Improving Fuel Efficiency of Crawler Excavator VOLVO EC300EL with Hybrid System

P. Ivanov, and V. Tsonev

***Abstract*—The current study aims to show a comparison between the fuel efficiency of conventional excavator Volvo EC300EL and the hybrid version of the same model. The main parameters of tested model are presented. The scheme of hydraulic hybrid technology is described. A real measurements of fuel consumption and loaded volume of material was performed in a test period of three days. The results were selected and on their base conclusions regarding the fuel efficiency of the hybrid version are presented at the end of the study.**

***Keywords* - fuel efficiency, fuel consumption, crawler excavator, hybrid system.**

I. Introduction

Improving the fuel efficiency of transport, construction, mining and industrial machinery is a pressing issue that is undergoing continuous development. In view of increasingly strict environmental regulations, passenger car manufacturers are gradually replacing internal combustion engines with electric ones. In some countries of the European Union, including Bulgaria, measures are imposed to oblige or encourage businesses and individuals to use electric cars. Despite their intense advertising, it is necessary to note that they still face several problems in their operation, such as limited range, unbuilt recharging infrastructure, influence of atmospheric conditions on the range (in winter, the battery capacity is smaller), uncertain future of batteries and their recycling and the financial impact on the owners of these vehicles.

Despite all the shortcomings or obviously underdeveloped systems at this stage, our imposed future relates to them, and the direction of development not only of vehicles, but also of all other machines using internal combustion engines, is electrification.

The Swedish manufacturer VOLVO in the construction equipment sector is also actively developing electric and autonomous machines that will be distinguished by incomparable fuel efficiency compared to the models currently in use. Here, the problems with loading the machines are even greater, especially when there is a need for continuous operation, such as those with LPG provide. Current developments are still subject to testing and their implementation in mass use is a future task [1, 2, 3]. Currently, some models of crawler excavators use a hydraulic hybrid system in operation, which improves fuel efficiency by up to 20% and fuel consumption by up to 17%, according to the manufacturer [4].

This report examines a real-world fuel consumption comparison test of a conventional VOLVO EC300EL crawler excavator versus the same model but with a factory-fitted hybrid system.

II. Basics

VOLVO EC300EL is a 34-ton crawler excavator that finds successful use in excavations for large construction sites, balustrades and small quarries. The model has been produced in this generation since 2015. A brief technical characteristic of the machine is presented in Table I [5].[2]

TABLE I
Technical characteristic of VOLVO EC300EL

Engine	Volvo D8M
EU Standard	Stage V
Maximum power	189 kW
At rpm	1 600 rpm
Maximum torque	1 290 Nm
At rpm	1 400 rpm
Engine volume	7.7 l
Hydraulic system	
Type of pumps	Axial - piston
Number of main pumps	2
Maximum flow	276 l/min
Maximum pressure	36.3 MPa
Travel system	
Maximum drawbar pull	248 kN
Travel speed low	3.6 km/h
Travel speed high	5.4 km/h
Woorking tools and attachments	
Boom, Heavy duty	6.20 m
Arm, Heavy duty	2.55; 3.05; 3.70 m
Bucket volume	1,6 – 2,5 m³
Beakout force ISO 6015	207 kN
Working parameters with arm 3.05 m	
Digging depth	7 340 mm
Maximum horizontal reach	10 710 mm
Maximum rach high	7 040 mm
Basic dimensions	
Transport length	10 500 mm
Transport width	3 190 mm
Transport height	3 360 mm

The difference between the conventional and the hybrid modification is only the supplemented hydraulic hybrid system.

Received: 03.04.2025
Published: 31.05.2025
https://doi.org/10.47978/TUS.2025.75.02.001

P. Ivanov is with the Technical University of Sofia, Sofia, 1000, 8 Kl. Ohridski Blvd, Bulgaria (ivanov.peter@abv.bg)

V. Tsonev is with the Technical University of Sofia, Sofia, 1000, 8 Kl. Ohridski Blvd, Bulgaria (tzonev@tu-sofia.bg)

Unlike other manufacturers VOLVO does not use electric hybrid systems [2, 6]. In this way, several disadvantages are avoided such as [4, 7]:

- Future replacement and recycling of batteries;
- Dependence of the efficiency of the system on the angle of rotation of the machine during operation;
- Dependence on atmospheric conditions.

