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ENERGY AND EXERGY ANALYSIS OF FUEL CONSUMPTION IN AGRICULTURAL SECTOR – SERBIAN CASE

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Abstract. *Agricultural sector is of great importance to every society. It is also a great energy consumer. Based on the relevant statistical data on the use of various energy sources, it can be concluded that diesel is the most used fuel in Serbia today. It is used to run the agricultural machineries. Therefore, a thermodynamic analysis of energy use in the agricultural sector of Serbia was conducted considering the fuel consumption for the ten-year period from 2008 to 2017. The paper presents an energy and exergy analysis of the use of energy products for the needs of agricultural mechanization in Serbia. A comparison was made with the available data from other countries.*

Key words: *energy efficiency, exergy efficiency, agricultural machinery, transport diesel, diesel gas oil*

1. INTRODUCTION

Agriculture has a great importance for every society. It ensures not only the food security of the country but also the production of raw materials for its own purposes and for the demands of other branches of the economy. Furthemore, taking into account the world trade of agricultural products, agriculture has a huge impact on the social and demographic aspects of every country. Considering the significant available natural and human resources and the achieved level of production and processing, agricultural activity in the Republic of Serbia is one of the key economic activities.

Serbia's agricultural sector is also a major energy user, using 2% of total final energy. Based on the data of the Total Energy Balance in 2017 [1], an overview of the use of total final energy by different sectors is shown in Figure 1**.**

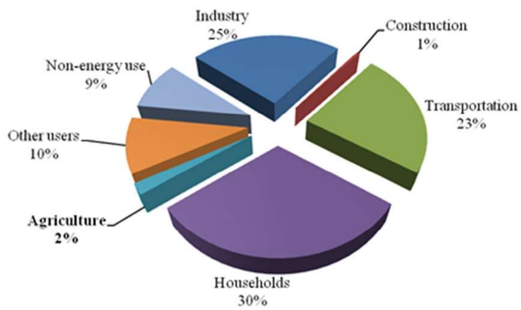


Fig. 1 Utilization of total final energy by different sectors in 2017 [1]

Agriculture consumes large quantities of scarce oil derivatives. Based on the relevant statistics on the use of different energy products in this sector, it can be concluded that diesel fuel is the most used energy source in Serbia today. A comparative overview of diesel fuel use in agriculture and other economic activities [2] is given in Figure 2.

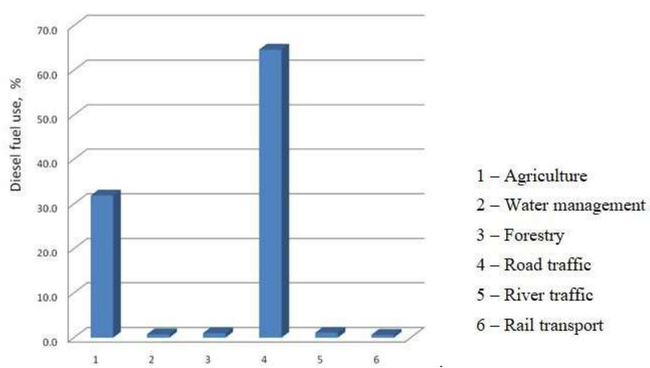


Fig. 2 Use of diesel fuel by different economic activities in 2003

A comprehensive approach considering energy use in the agricultural sector involves not only the amount of energy used, but also its quality, which can be achieved through exergy analysis. This paper analyzes the energy and exergy needs for agricultural machinery in Serbia and compares it with available data from other countries.

