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A STUDY OF THE FUEL CONSUMPTION OF HYBRID CAR TOYOTA YARIS

Summary. The paper presents the experimental results from a complex study of the fuel consumption of a hybrid car Toyota Yaris. Original data for motion at different constant speeds are obtained. The economical and energy characteristics of the car are observed and analyzed. Three typical urban and three inter-city routes are investigated. A significant decrease in the fuel consumption of the hybrid car is witnessed when it runs in urban conditions at “Eco Mode”. The motion on inter-city route, including short town passages and highway parts, is also investigated. The obtained original data are higher than the fuel consumption given by the producer and, practically, equal to the ones of the conventional gasoline car. The study indicates that the effect of a hybrid system is significant in urban conditions and is more evident at “Eco Mode”.

1. INTRODUCTION

One of the main sources of environmental pollution are vehicles [1, 2, 11, 17]. Over the last years, the alternative vehicle propulsion systems have become the main priority for a lot of automotive companies and research teams. The basic objective of those propulsions [4, 6, 7, 11, 15] is the achievement of energy independence from nonrenewable sources like liquid and gas fuels. One of the variants of vehicle propulsion, which is built in a few car models, is a hybrid system [6, 12, 13].

The first serial hybrid car was produced in 1997 and since that moment, the company Toyota has sold over 3 million hybrid cars. As a result of the use of hybrid and electric cars, the air pollution has reduced by 18 million tones [15, 17].

According to the information from the producers and a number of studies [2 - 5, 12, 16], a hybrid car consumes less fuel and generates less air pollution in comparison with a car equipped with a gasoline or diesel engine during movement in the city. Moreover, similar effect exists for inter-city conditions. That is one of the main advantages of hybrid cars because in city conditions, up to 50 km/h, the motion is realized using only electric energy from the battery.

In some studies [4, 6, 7, 12, 13, 16], there are verifications that a hybrid car has advantages vs gasoline car, even vs diesel car, especially in urban conditions. The fuel consumption in inter-city conditions is not well studied.

Currently, the studies on the fuel consumption of hybrid Toyota Yaris are limited. The small volume of experimental data is not appropriate for generalizations, and therefore additional experiments are needed.

The goal of this paper is to investigate the fuel consumption of a hybrid car Toyota Yaris on urban and inter-city routes.

All experiments in this study for the determination the fuel consumption were carried out with a hybrid car Toyota Yaris Hybrid 1.5 HSD (Fig. 1). The main characteristics of the car are presented in Table 1 [8, 10, 14].

Table 1

Main technical characteristics of the hybrid vehicle

Main technical characteristics	Toyota Yaris (P3) Hybrid
Modification	1.5 HSD Hybrid 100 Hp
Max Power/at engine speed	75 Hp /4 800 min ⁻¹
Max torque/at engine speed	111 Nm /4400 min ⁻¹
Max power of electric system	61 Hp
Max torque of electric system	207 Nm
Capacity of the battery	0,94 kWh
EVRO standard	EURO V
Tire dimensions	175/65 R15
Maximal speed	165 km/h
Time for acceleration from 0 to 100 km/h	11,8 s
Empty weight	1 120 kg

2. FUEL CONSUMPTION AT CONSTANT SPEED AND ENERGY CHARACTERISTIC

2.1. Test method and conditions

A series of tests were carried out on a horizontal straight part of the asphalt road with longitude over 2 km. The load of the car was 3 persons (including driver). During the experiments, the respective value of the speed was measured and maintained using a “fifth” wheel Peiseler and system DB Print (Fig. 1).

The fuel consumption was recorded with a testing device Flowtronic 205 (Fig. 2). Up to 50 km/h constant speed, the hybrid car runs on electric mode and does not consume fuel. Over the 50 km/h constant speed, the hybrid car runs only using ICE. In this case, spent energy is evaluated on the basis of the result of fuel consumption taking into account the energy equivalent of the gasoline, i.e. 11 gasoline = 9 kWh.

In electric mode, the energy consumption from a battery was recorded (as current and voltage) with a system Vitel Pro developed by a Bulgarian company. The fuel consumption was recorded with a testing device Flowtronic 205 (Fig. 2).

The results for the fuel consumption Q and energy consumption E are presented in Fig. 3. At a low constant speed, the energy consumption is a little higher (Fig. 3), which is a result of low values of the transmission and electric propulsion efficiency. Then, the energy consumption slowly goes down. Up to 50 km/h, fuel consumption is zero liter per 100 km (see Fig.3), because for the motion, the car uses only electric energy (approximately 0.08 – 0.1 kWh/km) from the battery. At constant speed over 50 km/h, the fuel consumption is practically equal to that one of the conventional variant of the same car. At high-speed conditions, the hybrid car runs using only ICE. Obviously, it is not appropriate to make the comparative analysis of different models of hybrid cars only on the basis of fuel consumption and energy characteristics. In real traffic conditions, the usage of the electric or ICE mode depends on many factors, including not only road conditions, speed, traffic density but also driver’s skills, discharge level of the battery, etc.

Our opinion is that an additional study of the fuel consumption of hybrid car in urban and inter-city conditions is needed. That way a full picture concerning fuel and energy properties of the tested car can be obtained.