A diagram of the VOLVO hybrid hydraulic system can be seen in Fig. 1 [4].

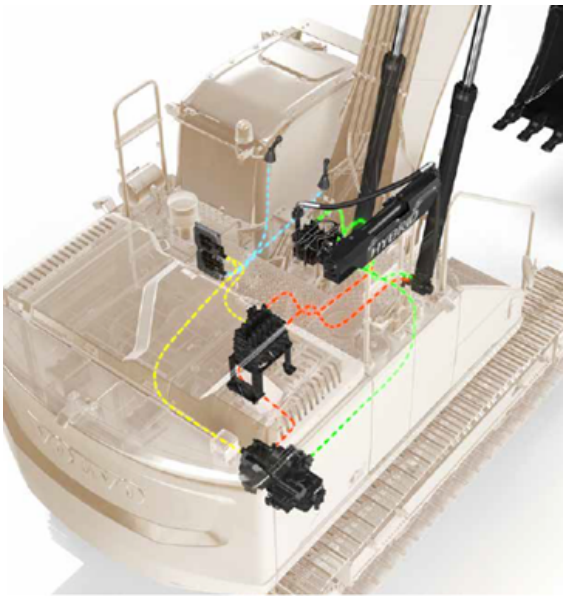

Fig. 1. Diagram of VOLVO hybrid hydraulic system [4].

An appearance of the hydraulic accumulator is shown in Fig. 2 [4].

Fig. 2. Hydraulic accumulator [4].

Uncomplicated and reliable, the hybrid solution harvests "free" energy generated by the downward movement of the excavator's boom and uses it to supplement the operation of the internal combustion engine. Powerful and regular boom down movements charge 20-liter hydraulic accumulators, which then supply power to drive auxiliary hydraulic motors that help power the hydraulic system and unload the engine. The machine has the same levels of handling and performance as the standard EC300E, including the ability to operate in ECO mode and Hybrid mode simultaneously. ECO mode is standard equipment for both modifications. It is a system that, through electronic control, reduces the losses of hydraulic pumps and improves their external characteristics [3, 4, 5, 12].

The first hybrid systems used in crawler excavators were precisely the hydraulic ones. Caterpillar built such a system already a decade ago, but subsequently it found limited application due to the high cost [1, 3, 8]. Scheme of CAT 336 hybrid system is shown on Fig. 3 [8].

Fig. 3. Scheme of CAT 336 hybrid hydraulic system [8].
1 – Hydraulic hybrid swing system; 2 – Electronic standardized programmable pump; 3 – Adaptive control system.

Another global manufacturer that implements hybrid systems on crawler excavators is Komatsu, but here the direction is towards an electric hybrid system. The combined drive includes an electric motor - a generator that replaces the classic swing motor for rotating the upper structure of the machine. When the upper structure rotates, the generator produces electricity, which in turn is stored in batteries. They power an electric motor that assists the internal combustion engine when the machine operator selects a high-speed power mode [2, 6, 10, 11]. This, in turn, reduces fuel consumption. A general diagram of such a solution is shown in Fig. 4 [6].

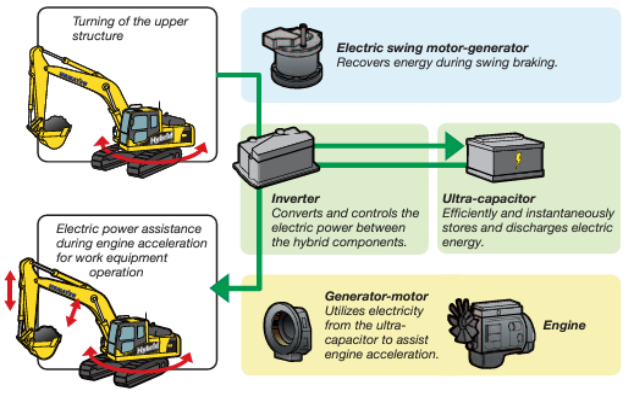

Fig. 4. Diagram of the Komatsu hybrid electric system [6].

The accumulated practical experience with the operation of machines with hybrid electric system in Bulgaria shows that the system works efficiently at large angles of rotation of the machine (approximately 150°), and the batteries for storing electrical energy are an expensive consumable that must be replaced in a period of 15,000 engine hours of operation [7, 10,11]. Paying the price of new batteries can negate the fuel savings made. The subsequent recycling of old batteries is also a significant problem.