2. THEORETICAL BASIS OF ENERGY AND EXERGY ANALYSIS

The first law of thermodynamics is the law of energy conservation. However, it does not provide information on how, when and where amount of performance is degraded. Exergy or work potential is the quantity that provides this information. In thermodynamics theory exergy is usually defined as maximal useful work, which could be obtained by existence of thermodynamic non-equilibrium between the observed system and environment [3]. Unlike energy, in energy processes exergy is lost, destroyed, which means that energy loses quality (energy degradation takes place). Exergy analysis

allows us to locate processes and devices where energy quality is lost and to devise strategies and measures for thermodynamical improvements.
Energy and exergy balances of an open thermodynamic system, at steady state process, can be written in the form:

$$Q + W_t + \sum_{ul,i} m_{ul,i}\,(h_{ul} + e_{k,ul} + e_{p,ul})_i = \sum_{izl,j} m_{izl,j}\,(h_{izl} + e_{k,izl} + e_{p,izl})_j \qquad (1)$$

and

$$Ex_Q + Ex_W + \sum_{ul,i} m_{ul,i}\, e_{x,ul,i} = \sum_{izl,j} m_{izl,j}\, e_{x,izl,j} + Ex_{gub} \qquad (2)$$

Where m_{ul} and m_{izl} represent, respectively, the mass of the substance entering the system and the mass of the substance exiting the system; Q is the heat transfer between the system and the environment; Ex_Q is the exergy by heat transfer Q; W_t represents the work performed by the system; Ex_W is the exergy transfer by work; W_t; Ex_{gub} represents exergy losses. The working substance under consideration is at temperature T, pressure p and has specific values of enthalpy h, kinetic energy e_k, potential energy e_p and flow exergy e_x.
Exergy losses due to thermodynamic irreversibility during the process are determined on the basis of the expression:

$$Ex_{gub} = T_0\,\Delta S_{is} \qquad (3)$$

Where $Ex_{gub} > 0$ for an irreversible process and $Ex_{gub} = 0$ for a reversible process.
The exergy by heat transfer is determined by applying equation:

$$Ex_Q = Q\left(1 - \frac{T_0}{T}\right). \qquad (4)$$

The exergy transfer by work equals the work performed:

$$Ex_W = W_t \qquad (5)$$

When it comes to flow exergy of a working substance it consists of the exergy of macroscopic kinetic energy e_k, the exergy of potential energy e_p, and the physical e_f and chemical part of exergy e_{ch}, arising from the thermodynamic imbalance of the fluid flow with respect to the environment. The environment is in equilibrium at constant values of temperature T_0 and pressure p_0, while the concentration of individual components in the environment is different from their concentrations in the working substance itself. In the general case the flow exergy can be written in the form:

$$e_x = e_k + e_p + e_f + e_{ch} \qquad (6)$$

In the case of hydrocarbon fuels, including diesel fuel, (assuming $e_k = 0$ and $e_p = 0$) the physical part of exergy at conditions close to the environment is approximately equal to zero $e_f = 0$. What follows is that the flow exergy of a fuel is equal to its specific chemical exergy, which can be written in the form [3-5]:

$$e_x = e_{ch} = \gamma_f H_f \qquad (7)$$

where γ_f is quality factor of the fuel, H_f is the higher heating value of the fuel. The value γ_f, which depends on the fuel composition, is determined according to the models available in the literature. Table 1. gives H_f, e_{ch} and γ_f for the most commonly used fuels. The values shown are determined for a constant reference state of the environment - air at temperature $t_0 = 25^{o}C$ and pressure $p_0 = 1$ atm.

Table 1 Properties of appropriate fuels [4]

Fuel	H_f [kJ/kg]	e_{ch} [kJ/kg]	γ_f [−]
Gasoline	47.849	47.394	0.99
Natural Gas	55.448	51.702	0.93
Fuel Oil	47.405	47.101	0.99
Diesel	39.500	42.265	1.07

The performance of the device can be described by energy (η) and exergy (η_{ex}) efficiencies, which are defined in the usual way - as the ratio of useful and input value. The useful effect of agricultural machinery is in the form of mechanical work, which is obtained at the expense of motor fuel combustion. What follows is that the energy and exergy efficiency of machines using a certain type of fuel can be expressed in the form of:

$$\eta_m = \frac{W_t}{m_f H_f} \tag{8}$$

and

$$\eta_{ex,m} = \frac{Ex_W}{m_f e_f} = \frac{W_t}{m_f \gamma_f H_f} = \frac{\eta_m}{\gamma_f} \tag{9}$$

3. DATA ANALYSIS, RESULTS AND DISCUSSION

The analysis of the amount of energy products used in the agricultural sector was conducted on the basis of database Balance of Oil and Oil Derivates within the annual energy statistics of the Statistical Office of the Republic of Serbia. The analysis covers the share of *transport diesel* (diesel label) and *diesel gas oil* (gas oil label), which are assumed to be used in their entirety as an energy source for the operation of agricultural machinery. The participation of the remaining energy sources is very small, which is why it is neglected in this paper.