Fig. 1. Tested hybrid car Toyota Yaris Hybrid 1.5 HSD with a “fifth” wheel Peiseler and system DB Print (in the car)



Fig. 2. Testing device for fuel consumption Flowtronic 205

3. STUDY OF THE FUEL CONSUMPTION OF THE HYBRID CAR IN URBAN CONDITIONS

3.1. Test method and conditions

The experiments include a series of tests on urban routes in Bulgarian town Ruse. The results for the current fuel consumption of the hybrid car were read from car board computer (Fig. 2) every 1 min.

The consumption of fuel on three typical urban routes [9] was investigated:

- Route 1: “Rail station – Danube bridge – Rail station” (Fig. 4);
- Route 2: “Rail station – River station – Rail station” (Fig. 5); and
- Route 3: “Rail station – Droujba 3 – Rail station” (Fig. 5).

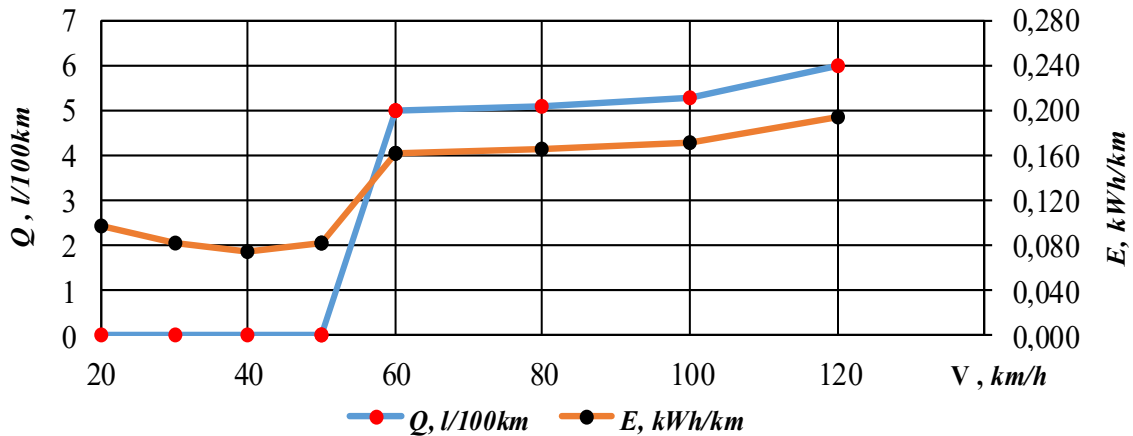


Fig. 3. Fuel consumption and energy characteristics of hybrid car Toyota Yaris Hybrid 1.5 HSD

The first route has a predominant plane terrain and a distance of 15.3 km. The second one includes horizontal and also parts with longitudinal inclination. On this route, the motion in one direction and return to start point is realized by passing through different streets, because of the presence of one-way streets. Distance of the second route is 4.6 km. The third route has a predominant hill terrain and the distance is 6.4 km.

Motion was realized in the traffic peak period – 17-18h. Every route was divided into two modes – without and with activated “ECO MODE” of the hybrid system. The load of the car was 3 persons (including driver). During the all experiments, the climate control was working.

The choice of the routes was realized taking into account the fact that all are with intensive traffic, different traffic regulation and include parts with different inclinations. The experiments started with clearing the indication of the car board computer. During the experiment, the fuel consumption was registered every minute. After the end of the motion, the average values were recorded from the carboard computer. Before a series of road experiments, a verification of the fuel consumption, indicated by the vehicle board computer, was done using Flowtronic 205 (Fig.2.). The difference between board computer and Flowtronic 205 result for the average fuel consumption, passing a distance of 2km, at different speeds was less than 2%.

Every experiment was repeated 3 times. At the end of the experiments, in the laboratory, the results were preceded and the graphics were created [2]. The results without working “ECO MODE” are presented in Fig. 7, a, c and e. With working “ECO MODE,” the result of fuel consumption is presented in Fig. 7, b, d and f. All results in urban conditions are summarized in Table 2.

3.2. Analysis of the results for the fuel consumption of the hybrid car in urban conditions

The average fuel consumption of the hybrid car Toyota Yaris is significantly higher from that one indicated from the producer in the technical specification (see Tables 1, 2 and 4). Possible reason for that difference can be explained with the density of the real traffic in Ruse at peak period and European city cycle. It is obvious that the fuel consumption of the HEV on all three routes without “ECO MODE” is higher than that the one with working “ECO MODE”. Using “ECO MODE,” the car accelerates slowly.

The fuel consumption on the first route without and with working “ECO MODE” is, respectively, 61.3% and 35.4% higher than indicated in technical specification of the producer. The fuel consumption on the second route without and with working “ECO MODE” is, respectively, 119.4% and 64.5% higher than indicated in the technical specification of the producer. The fuel consumption on the third route without and with working “ECO MODE” is, respectively, 87.1% and 74.2% higher than indicated in the technical specification of the producer.

In urban conditions, the energy saved in the battery and regeneration of the energy during braking is used more actively. The less using of the ICE decreases the fuel consumption, and energy performance of the hybrid car is similar to that one of the less powerful conventional model Toyota Yaris (P3) - 1.0 VVT-i 5 M/T (Tab. 4).

