 50% change of Er as the dividing line, we way classify raw materials and processes in the food chain into two groups. Raw materials with Er $>$ 0.5 are sensitive to energy input into processing and distribution. To decrease Er changes in these materials during processing, it is necessary to lower energy consumption by the processing industry. Hence, energy management and conservation become very important, and they are the main factors affecting the change of Er. Raw materials with Er $<$ 0.5 are less sensitive to energy intensiveness of processing. Total energy consumption is mainly affected by the raw material and because of this, raw material management and conservation become very important.

MEASURES FAVOURING LOWER ENERGY USE IN FOOD PROCESSING

The above discussion shows that energy efficiency of the food processing industry can be improved by proper management and conservation of raw materials and energy. The approach to this improvement depends on the raw material being processed.

The most important goal when raw materials with Er $<$ 0.5 are being *processed is full and appropriate utilization of raw materials.*

This can be achieved by:

— reduction of raw material losses in processing, storage and transportation;

— use of waste materials to produce animal feed or energetic materials,

— development of wasteless technologies.

Measures improving energy management should be undertaken with less priority.

The improvement of energy management and energy conservation become of foremost importance when raw materials with Er $>$ 0.5 are processed. Experience from a wide range of industries shows that energy saving measures are as follows [4]:

— good housekeeping and skilful management,

— part replacement,

— modification of existing plants,

— new processes,

— improved efficiency of energy use in buildings.

Let us elaborate on some of these.

Good housekeeping and skilful management. It is normally possible to resolve the energy use into three components:

— production related process energy use,

— production unrelated process energy use,
— non-process use.

The production related uses are those where is a relationship between production and energy consumption. The production unrelated process energy uses are those which are part of the process, but which do not vary with the rate of production. These comprise such things as heat losses, the energy used to bring the plant to running conditions, etc. These components of energy use are shown in Fig. 8.

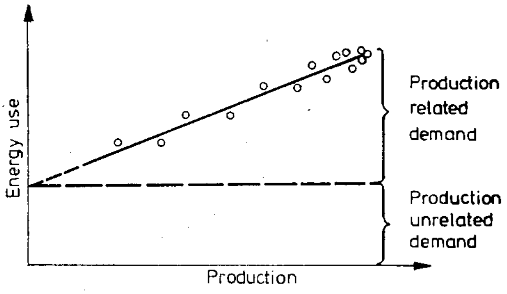

Fig. 8. Components of production process energy use [4]

Non-process uses include lights, building space heating, workshops, the canteen, etc. This is energy use not essential to production.

Production related energy demand is usually fixed by the design of the plant. Therefore, the main areas for saving energy by housekeeping and skilful management tend to be in non-process and process unrelated uses. These can be done only by ensuring adequate instrumentation, and subjecting energy use to proper measurement and analysis.

Part replacement. The food manufacturer normally expects his equipment to last a considerable time. Normal wear of parts takes place during the equipment exploitation, and he is not likely to throw out a serviceable machine and replace it just to save energy. Instead, good maintenance takes place and particular components are replaced at low cost. The state of the equipment decides about its running costs and energy use. In some cases a serviceable equipment can be improved by replacement of old parts with parts newly designed. This can certainly apply to burners, some types of fans, etc.

Modification of existing plant. The most common form of this is heat recovery, where the plant itself is not changed. New devices are added such as heat pumps, heat pipes, thermal and mechanical vapor recompression, re-use of air from dryers, etc. Moreover, to recover waste heat new processes are designed and introduced to the existing plant. Recovery of waste heat has a great potential and, as we think, is one of the possible solutions to the limited energy supply.

New processes. In considering new processes it is important to bear in mind the special requirements of the food processing industry. Process change for energy saving can be approached in three possible ways, namely by:

— changing the process to produce the same product in the same way, e.g. by changing the equipment;

— changing the process to produce the same product by a different method, e.g. the use of reverse osmosis to concentrate a product, or aseptic filling instead of post-filling heat treatment;

— changing the process to produce a new product.

The energy-saving measures listed above require different amounts of skill, power and money. Some of them can be introduced without any investment, while others may need expensive investments. The measures can be considered as short- and long-term, but introduction of new processes is probably one of the most difficult approaches to save energy. A new available technology takes time to penetrate industry. Also, any new development may find itself up against institutional or consumer resistance.

In the context of the above discussion it seems obvious that energy savings by proper management are easier and in many cases they would be low-level investments and short-term measures. The development of new technologies, on the other hand, is more difficult, usually being a high-level investment and long-term approach.

Summing up the role of energy in the food chain, especially in food processing, it can be said that a reduction of energy input can be achieved by proper management of raw materials and energy. Depending on the energy ratio of the raw material the measures to save energy differ as to quality and sequence of introduction. However, even small savings obtained in each plant add up to thousands of tons of coal saved on the global scale. The saved fuel can be used to produce more food. Let us thus begin with these small savings. They are worth a lot.

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ZUŻYCIE ENERGII W PRODUKCJI ŻYWNOŚCI

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Streszczenie

W pracy omówiono znaczenie energii w życiu człowieka i w produkcji żywności. Porównując aktualne ciągnione zużycie energii w produkcji żywności oraz energetyczne potrzeby człowieka i jego zdolność do wykonywania pracy wykazano, że energia jest niezbędna do utrzymania poziomu życia na względnie dobrym poziomie.

Zużycie energii w łańcuchu produkcji żywności jest znaczne i wywiera wpływ na gospodarkę energetyczną każdego kraju. Łańcuch produkcji żywności składa się z wielu ogniw, z tym, że w pracy poruszono tylko zagadnienia związane z rolnictwem i przetwórstwem. Rolnictwo jest producentem energii zawartej w żywności, natomiast przetwórstwo tylko uszlachetnia, konserwuje i rozprowadza produkty rolnicze. Sprawność łańcucha produkcji żywności i poszczególnych ogniw oceniana jest za pomocą stosunku energii zawartej w żywności do wkładu energii pierwotnej na jej wyprodukowanie. Na bazie tego stosunku i jego zmian w procesach technologicznych zaproponowano podział surowców dla przemysłu spożywczego na dwie grupy. Pierwsza grupa zawiera surowce o stosunku energii mniejszym niż 0,5, a druga — o stosunku większym niż 0,5. W celu uzyskania wysokiej sprawności energetycznej łańcucha żywności pierwsza grupa materiałów musi być przetwarzana w warunkach bardzo racjonalnej gospodarki surowcowej. Oszczędna gospodarka energią również odgrywa tu rolę, ale wpływa na sprawność energetyczną łańcucha w małym stopniu. Druga grupa materiałów wymaga oszczędnej gospodarki energią, aby uzyskać odpowiednio wysoką sprawność energetyczną łańcucha produkcji żywności. Gospodarka surowcem wpływa na sprawność w mniejszym stopniu.

Kierunki działań zmierzających do poprawienia gospodarki energią w przemyśle spożywczym są również omówione w niniejszej pracy.