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Improving energy efficiency of biotechnical agricultural systems – scientific and organisational Issues

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Abstract. The production process of an agricultural and industrial complex (AIC) includes processing of big areas of fertile soil that receive sun-generated electromagnetic energy. This is one of the peculiarities of the AIC, determined by the fact that the AIC produces primary (plant-based) food. The plants use part of the sun-generated energy to synthesise biological energy, which forms the nutrition value of the product and which is measured by a rational (relative) factor per unit of area. A plant community is a biological system where each plant is a biological element. The amount of fuel energy (which is anthropogenic unlike sun-generated energy) consumed by an AIC company to produce plant-based food is determined by the energy efficiency of the technical elements (fuel cells, both mobile and immobile) included in the consumer energy system (CES).Crops also supply food for livestock farming, which is the second biological branch of AIC and produces the second type of food, meat and poultry. Animals and poultry are raised using daily feed flow as the source of energy. As the energy consumption and the energy efficiency (expenses and return on investment, respectively) are determined by the technical part of the consumer energy system, it is necessary to find the dependence between the CES and biological systems (crop farming and animal farming) in the food production process.

Key words: energy saving, power consumption of production, criteria of energy efficiency, consumer power system.

INTRODUCTION

The concept of energy efficiency can be defined in various ways, the most popular of which is the relative decrease in energy consumption. Taking into account the overall aim of generating energy for the production of material goods and the fact that the material goods are the product of any enterprise, then product energy contents could be a relatively common unit of measurement, showing the amount of energy used to produce one piece of the final product. However, this value is applicable to similar plants producing similar products and is not suitable for evaluating the energy efficiency of a big corporation, region or state. As the sales markets and demand for products are the common evaluation factors of the units at this level, then the focus of analysis shifted from energy efficiency to gross regional product (GRP) and gross domestic product (GDP) energy contents, introducing a very specific indicator of energy contents of profit.

Even though this indicator shows efficiency indirectly (by means of demand),it does not impede the evaluation of energy-efficiency for the purposes of production development and for justifying the control methods of efficiency. International energy efficiency practices (Stasinopoulos et al., 2012), led to two important principles – integrated approach to system design and sustainable system development. Numerous instructive examples of energy consumption efficiency analysis in various production processes, cited in the book, use the efficiency factor (generally accepted non-dimensional parameter) as the means of evaluation. 'Efficient use of energy' (Karpov & Yuldashev, 2010), the concept of consumer energy system (CES) Fig. 1 – offers its own relative indicator to analyse the consumer energy efficiency.

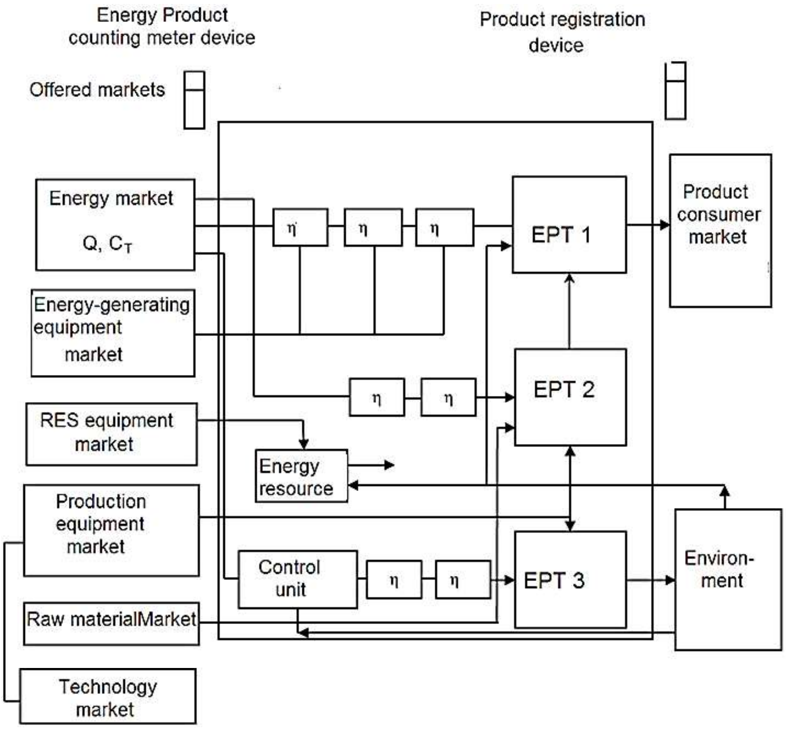

Figure 1. Energy scheme of the CES.