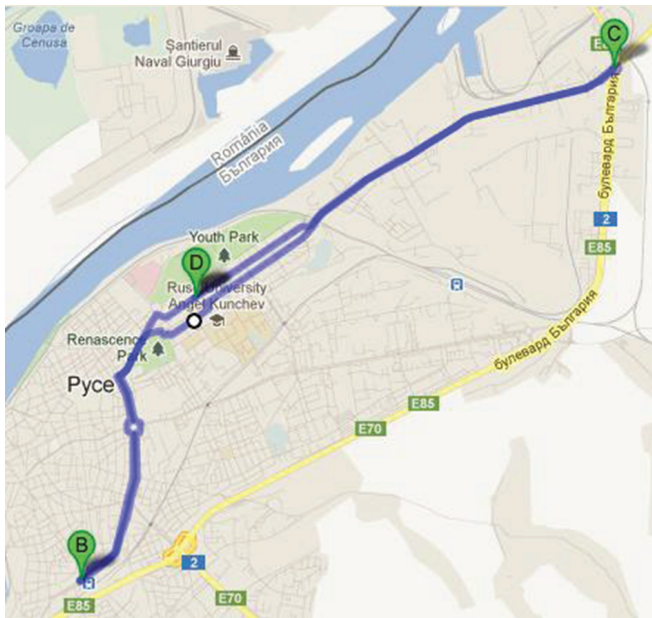


Fig. 4. Route 1 “Rail station – Danube bridge – Rail station”

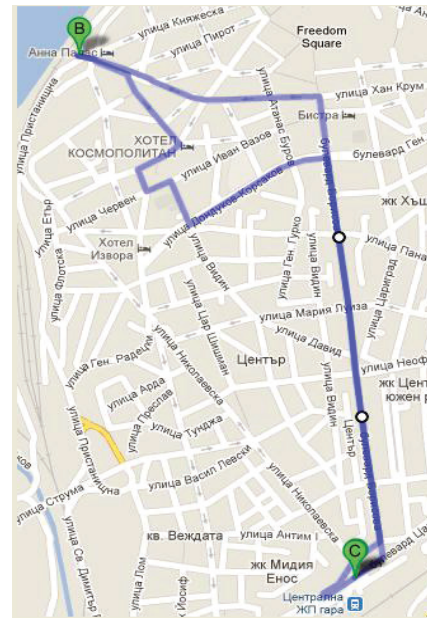


Fig. 5. Route 2 “Rail station – River station – Rail station”



Fig. 6. Route 3 “Rail station – Droujba 3 – Rail station”

Table 2

Obtained results for distance S , average speed V_{av} , time t , average fuel consumption Q_{av} , and in urban routes, concerning hybrid car and conventional car with similar power

Route Results	Toyota Yaris (P3) 1.5 HSD Hybrid				Toyota Yaris (P3) 1,0 VVT-i 5 M/T	
	Distance S , km	Average speed V_{av} , km/h	Travel time t , min	Q_{av} , l/100km		Q_r , l/100km
				without Eco Mode	with Eco Mode	
“Rail station – Danube bridge – Rail station”	15.3	23	30	5.0	4.2	4.9
“Rail station – River station – Rail station”	4.6	21	14	6.8	5.1	6.7
“Rail station – Droujba 3 – Rail station”	6.4	22	12	5.8	5.4	5.8

