Research on Fuel Consumption for Different Values of Capacity Factor of Engine of Combine Harvester

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Abstract. In article the authors substantiate that fuel consumption of combine harvester is usually influenced by design features of combine harvester: productivity, engine capacity and fuel efficiency of engine, the size of silo and grain unloading speed, the transport speed of combine, and other design features. The authors found out that specific fuel consumption of combine harvester tends to decrease with increasing of crop yield. When the normative yield, which provides passport throughput of combine, is achieved, further reduction of specific fuel consumption becomes minimal. This reduction is greater for straw – 1:1.0. Therefore, when the ratio of grain to non-grain part of mass is 1:1.5 and yield is increased to 2.5 t/ha, we observe sharp decrease in specific fuel consumption. The straw index also significantly influences the formation of specific fuel consumption of combine harvester, with yield of 4.5 t/ha and ratio of grain to non-grain part of 1:1.0, the specific fuel consumption is 2.83 l/t, and at the same yield and straw rate and ratio of grain to non-grain part of 1:2 the specific fuel consumption is 4.15 l/t (increase of 47%).

1. Introduction

Growth of agricultural production during the last years stipulated expansion of demand on an agricultural technique from the side of agrarians [1], that gave the shove of both market of technique development, domestic mechanical engineering and import of products from the leading world producers [2]. It is difficult to understand even to the specialists the matters of acquisition of economically efficient for the household, high-quality technique, among the variety of combine harvesters [3]. Thus collection of grain-crops is the decisive, final stage that gives a big impact on a production cost of grain in an agricultural enterprise [4]. Estimating the prospect of acquisition of combine harvester, the Ukrainian consumer pays the special attention on its fuel economy [5]. For this purpose, is used the index of specific fuel consumption (consumption of fuel in kg or litres per 1 ton of collected grain) [6]. Monitoring of work in the real exploitation of combine harvesters shows that this index varies from 2.5 l/t to 7.0 l/t [7]. It is obvious that on the fuel economy of combine harvester affects the brand of engine of combine harvester and specific agrobiological, organizational, service
conditions of its use by an agricultural enterprise [8]. Exact answer on the fuel consumption of combine harvester at collection of grain-crops it is possible to get only by testing in the specific conditions of the specific enterprise [9]. However, it is almost impossible to provide mentioned approach due to its costliness and duration [10]. Therefore, the development of model that would enable conducting such estimation virtually by a computer graphic design is relevant and perspective.

2. Purpose of research
The research is based on theoretical researches and on monitoring of work of combine harvesters in the conditions of real exploitation. The information got from monitoring is a basis for making decisions on the modeling of fuel consumption of a combine harvester.

3. Materials and methods
The fuel consumption of the combine harvester is usually affected by the construction features of the combine harvester: productivity, engine capacity and fuel economy of the engine, the size of the silo and the grain unloading speed [11], the transportation speed of the combine harvester and other features [12]. On the other hand, the fuel consumption is significantly affected by the harvesting conditions, that are characterized by the following indicators: type and yield of the crop, straw condition, selected mode of crop harvesting of non-cereal part (swath or shredding with spreading), straw and grain humidity, clogging, fallowness, rut length, slope of the field, humidity and hardness of the soil, time of transportation to the grain unloading place and to the place of night parking [13].

The periods of operating time, related with a work of engine of combine harvester and its fuel consumption, include: time spent on the main work (threshing of the grain) [14], time spent on turning at the end of the fill [15]; time spent on moving the combine harvester to the place of unloading of grain and back; time spent on unloading grain into the vehicle; idle time moving (to the night parking place and back, from field to field also) [16]. We will consider fuel consumption in each of these periods of time [17]. At the implementation of basic work, the engine power of combine harvester is calculated by the method [21]

\[ K_1 = q_1 \cdot \frac{1}{n \cdot \xi_1} \left(10^3 \cdot W_{h1} \cdot \gamma_n \right)^{1/3}, \text{l/t} \]  

(1)

where: \( q_1 \) – actual specific fuel consumption by engine at use of power factor, gram/kilowatt-hour; \( \xi_1 \) – coefficient of the use of effective power for main operations of combine harvester; \( N_{e1} \) – operating engine power, kilowatt; \( W_{h1} \) – productivity of the combine for the basic working time, calculated on carrying capacity of combine harvester, t/h; \( \gamma_n \) – specific weight of diesel fuel, kg/l.

Productivity during performing the main operations (threshing) is calculated using dependency:

\[ W_{h1} = 3.6 \cdot q_n \cdot k_y \cdot (1 + \delta_c)^{-1}, \text{t/h} \]  

(2)

where: \( q_n \) – nominal (passport) carrying capacity of combine harvester, kg/sec; \( k_y \) – coefficient which takes into account the terms of collection (humidity, clogging, straw condition); \( \delta_c \) – straw condition (ratio of non-grain part to grain mass unit).