This indicator defines the relative energy contents *Qe* that is constantly moving through the technical element (TE) as the ratio between the input energy *Qi* (original measurable energy supplied to TE) and output energy *Qo* (measurable energy, leaving TE), i.e. $Qe = Qi / Qo$.

The introduction of the indicator makes it possible to analyse the efficiency of every individual TE as $Qe = 1 - \Delta Q/QQ$ (where $\Delta Q = Q_i - Q_k$ = energy losses in TE).and the efficiency of the energy transfer line connecting consecutive TEs, reveal the types of energy used by CES and efficiency of various types of products, simulate CES with a single TE that represents the total input energy and the sum of energy losses in the system.

Energy-technological processes (ETPs) that generate the result *R* by consuming the input energy are the key for CES energy efficiency. The value *R* is defined by the product manufacturing technology. The ETPs also determine the energy contents of the result *R*, where the energy contents is primary not only for the CES but also for the complete energy transfer system, from the energy generation point to the ETP.

MATERIALS AND METHODS

The basis of the research methods is made up of mathematical analysis of the energy efficiency criteria and suggestions to reduce energy waste. Therefore, the main and primary aim of the analysis of the biotechnical system (i.e. the conglomerate of the technical and biological systems within an AIC) is to define the specific role that the energy and technology processes of the technical system play in the efficiency of the biological system. Following our methodology, we first calculate the amount of consumed energy theoretically required (without losses) to receive *R* with the best achievable $Qe = 1$ (maximum efficiency), and then compare it to the measured amount of energy, actually consumed by ETP and exceeding the calculated net amount by the sum of various losses.

The share of the losses compared to the theoretical (minimum) energy consumption used to receive R defines both the reason (losses) and the value of the actual increment of the minimum Qe = 1 (at the minimum energy consumption). The advantage of the method to analyse the energy efficiency (using modern-type meters, PES and ETP with pre-defined R), offered by the Scientific School, entails the possibility to divide (differentiate) the consumed energy into two types: active energy and losses caused by the physical properties of various TEs.

Taking a multi-level hydroponic narrow-shelf greenhouse technology as an example (Kabanen, 2008), he proves that due to the design of the electric lamp it is not physically possible to arrange the shelves and the light flow within the greenhouse space to avoid the light losses. Moreover, this type of loss cannot be compensated even by increasing the power of the lamp and the energy consumption. The losses can be reduced or eliminated by using a light emitting diode instead of the traditional lamp.

Therefore, the Scientific School method allows defining and reducing in each of the CES energy lines the losses that increase the relative energy contents over *1*. The totalities of all the theoretical (calculated) amounts of energy in all energy lines on one hand and all losses on the other are the two complementary components of the amount of energy that CES used to make the product. The school suggests treating the first component as a system active energy and the second as a system loss. These two components determine the energy contents of the product, differentiated by the usage efficiency, not by a traditionally calculated statistical average one. We have to note that this differentiation is possible for energy consumer systems, but not for the energy transfer systems, which is why we can reasonably argue that any attempt to reduce the energy contents must begin with the energy audit of the consumer systems.

The possibility to control energy savings in technical consumer systems (i.e. in CES) has been experimentally verified in laboratory and real-life conditions, so we can claim that we are scientifically and methodologically ready to address this issue.

The extended CES layout including both fixed and mobile processes, land treatment and livestock-related processes describes the links between CES and the processes that support biological activities. Main focus was on basic energy flows to biological objects (plants, animals, poultry). Fig. 2 shows the results of the analysis of energy links between technical and biological objects.