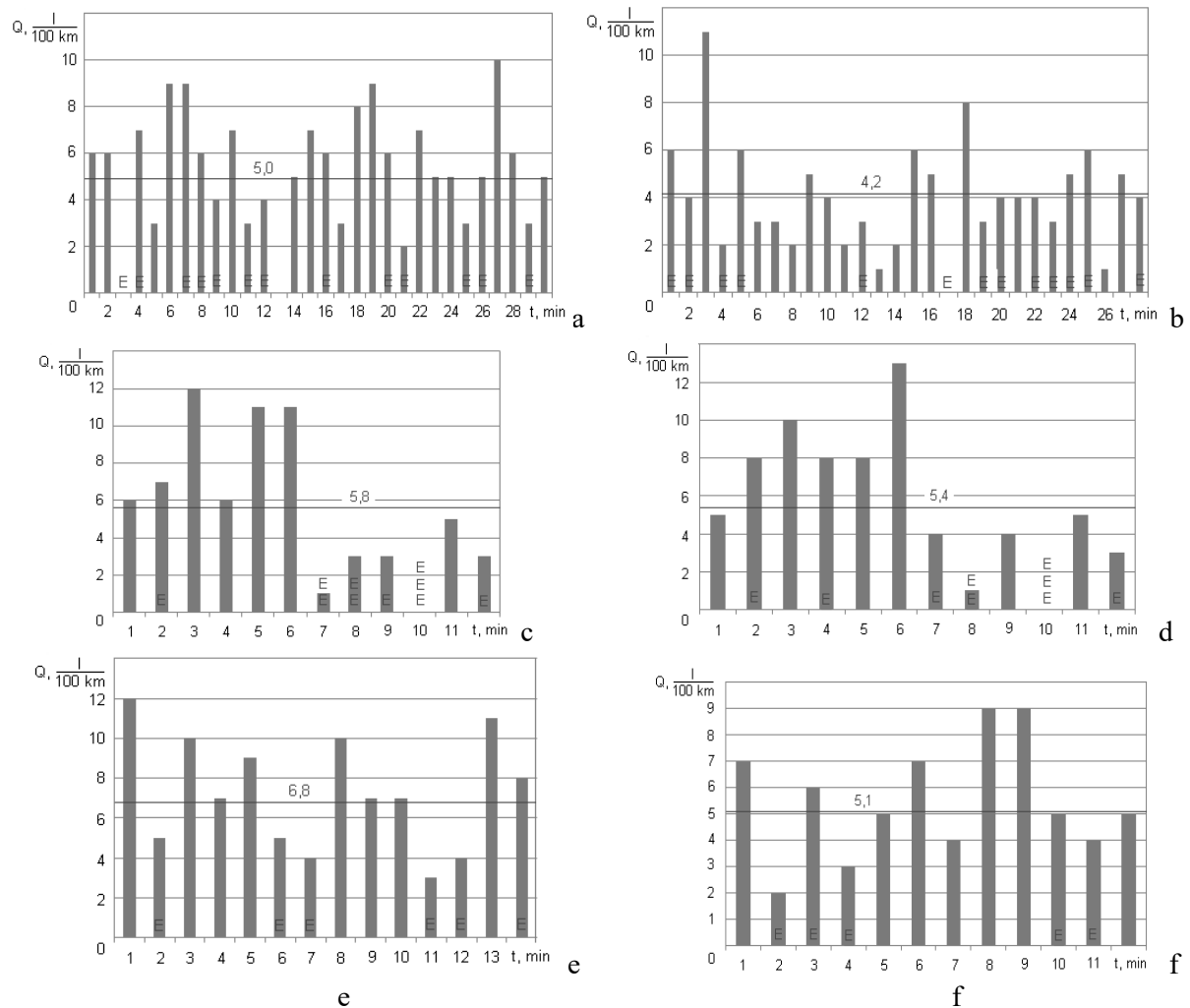


Fig. 7. Current and average fuel consumption on: a - route 1, without “ECO Mode”; b - route 1, with “ECO Mode”; c - route 2, without “ECO Mode”; d - route 2, with “ECO Mode”; e - route 3, without “ECO Mode”; f - route 3, with “ECO Mode”

4. STUDY OF THE FUEL CONSUMPTION OF THE HYBRID CAR IN INTER-CITY CONDITIONS

4.1. Test method and conditions

Fuel consumption on three inter-city routes were investigated:

- Route 1: “Ruse – Varna – resort Golden sands – Ruse” (Fig. 8);
- Route 2: “Ruse – Sozopol – Ruse” (Fig. 9); and
- Route 3: “Ruse – Silistra – Ruse” (Fig. 10).

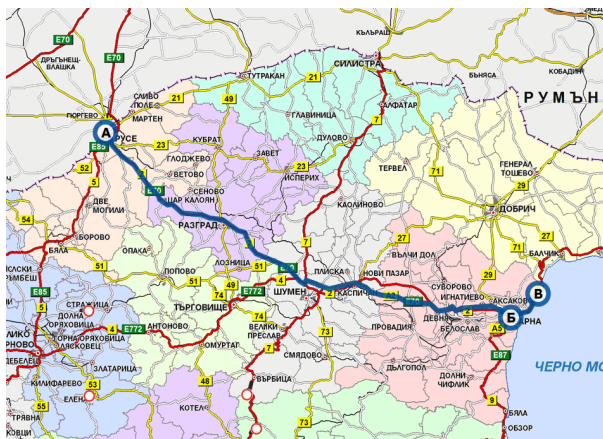


Fig. 8. Inter-city route 1 “Ruse – Varna – resort Golden sands – Ruse”



Fig. 9. Inter-city route 2 “Ruse – Sozopol – Ruse”

The choice of the routes was made taking into account the combination of the inter-town, highway and urban parts. The combination of the uphill, downhill and horizontal parts in the routes is also considered.

The experiments started with clearing the indication of the carboard computer. During the experiment, the fuel consumption was recorded every minute. After the end of the motion, the average values were recorded from the car board computer. At the end of the experiments, in the laboratory, the results were preceded and the graphics were created. Route 1: “Ruse – Varna – resort Golden sands” and return (Fig. 8) includes motion on the first class road Ruse – Shumen, on the high way Shumen – Varna and in urban conditions. Route 2: “Ruse – Sozopol - Ruse” (Fig. 9) has a specific relief (motion uphill, downhill and horizontal parts). The route distance is 300km. The experiment was done with 2 passengers and working climate control. Route 3: “Ruse – Silistra_ Ruse” (Fig. 10) is 116.9 km. The experiment was done with working climate control. The load was 4 passengers in direction Ruse – Silistra and 3 passengers in direction Silistra – Ruse. The route is plane and different number of passengers gives the possibility to estimate the influence of the car load on the fuel consumption.