In the last decade, hybrid systems have enjoyed popularity, and every vehicle manufacturer actively advertises the solution they use. In practice, it is difficult to argue which system is more effective and more durable in terms of technology. The comparative analysis of the two types of hybrid systems outside of the manufacturers'

advertising campaigns shows the following [1, 2, 6, 8]:

- Advantages of a hydraulic hybrid hydraulic system compared to an electric one:
  - simpler construction;
  - lack of accumulator batteries;
- Disadvantages of a hybrid hydraulic system compared to an electric one:
  - due to the use of a working fluid, the system can be assessed as less reliable from the point of view of the possibility of a malfunction in the connections between the individual components;
  - the elements of the hydraulic system are more voluminous and heavier, which is sometimes associated with difficulties in their placement in the engine compartment. This statement is only correct if the batteries of the electrical system are not considered.

III. PRACTICAL EXPERIMENTS

For the purposes of this study, a three-day practical experiment was conducted, consisting in measuring the fuel efficiency and fuel consumption of VOLVO EC300EL and VOLVO EC300EL HYBRID crawler excavators.

To maximally accurate exposition, the following explanations are made:

- "Fuel efficiency" refers to the amount of fuel in liters that the machine has used to process a given amount of material. The unit of measurement is l/t (liter per ton);
- By "Fuel consumption" is meant the amount of fuel in liters that the machine has used in one hour of operation, assuming that the hour is 50 minutes, since in practice 60 minutes can never be efficiently worked. The unit of measurement is l/h (liter per hour).

The average fuel consumption of a conventional EC300EL (according to manufacturer data) is listed in Table II [9].

TABLE II
AVERAGE FUEL CONSUMPTION OF A CONVENTIONAL EC300EL

Light mode	8.5 l/h
Middle mode	12.8 l/h
Heavy mode	19.8 l/h

Explanation:

- Light mode is work with loose soil, dry sand, etc.
- Medium mode is work with wet sand, clay, a combination of earth and stones, etc.
- Heavy mode is work with large stones, bent pieces, etc.

The tests was carried out for three full working days in the period 06 - 08.11.2023, on the balustrade near the town of Iskar, Pleven region. Three three-axle Renault K 6x4 road dump trucks with 16 m³ bodies were provided for both machines. The machines worked side by side, loading the dump trucks at the same ground level by turning 90°. The transport distance in one direction was 700 m, and the material - wet sand with a bulk mass of 1.6 t/m³ - was transported from the mining site to the screening and washing plant. Each machine was filled at the beginning and end of the working day from the same column with the same fuel until the filling pump was turned off. The working hours were from 8:00 a.m. to 12:00 p.m. and from 1:00 p.m. to 5:00 p.m. Both machines were equipped with identical booms, a 3.05 m arm and a 2.0 m³ bucket. To minimize the role of the human factor, two experienced operators were used, who are working with a conventional VOLVO EC300EL since 2019. On the first day, the two operators were distributed to the machines according to their wishes, on the second day they exchanged, and on the third - they exchanged the machines after the lunch break. The machines were operated on a third range of economy mode corresponding to a variation between 1350 and 1400 rpm of the engine, i.e. around the maximum torque, where fuel consumption should be minimum and the efficiency of the hydraulic system - maximum.

The results of the practical experiments are given in the Tables III, IV, V, VI, VII and VIII.

TABLE III
RESULTS OF DAY 1 (FUEL CONSUMPTION)

Fuel consumption after the end of the day, l/h	
EC300EL	15.21
EC300EL Hybrid	12.76
Difference vs EC300EL	**16.11 %**

TABLE IV
RESULTS OF DAY 1 (FUEL EFFICIENCY)

Hourly fuel efficiency, l/t	
EC300EL	0.0528
EC300EL Hybrid	0.0420
Difference vs EC300EL	**20.45 %**

TABLE V
RESULTS OF DAY 2 (FUEL CONSUMPTION)

Fuel consumption after the end of the day, l/h	
EC300EL	15.34
EC300EL Hybrid	12.92
Difference vs EC300EL	**15.78 %**

TABLE VI
RESULTS OF DAY 2 (FUEL EFFICIENCY)