The overall energy efficiency of oil and oil derivates use in the agricultural sector of Serbia is determined by the expression:

$$\eta = \eta_{diesel} + \eta_{gas\ oil} = \eta_{m,diesel} \cdot f_{diesel} + \eta_{m,gas\ oil} \cdot f_{gas\ oil} \tag{10}$$

while the following is used to determine the overall exergy efficiency of oil and oil derivates use:

$$\eta_{ex} = \eta_{ex,diesel} + \eta_{ex,gas\ oil} = \eta_{ex,m,diesel} \cdot f_{diesel} + \eta_{ex,m,gas\ oil} \cdot f_{gas\ oil} \tag{11}$$

which on the basis of expressions (9) and (10) can be represented in the form:

$$\eta_{ex} = \frac{\eta_{m,diesel}}{\gamma_{diesel}} \cdot f_{diesel} + \frac{\eta_{m,gas\ oil}}{\gamma_{gas\ oil}} \cdot f_{gas\ oil} = \frac{\eta_{diesel}}{\gamma_{diesel}} + \frac{\eta_{gas\ oil}}{\gamma_{gas\ oil}} \tag{12}$$

Energy fraction of fuel f represents the energy share of a given type of fuel in the considered sector. When it comes to the energy efficiency of agricultural machinery, its value is about 35% [6] in the case of modern machinery. Considering the characteristics of agricultural machine park in Serbia, energy efficiency ranges from 30-35%. In practice agricultural machines do not operate continuously at nominal regime, their energy efficiency is slightly lower. It is estimated that in real conditions the energy efficiency of agricultural machinery in Serbia is around 27%. An overview of the used data [7], as well as energy fraction of fuels, for the ten-year period from 2008 to 2017, is given in Table 2.

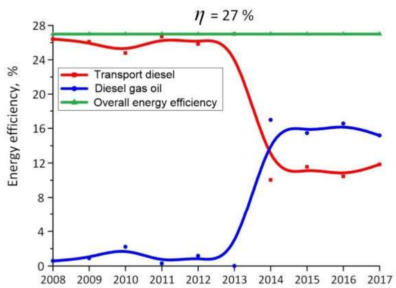
Table 2 Data on energy use in the agricultural sector of Serbia

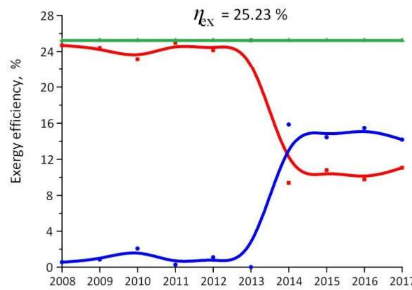
Year	Energy input [TJ]		Energy fraction of fuel [%]		Estimated energy efficiency [%]
	Transport diesel	Diesel gas oil	f_{diesel}	$f_{gas\ oil}$	η_m
2017	2400	3079	43,80	56,20	27
2016	2138	3391	38,67	61,33	27
2015	1777	2380	42,75	57,25	27
2014	1766	2990	37,13	62,87	27
2013	5099	-	100	-	27
2012	4827	218	95,68	4,32	27
2011	2270	25	98,91	1,09	27
2010	1923	172	91,79	8,21	27
2009	2899	100	96,67	3,33	27
2008	1924	43	97,81	2,19	27

Based on the expressions (10) and (12) and the presented statistics, energy and exergy efficiency of agricultural machinery in Serbia in the period from 2008 to 2017 were determined (Figure 3).

The diagram clearly shows a decline in the use of transport diesel, with a simultaneous increase in the use of diesel gas oil starting in 2014. This is due to the ban on the production and marketing of D2 diesel in the domestic market, which was introduced to follow European Union standards. As a substitute for this fuel, which was used as an energy source for agricultural machinery, new, higher quality fuel was introduced - diesel gas oil 0.1.