During the pass of the routes, the fuel consumption for separated parts of route is recorded and drawn on the figures. The “ECO MODE” was deactivated for all 3 routes.

The results for current and average fuel consumption of the hybrid car are presented in Figs. 11-13. The color lines indicate the average fuel consumption for the specific part of the routes and average for whole routes (in red). One can see the difference between fuel consumption in city and inter-city motion.

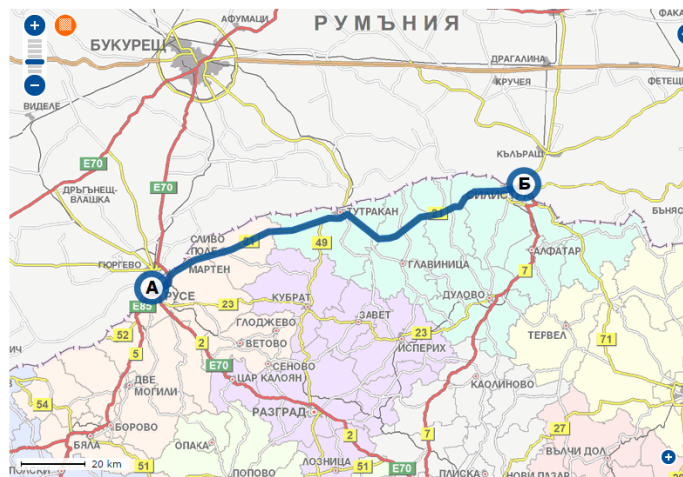


Fig. 10. Inter-city route 3 “Ruse – Silistra – Ruse”

Table 3

Obtained results for distance S , average speed V_{av} , time t , average fuel consumption Q_{av} , and average route fuel consumption Q_r (two directions) in inter-city routes

Routes	Results				
	S , km	V_{av} , km/h	t , min	Q_{av} , l/100km	Q_r , l/100km
Route 1 “Ruse – Varna – resort Golden sands” – with 4 persons	212	77.1	165	5.25	5.18
Route 1 “resort Golden sands – Varna – Ruse” - with 4 persons	212	78.4	163	5.10	
Route 2 “Ruse – Sozopol” - with 2 persons	300	71.8	251	4.5	4.6
Route 2 “Sozopol – Ruse ” - with 2 persons	300	70.4	247	4.7	
Route 3 “Ruse – Silistra” - with 4 persons	116.9	62.2	113	5	-
Route 3 “Silistra – Ruse ”- with 3 persons	116.9	65	108	4.35	-

Table 4

Fuel consumption Q given by the producer for the hybrid and conventional car with similar power

Conventional models	Q , l/100 km		
	Urban cycle	Inter-city cycle	Combined cycle
Toyota Yaris (P3) -1.5 HSD Hybrid (100 Hp)	3.1	3.5	3.5
Toyota Yaris (P3) - 1.0 VVT-i 5 M/T (69 Hp)	5.7	4.2	4.8