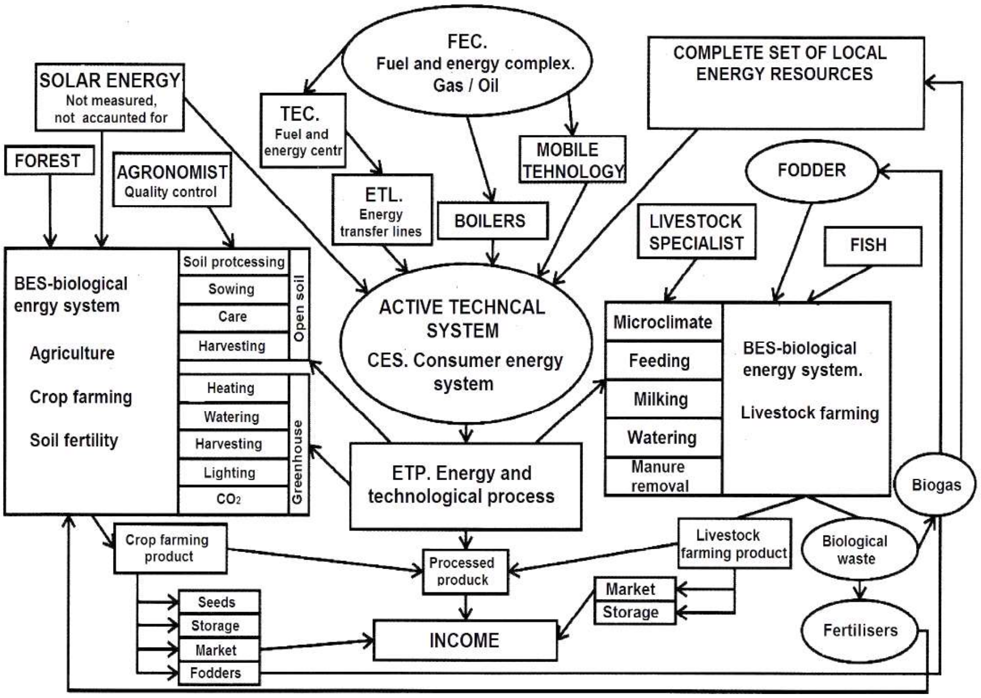

Figure 2. Energy links between CES, plant and animal farming.

The general industry-related energy layout reveals some important characteristics. Solar energy, transformed by plants into nutritional biological energy, and not anthropogenic (fuel) energy, is the source of nutritional biological energy contained in the basic agricultural plant products. The figure shows examples of fuel consumption in order to grow plants in open soil and in a greenhouse (left) and to keep animals (right). The 'fodder' line connecting the left and the right sides shows that the fodder of plant origin, containing biological energy and not fuel energy, is the main energy flow keeping the animals alive. This means that the energy contents of food production (both plant and animal) in the traditional meaning of the term is created by the technical system (PES), maintaining the plant and animal farming only, i.e. the energy contents of the farms fully depend on the energy efficiency of the power equipment used, on the plant farming technology and on the soil productivity.

As proven by the electric water heating experiments (Karpov et al., 2016), the technical equipment of the energy and technological process (ETP) can be considered a TE where energy is supplied and technological result *R* of the energy consumption is created and monitored. Meanwhile, the action (energy consumption) process is the only one of all the TE processes to register the energy losses that increase the energy contents of the product and reduce the energy use efficiency.

This is presenting on the diagram of water heating at various ΔT (Fig. 3). The squares (non-hatched part) are the analytical foundation of the figure. These show the scales of the axis values in each quadrant as built according to the preliminary calculations. The first quadrant shows the amount of energy used to heat 20 litres of water by ΔT = 40 °C (Q = cmΔT, where Q = 3,352 KJ, time t = Q/P = 2,682 seconds and P – constant electric heater capacity).

The other two quadrants do not pose any questions. In the course of the experiment performed to verify the calculations, it turned out that the heating time determined by a straight line in the third quadrant and reflecting the ΔT value has increased by Δt. While the heater capacity remained constant, the amount of the consumed energy increased by up to 4,165 KJ pro rate the time. The energy losses are shown in the first quadrant as the increment of the calculated 3,352 KJ by 813 KJ. However, these are not actual losses, but the indirect result of its estimation at the heater input, i.e. this is the increment of the amount of energy supplied to ETP, not including the losses in the supply line within the enterprise.

Nevertheless, this increment allows evaluating the relative energy contents of the water heating process under certain conditions that are variables in the real-life environment (initial water temperature, ambient air temperature, presence / absence of air exchange, condition of the heater body thermal insulation, amount of the heated water, etc.). Considering that any direct measurement of the energy loss is not possible, that any PES contains a lot of ETPs, that these are of various duration (from daily to annual), and that farming takes place in various climates, it would be reasonable not to determine certain energy contents of a product but to find a certain acceptable minimum value and monitor and find reasons for deviations therefrom.