In the calculations as the nominal carrying capacity of a particular brand of combine harvester was taken the numerical value written in passport [20], and in the case of absence of such information, was calculated by the method [21]. Calculation of the coefficient of harvesting conditions \( k_y \) was performed according to the following method [22]. Numerical value of specific fuel consumption by combine harvester during turnings at the end of bend is determined by following dependence:

\[ g_{K2} = \tau_2 \cdot q_2 \cdot N_{e2} \cdot \xi_2 \left(10^3 \cdot W_{h1} \cdot \gamma_n \right)^{1/3}, \text{l/t} \]  

(3)
where: \( \tau_2 \) – specific working time spent for turning at the end of the bend, hour; \( q_2 \) – actual specific fuel consumption by the engine at use of power factor \( \xi_2 \), gram/kilowatt-hour; \( \xi_2 \) – coefficient of the use of effective power during turnings at the end of bend.

Specific expenses of working hours on turnings can be determined by a formula:

\[
\tau_2 = T_2 \cdot W_{h1} \cdot \left(0.36 \cdot L_g \cdot B_p \cdot U\right)^{-1}, \text{hours}
\]  

(4)

where: \( T_2 \) – average duration of turning of the combine harvester at the end of the bend, hour; \( L_g \) – average length of the rut, m; \( B_p \) – working width of capture, m; \( U \) – average yield, t/ha.

Specific fuel consumption of the combine harvester during moving to the place of unloading of grain and back:

\[
g_{K3} = \tau_3 \cdot q_3 \cdot Ne_n \cdot \xi_3 \cdot \left(10^3 \cdot W_{h1} \cdot \gamma_n\right)^{-1}, \text{l/ha}
\]  

(5)

where: \( \tau_3 \) – specific working time spent for moving to the unloading point of the bunker and back, hour; \( q_3 \) – actual specific fuel consumption of the engine at use of power factor \( \xi_3 \), gram/kilowatt-hour; \( \xi_3 \) – coefficient of use of effective power during moving to the unloading point of the bunker and back.

Calculation of the specific time spent on movements is determined by the following dependence:

\[
\tau_3 = T_3 \cdot W_{h1} \cdot \left(3600 \cdot G_b \cdot \rho_3\right)^{-1},
\]  

(6)

where: \( \rho_3 \) – specific weight of grain, t/m\(^3\); \( G_b \) – combine harvester bin volume, m\(^3\); \( T_3 \) – average time for combine movement to and from the place of unloading, sec.

Specific fuel consumption during unloading of the grain harvester bunker into transportation vehicle is determined by the following formula:

\[
g_{K4} = \tau_4 \cdot q_4 \cdot Ne_n \cdot \xi_4 \cdot \left(10^3 \cdot W_{h1} \cdot \gamma_n\right)^{-1}.
\]  

(7)

Specific working time spent on unloading of the combine harvester bunker can be determined by the following formula:

\[
\tau_3 = W_{h1} \cdot \left(3.6 \cdot V_r \cdot \rho_3\right)^{-1},
\]  

(8)

where: \( V_r \) – speed of unloading of grain from the bunker, kg/sec.

During harvesting combine harvester moves from field to field and from the parking lot to the field [23]. In this case, the engine is not running at its full power and is actually idling [24]. The specific fuel consumption at such operations is determined by the following formula:

\[
g_{K5} = \tau_5 \cdot q_5 \cdot Ne_n \cdot \xi_5 \cdot \left(10^3 \cdot W_{h1} \cdot \gamma_n\right)^{-1},
\]  

(9)

where: \( \tau_5 \) – specific working time spent on relocation; \( q_5 \) – actual specific fuel consumption of the engine at use of power factor \( \xi_5 \), gram/kilowatt-hour; \( \xi_5 \) – coefficient of use of effective power during moving from field to field and from parking place to field.

Specific working time spent on relocation are approximately determined using the following dependency:

\[
\tau_5 = 2 \cdot L_s \left(T_{ld} \cdot V_p\right)^{-1} + L_f \cdot W_{h1} \left(S_s \cdot V_p \cdot U\right)^{-1},
\]  

(10)
where: $L_0$ – average distance from the parking lot (machine yard) to the place of work (field), km; $T_{id}$ – average basic working time of a combine harvester per day, hour; $V_p$ – speed of the combine harvester during relocation, km/h; $L_p$ – average distance from field to field, km; $S_s$ – average area of the harvesting field, ha.

Specific fuel consumption can be determined using the analytical model of Leiderman [25, 26], which is a system of polynomial functions with constant coefficients, also taking into account the environmental impact:

$$g_f = g_n \cdot \left( A - B \cdot n \cdot (n_n)^1 + C \cdot n^2 \cdot (n_n)^2 \right), \text{gram/kilowatt-hour}$$

(11)

where: $g_f$ – actual specific fuel consumption, gram/kilowatt-hour; $g_n$ – documented specific fuel consumption at rated engine speed, gram/kilowatt-hour. Thus for simplification the coefficient of the use of power will be marked as $n \cdot (n_n)^1 = k_N$.

4. Results and discussion

Using the specified method of determination of parameters of Leiderman's functions was made the specified equation of specific fuel consumption, taking into account construction, terms of work and influence of environment $g_f = g_n \cdot \left( 1.8757 - 1.7471 \cdot n \cdot (n_n)^1 + 0.8714 \cdot n^2 \cdot (n_n)^2 \right)$.