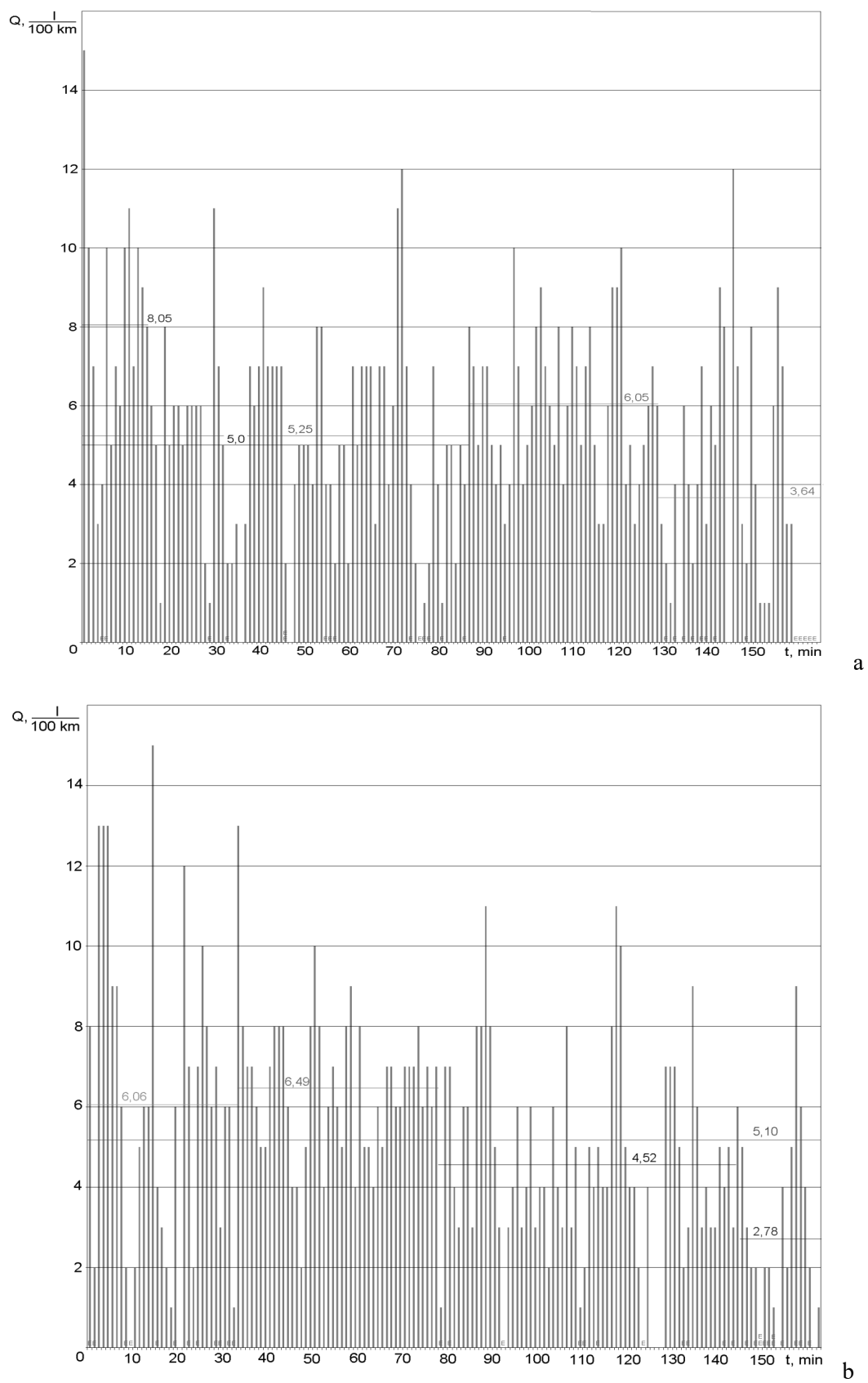
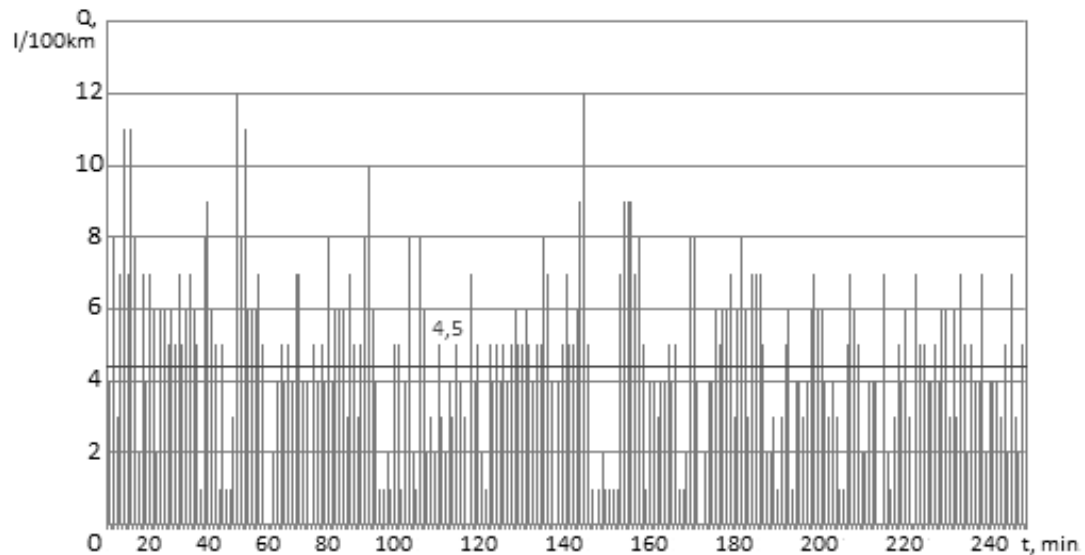
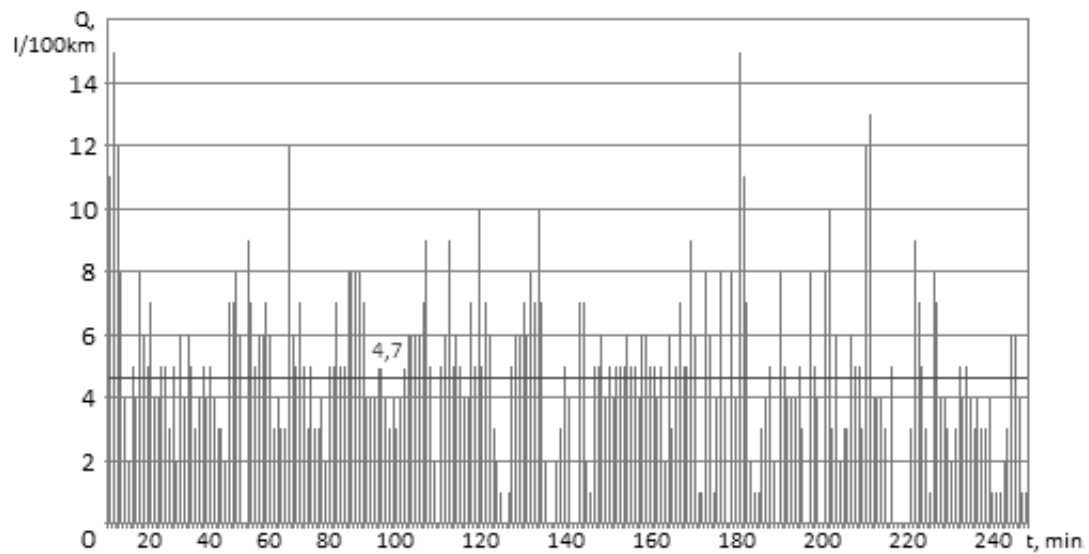