The comparison of the diagrams shows that the energy and exergy efficiency of agricultural machines in Serbia are very close to each other. This is also true when comparing the efficiencies of machines that use transport diesel, and those that use diesel gas oil, and it also applies when comparing the overall energy and exergy efficiency of oil and oil derivates use.





a) Energy efficiency of agricultural machinery
b) Exergy efficiency of agricultural machinery

Fig. 3 Efficiency of machines in the agricultural sector of Serbia from 2008 to 2017

This is due to the use of high quality fossil fuels to drive mechanization in the Serbian agricultural sector, which have quality factors of the fuel around 1.

Average values of energy and exergy efficiency of agricultural machinery for the analyzed types of fuel, which are equal to the product of machine efficiency and energy fraction of a given type of fuel, as well as the overall average energy and exergy efficiency of oil and oil derivates use in the agricultural sector of Serbia, are shown in Table 3.

Table 3 Average energy and exergy efficiency of agricultural machines for the period from 2008 to 2017

Types of fuel	Average energy efficiency [%]	Average exergy efficiency [%]
Transport diesel	20.07	18.75
Diesel gas oil	6.93	6.48
Overall average	27	25.23

Based on the presented values, it is concluded that the overall average energy and overall average exergy efficiency of oil and oil derivates use in the agricultural sector of Serbia for the period 2008 to 2017 are respectively 27% and 25.23%.

A comparison of these values was made with the overall average energy and exergy efficiency of oil and oil derivates use in the agricultural sector of Malaysia [4] and the transportation sector of Saudi Arabia [8]. Comparative results are shown in Figure 4.

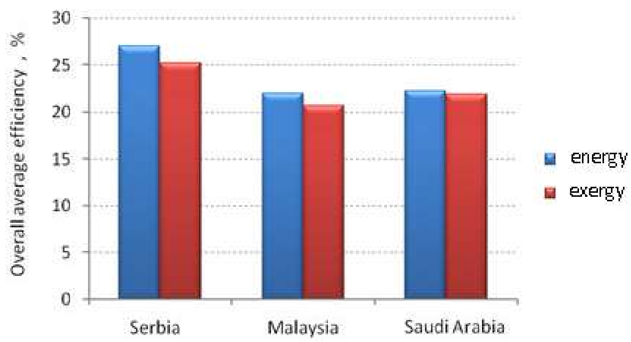


Fig. 4 Comparison of the overall average energy and exergy efficiency of the Serbian agricultural sector with other countries

The values of efficiency in these countries are approximate, but in the case of Serbia the values are slightly higher. The overall average exergy efficiency of all three analyzed sectors is lower than energy efficiency. This is due to the fact that diesel in all three countries, along with gasoline in Saudi Arabia, is a prime energy source whose quality factor is slightly greater than 1.

4. Conclusions

Based on the available data, an analysis concerning the energy and, for the first time, the exergy efficiency of energy use in the agricultural sector of Serbia was conducted. From the obtained results the following can be concluded:

- The overall average values of energy and exergy efficiency of oil and oil derivates use for the purposes of agricultural machinery in Serbia in the period 2008 to 2017 are 27% and 25.23% respectively.
- The exergy efficiency of the Serbian agricultural sector has a similar, slightly lower value than the energy efficiency, due to the use of high quality diesel fuel as a prime energy source.
- The overall average energy and exergy efficiency of the agricultural sector of Serbia, the agricultural sector of Malaysia and the transport sector of Saudi Arabia have approximate values, although in the case of Serbia they are slightly higher.
- The presented analysis was conducted from the final energy use point of view in the agricultural sector of Serbia. In order to obtain a more complete qualitative picture on the basis of which an improvement strategy in this sector would be devised, it is necessary to observe the entire flow of energy transformations from primary to final energy.
- Renewable energy sources have lower factors of converting final energy into primary energy [9]. In this regard it could be shown that the use of e.g. biodiesel would be more favorable choice than conventional fossil fuels.

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