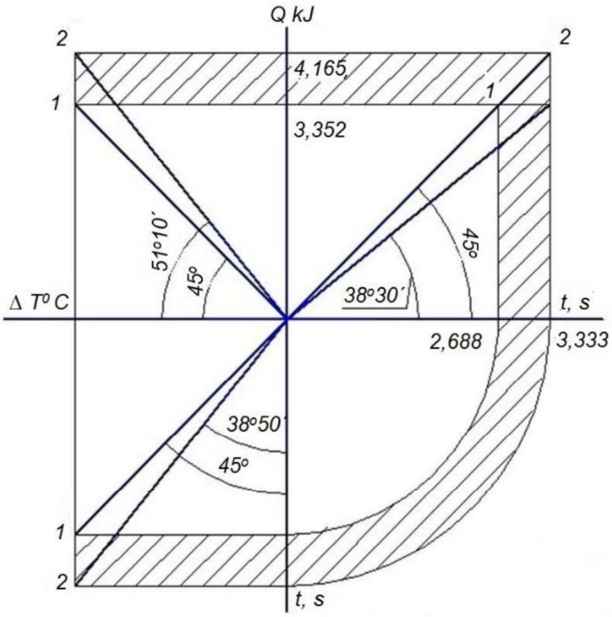

Figure 3. Energy diagram of water heating.

Taking into account the high relevance of the energy efficiency, high importance of technical consumer systems for methodological purposes and unique role of ETP energy within the systems as the means to determine the losses, we suggest distinguishing PES of plants as a separate class of active technical systems.

RESULTS AND DISCUSSION

This class may include the industrial technical systems that are supplied with energy in order to receive the result (product) of the system technology. These systems shall have the second (in addition to reliability) key indicator – high energy efficiency. It should be clear that any technical system which is reliable enough to keep operating, may do it with unacceptably high energy contents of the technological result, which in turn leads to unacceptably high energy contents of the final product, loss of competitive capacity and reduces the economic position of the whole plant. That is why informational support of the production process must be an indispensable part of any active technical system with the aim to determine the energy contents of the product and the system structure of the energy contents. The structure must be defined by the energy contents of all consumer system ETPs that are the result of the energy application and the primary indicator of the energy efficiency, as this indicator is obtained in the very end of the energy supply and usage chain. The closer the imaginary locus of the indicator is to its source (along the energy transfer line), the larger is its value due to increased losses of energy in the technical elements that form the energy transfer line. This is the reason why unbiased efficiency of energy usage cannot be determined in the energy transfer lines all the way to the consumer. This description of energy saving method allows postulating that this method makes CES a self-sufficient system indicator for the purposes of managing the energy contents of the final product. Inclusion of biological objects in the system means adding more ETPs and upgrading to a biotechnical energy system (Fig. 2), although the analysis of the energy efficiency of these processes remains basically the same, as the processes remain active processes and therefore the method of defining the energy contents of the biological products (fodder, food) does not change either. The only new factor is that the value of the product will be annually defined mainly by the productivity of the crop, soil fertility, and local climate, not by the amount of energy input in ETP. This is the reason for introducing innovative management of energy and biological processes at all stages of the crop vegetation in order to increase the specific (per unit of soil area) yield.

In terms of energy efficiency management, the multi-factor yield dependence may lead to using the soil for energy production, for instance, instead of biomass production. Therefore, the strict requirements of the energy efficiency make the agricultural energy (as a consumer energy system) management a multi-discipline occupation which in turn generates new requirements for professional training in agricultural schools.

CONCLUSIONS

Establishing the connections between the biological and technical systems will allow applying mathematical methods to determine and evaluate certain criteria of biological systems. For example, a unit of land area can be evaluated and controlled both in statics and dynamics and not only in terms of growth efficiency. We will be able to evaluate the available area as a renewable energy resource (wind, sun, water flow) and offer the principles of using this resource. The treatment of biological waste as an additional source of energy will become more practical. The need to co-ordinate professional training curricula of biological, technical, and legal specialists employed by AICs will be evident, pressed by the competition in the sale of products. We should also highlight that the request for energy efficiency raises new scientific issues of agricultural production. The reason for these issues is the combination of determined and probability processes that form the energy contents of the monetary investments in the business. The research shows that mathematically, the calculation of the energy loss involves the differentiation of energy as a time function of complimentary elements with variable degree of smallness, i.e. the section of further mathematics, which is not included in the curriculum of the agricultural university. The possible multi-functional application of a square unit introduces a new field for the simplified numerical calculation of integral for the purposes of the agricultural energy management in addition to the standard units of time and length. This allows, in particular, comparing biological and non-biological technologies, considering energy-containing biological waste as a source of energy, and generating a unified approach to other biological objects in the country (e.g. forest or fish).Territorial differentiation of fertile soils creates new ways for using modern scientific and technical achievements (GPS, robots, drones, etc.) in precise land management.

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