Fig. 11. Current and average fuel consumption on: a - route 1 "Ruse – Varna – resort Golden sands"; b - route 1 "resort Golden sands – Varna – Ruse"

The obtained results for the studied routes are summarized in Tab. 3. The fuel consumption indicated in the technical specification of the producer for the hybrid car and equivalent conventional model Toyota Yaris (P3) - 1.0 VVT-i 5 M/T (69 Hp) of the same producer is presented in Tab. 4



a



b

Fig. 12. Current and average fuel consumption on: a - route 2 "Ruse – Sozopol"; b - route 2 "Sozopol – Ruse"

4.2. Analysis of the results for the fuel consumption of the hybrid car in inter-city conditions

Route 1 "Ruse – Varna – resort Golden sands – Ruse". The obtained results show that the average fuel consumption of the whole route is significantly higher than indicated in the technical specification of the producer (see Tables 3 and 4). The difference is up to 40-50%. The reason probably is different motion intensity out of the towns and on the high way, in comparison with used European cycle using by the producer to estimate the fuel consumption of the hybrid car. The sign "E" on the Fig. 11 indicates the regeneration of the energy (30 Wh) in the battery. Less using the ICE decreases the fuel consumption of the hybrid car in urban condition and this way decreases the consumption for whole

route. In inter-city conditions, the fuel consumption is similar to that one of the conventional car of the same producer (5.4 l/100 km for the combined cycle of motion). In this case, the effect of the hybrid system is minimal.

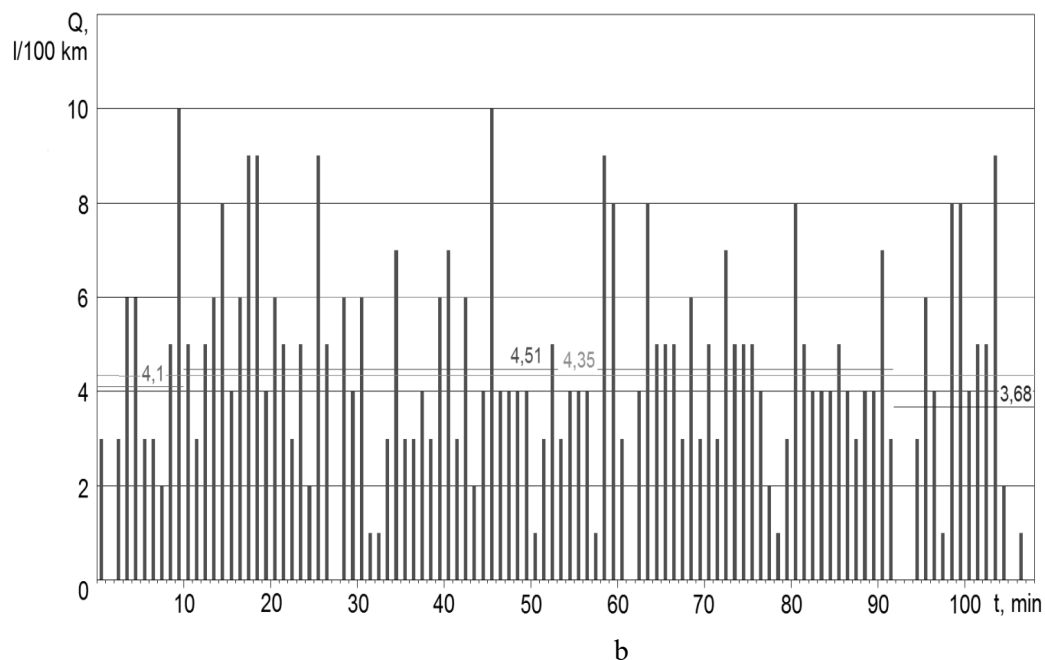
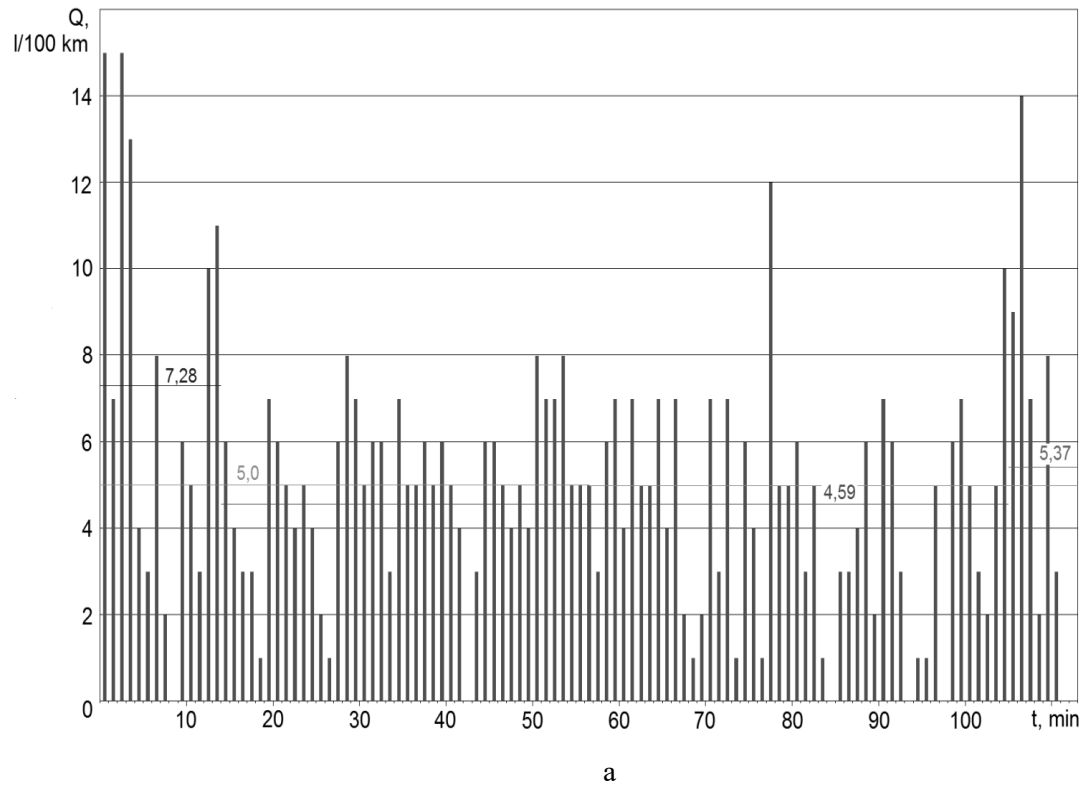