Taking into account the entered coefficient of the use of power $k_N$, we will have:

$$g_f = g_n \cdot \left( 1.8757 - 1.7471 \cdot k_N + 0.8714 \cdot k_N^2 \right).$$

(12)

As the engine of combine harvester in terms of operation, is different from the tractor (higher forcing, distribution of power take-off on two sides, more difficult working conditions (dustiness, constantly high temperature, etc.), nominal crankshaft speed), the following linear correlation is appropriate $g_f \cdot (g_n)^{-1}$ on the described modes of work (main work, relocation, turnings). Therefore for the calculation of actual specific fuel consumption of engines $g_1, g_2, g_3, g_4, g_5$ it is suggested to use equation (12) in figure 1. Modern combine harvesters are equipped with engines that have sufficient power for various harvesting methods and technologies, for difficult conditions too. For different types of work, the engine has its value of the load factor. In particular for normal harvesting conditions during laying of straw in a roll $\xi_0 = 0.7...0.75$ (figure 1); during grinding of straw by a shredder $\xi_1 = 0.8...0.9$. Other values of engine load factor during cornering $\xi_2$, during relocation to the place of unloading of the grain tank $\xi_3$, during unloading of the grain tank $\xi_4$, during moving to the parking place and to the field $\xi_5$ differ slightly and are within range 0.2...0.35. The final specific fuel consumption of combine harvester during harvesting is determined by the sum of:

$$\xi_{\Sigma} = \sum_{i=1}^{5} \xi_i = \xi_1 + \xi_2 + \xi_3 + \xi_4 + \xi_5.$$  

(13)

Obtained mathematical model allows us to establish the influence of individual factors, typical for different working conditions, on the specific fuel consumption of combine harvesters. The result of this work is the determination of the dependence of specific fuel consumption change on yield and straw condition of the crops. The object of the study is the combine harvester Slavutich KZC-9F. More than 300 units of Slavutich KZC-9F operate in the fields of Ukraine. As the conditions of use were taken average conditions for the forest steppe zone of Ukraine. According to this model was developed a program for determining the specific fuel consumption (figure 2). Delphi 7 was used for programming. These dependencies (figure 3) showed that specific fuel consumption of the combine
harvester tends to decrease with increasing of crop yield. There is a sharp decrease in the segment of low yield, regardless of the straw condition.

**Figure 1.** Estimated value (12) of actual specific fuel consumption for different values of use of power coefficient.

**Figure 2.** Main page of the program for calculating the fuel consumption.

This happens due to the underloading of thresher by grain and of the combine harvester engine in general. When the normative yield, that provides documented carrying capacity, is reached, further reduction of the specific fuel consumption becomes minimal. This reduction is greater for a straw –
Therefore, when the ratio of grain to the non-grain part of the mass is 1:1.5 and the yield is increased to 2.5 t/ha, we observe a sharp decrease in the specific fuel consumption.

**Figure 3.** Dependence of specific fuel consumption of combine harvester KZC-9F on yield and straw conditions.

For example, at yield 1.5 t/ha specific fuel consumption is 4.52 l/t, and at 2.5 t/ha – 3.58 l/t. In addition, with a further increase in yield, the specific consumption slightly decreases and at 4.5 t/ha it becomes 3.52 l/t. The straw condition index also significantly affects the formation of the specific fuel consumption of the combine harvester. With a yield of 4.5 t/ha and a ratio of grain to the non-grain part of 1:1.0, the specific fuel consumption is 2.83 l/t, and at the same yield and straw rate and a ratio of grain to the non-grain part of 1:2, the specific fuel consumption is 4.15 l/t (increased on 47%). Also straw rate affects the extreme point. So the sharp transition of reduction of specific fuel consumption for straw condition index occurs at a yield of 2.9 t/ha, and at a straw rate of 1:2 this change occurs at a yield of 1.9 t/ha.

5. **Conclusions**

1. The authors found out that specific fuel consumption of combine harvester tends to decrease with increasing of crop yield. There is sharp decrease in segment with low yield, regardless of straw condition. This happens due to under loading of harvesting weight of thresher and of combine harvester engine in general. When the normative yield, which provides passport throughput of combine, is achieved, further reduction of specific fuel consumption becomes minimal. This reduction is greater for straw – 1:1.0. Therefore, when the ratio of grain to non-grain part of mass is 1:1.5 and yield is increased to 2.5 t/ha, we observe sharp decrease in specific fuel consumption.

2. The straw index also significantly influences the formation of specific fuel consumption of combine harvester. With yield of 4.5 t/ha and ratio of grain to non-grain part of 1:1.0, the specific fuel consumption is 2.83 l/t, and at the same yield and straw rate and ratio of grain to non-grain part of 1:2 the specific fuel consumption is 4.15 l/t (increase of 47%). Also straw rate affects the extreme point. So the sharp transition of reduction of specific fuel consumption for straw rate occurs at yield of 2.9 t/ha, then at straw rate of 1:2 this change occurs at yield of 1.9 t/ha.

6. **References**

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