Hourly fuel efficiency, l/t	
EC300EL	0.0533
EC300EL Hybrid	0.0448
Difference vs EC300EL	**15.95 %**

TABLE VII
RESULTS OF DAY 3 (FUEL CONSUMPTION)

Fuel consumption after the end of the day, l/h	
EC300EL	15.63
EC300EL Hybrid	13.07
Difference vs EC300EL	**16.38 %**

TABLE VIII
RESULTS OF DAY 3 (FUEL EFFICIENCY)

Hourly fuel efficiency, l/t	
EC300EL	0.0542
EC300EL Hybrid	0.0453
Difference vs EC300EL	**16.42 %**

On the first day, the operator of the conventional EC300EL loaded 18 dump trucks per hour, and the operator of the EC300EL Hybrid loaded 19 dump trucks per hour.

On the second and third day, both machines loaded 18 dump trucks per hour.

IV. CONCLUSIONS

After the tests, the following conclusions can be made:

- The data presented by the manufacturer regarding the improved fuel economy (up to 17%) and fuel efficiency (up to 20%) of the hybrid modification of the EC300EL model can be accepted as reliable;

- The actual results achieved are largely dependent on the machine operator. On the first day, the operator of the hybrid machine managed to load one dump truck more every hour, something that the second operator did not achieve on the second day;

- The opinion of both operators is that the hybrid hydraulic system makes the excavator faster and makes work movements easier;

- Both operators accept that the hybrid machine is more precise in combination movements of the working tools (boom and arm or arm and boom), which improves the operator efficiency;

- A calculation shows that by 2 l/h less fuel consumption and 8 hours working day, the annual cost save will be 10 560 BGN with 22 working days per month and a price of diesel 2,5 BGN.

After the end of the test both machines were checked by service technicians. The components of the hybrid system were visually checked for oil leakages. The flow and the pressure of the hydraulic accumulator ware checked. All parameters were in norm.

REFERENCES

[1] K. Heybroek, M. Sahlman, "A hydraulic hybrid excavator based on multi-chamber cylinders and secondary control–design and experimental validation", *International Journal of Fluid Power*, *19*(2), *91-105*, 2018.

[2] J. M. Lee, J. H. Cho, J. H. Yoo, "Modeling and simulation of the swing system of crawler-type medium hydraulic excavator using dynamic friction model", *Fluid Power Systems Technology*, Vol. *45974*, *V001T01A013*, American Society of Mechanical Engineers, 2014.

[3] D. Yue, H. Gao, Z. Liu, L. Wei, Y. Liu, X. Zuo, "Potential energy recovery and direct reuse system of hydraulic hybrid excavators based on the digital pump", *Energies*, *16(13)*, *5229*, 2023.

[4] "Volvo EC300EL Hybrid", Ref. No *20059917_D / English-21 / 2023.08 / EXC / Volvo, Global Marketing.*

[5] "Volvo EC300EL", Ref. No *20059439_E / English-21 / 2022.03 / EXC / Volvo, Global Marketing*.

[6] "Komatsu HB215LC", Ref. No *UENSS17100 2014.10 / English*.

[7] P. Ivanov, "Systems for Improving of Energy Efficiency in Construction Machines", *BulTrans-2016*, Sozopol, Bulgaria, 2016, *105-108*.

[8] "CAT 336 EH", Ref No *AEHQ6948 / 2013.01 / English*.

[9] "Volvo performance manual", Ref. No *21_20001111_H / 2018.05 / English-21 / GPPE / Volvo*.

[10] Y. Lin, T. Lin, Q. Chen, Z. Li, S. Fu, H. Ren, T. Guo, "Research Progress on Key Technologies of Electric Construction Machinery", *China Hydraulic and Pneumatic, 45,1,* 2021

[11] T-L. Lin, Y. Ye, S. Fu, Q. Liu, "Energy-saving System of Swing for Hydraulic Excavators Based on Electric Energy Recovery Technology." *China Journal Highway Transport 27*, 120–126, 2014

[12] J. Hutcheson, D. Abrahams, J. Macpherson, N. Caldwell, D. Rampen, "Demonstration of Efficient Energy Recovery Systems Using Digital Displacement® Hydraulics. In Proceedings of the BATH/ASME" *2020 Symposium on Fluid Power and Motion Control, Virtual, Online, 9–11*, September 2020.