Fig. 13. Current and average fuel consumption on: a - route 3 "Ruse – Silistra"; b - route 3 "Silistra – Ruse"

Route 2 "Ruse – Sozopol – Ruse". Differences of the fuel consumption in separated parts of the route in two directions are minimal. Exception is this part that concerns exit and entrance in Ruse because of uphill and downhill motion in different directions of the route. One can see on the figures

parts with zero consumption. They correspond to passes through small villages, with limited speed less than 50 km/h. During those periods, hybrid car was moving on the electric energy only, thanks to full charged battery in inter-city conditions. The fuel consumption of the hybrid car on the route is significantly higher than indicated in the technical specification of the producer (see Tab. 3 and 4).

Route 3 “Ruse – Silistra – Ruse”. In inter-city conditions, the fuel consumption is similar to that one of the conventional car of the same producer and the effect of the hybrid system is minimal. Less consumption is recorded during the exit of Silistra and during the entrance in Ruse, because of the downhill motion. The difference of 1 person less into return direction causes a less fuel consumption of 0.65 l/100km.

5. CONCLUSIONS

This study is a complex study of the fuel consumption of a hybrid car Toyota Yaris. Original data for motion at different constant speeds were obtained. The economical and energy characteristics of the car are observed and analyzed. At low constant speed, energy consumption is a little higher (Fig. 3), which is a result of low values of the transmission and electric propulsion efficiency. Then the energy consumption slowly goes down. Up to 50 km/h, fuel consumption is zero l/100 km, because for the motion, the car uses only electric energy (approximately 0.08–0.1 kWh/km) from the battery. At constant speed over 50 km/h, the fuel consumption is practically equal to that one of the conventional variant of the same car. At high-speed conditions, the hybrid car runs using only ICE. It is not appropriate to make a comparative analysis of different models hybrid cars only on the basis of fuel consumption and energy characteristics.

The fuel consumption at urban routes is different for the separated routes (Tab. 2 and Fig.7). Probably the differences are generated by the terrain, the traffic, and battery recharge. In real urban conditions, at rush hours, the hybrid car has a significantly higher consumption than indicated in the technical specification of the producer – for studied routes from 61.3 to 119.4%. The usage of “ECO MODE”, in urban conditions, reduces the fuel consumption from 7.4 to 33% for separate routes and average for all routes consists 20%. Improving fuel consumption is connected with worse dynamic performance.

In the real inter-city conditions, the motion of the hybrid car is essentially realized by the ICE. The investigated car has a 31.4-48% higher fuel consumption than indicated in the technical specification of the producer. The usage of the “ECO MODE” in inter-city conditions has no significant effect. The minimal effect (under 4%) is a result of motion in villages with limited speed, basically on the electric energy.

The effect of the hybrid driving system is contradictory. In urban conditions, a hybrid system has up to 31.3% less fuel consumption (with “ECO MODE”) in comparison with an equivalent conventional model. In inter-city conditions, the fuel consumption is practically equal to that one of the conventional car Toyota Yaris (P3) - 1.0 VVT-i 5 M/T. The effect on the consumption in urban conditions depends on the intensity of the motion, road profile, possibility for regeneration, “green wave,” etc.

In the opinion of the research team, battery with higher capacity should be built. This action will improve the effect of the hybrid system. The existing battery of 0.94 kWh assures a motion of 3 km on horizontal terrain, which is not enough in an urban route of a middle-size East European town.

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