PROBLEMS OF FUEL CONSUMPTION MEASUREMENTS IN RESEARCH OF LIQUID PHASE LPG INJECTION ENGINE

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Abstract

In research of LPG fuelling engine, often used method of fuel consumption measurement is weighing of fuel tank. This method is not proper for fuelling system with fuel pump located in the tank. When LPG pump is working are generated vibration that introduce significant disturbance of fuel tank mass measurement. For test bed research of liquid LPG fuelling engine with sequential injection system (system of V generation), measurement of fuel consumption is very difficult because there are fuel vaporization problems in the fuel pipes, too.

This paper presents LPG measurement system, with two of mass flow meters in differential configuration, proposed by authors. This system allow for accurate measurement of LPG fuel consumption. The described system was used for MD-111E engine in test bench research. This engine was fuelling with liquid phase sequential injection system into the suction manifold. Significant problem in the liquid phase injection system is the measuring of fuel consumption. This required of LPG pump installed of the proper rate of delivery to reduce vaporization of fuel. Average relative difference of measured fuel consumption per hour δG_h*, for location of flowmeter sensors in the injectors circuit did not exceeded 2%.*

Keywords: *LPG engine, liquid LPG fuelling, LPG fuel consumption measurement*

1. Introduction

Measurement of fuel consumption is very important part of engine testing. Parameters of fuel consumption determine ecological and economic aspect of engine work. Fuel consumption depends on thermal energy utilization during fuel energy conversion on the mechanical work. It is the index of engine total efficiency.

In practice there are two principal methods of fuel consumption determination: volumetric consumption and mass consumption. The difference is that in mass method measuring dose is fuel mass, instead of volume in volumetric method. In mass method we do not make errors connected with change of fuel density in function of temperature. Therefore, measuring accuracy is addicted to measuring instrument in fuel consumption system.

Measurement of LPG fuel consumption in case of gaseous phase fuelling engine, systems of fuel consumption measurement are similar to systems used in petrol or diesel fuel measurement. In this case measurements are realized with use of mass method fuel consumption determining by mass of fuel LPG tank changes. This is easy to do for research of small engines and for relatively small fuel consumption. Here we can use fuel tank with small volume and mass. For large cubic capacity engines also large fuel tanks have to be used. Weighing of such great mass container is difficult and connected with greater measuring error, for the sake of lesser measuring accuracy of used balance. In this case we have to use additional small fuel measurement container. Example of this type solution is system worked out in Department of Automotive Vehicles and Internal Combustion Engines of Rzeszow University of Technology (Fig. 1).

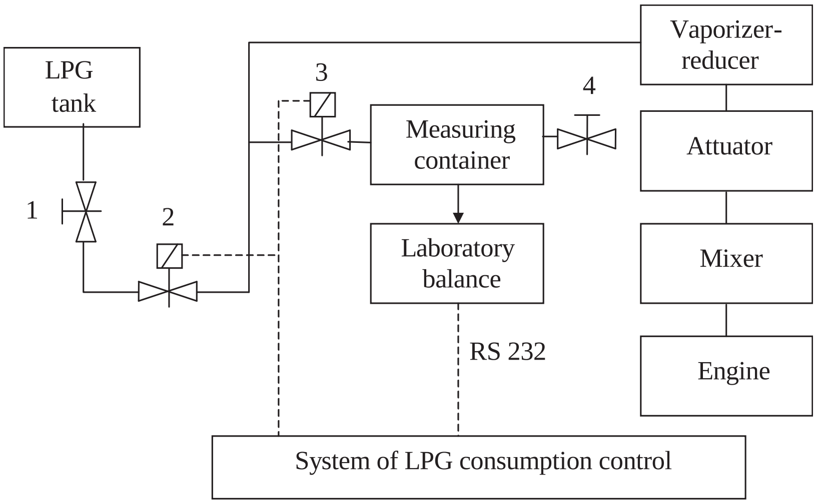

Fig. 1. Schematic diagram of measuring position of LPG fuel consumption: 1, 4 - hand operated LPG valves, 2, 3 - LPG solenoid valves

In this system solenoid valves are steering by the switches in the control system. Working of solenoid valve is signal by the control lamp in the control system. Laboratory balance by the RS-232 joint is connected with the gas consumption device. This device computes fuel consumption per hour in specified measurement time. First step of fuel consumption measurement is the measuring container filling. For that purpose there is necessary to open valves (1), (2) and (3), as well as vent valve of measuring container (4). After the container of LPG became filled, the valves (3) and (4) closed. The engine during starting, heating-up and operating parameters stabilization, works with LPG fuel from the main tank. In these cases valves (1) and (2) are opened. LPG measurements start if the valve (3) is open and the valve (2) is close. Change of measuring container mass is measured by laboratory balance WPT 6, as well as recorded by the system calculating of LPG fuel consumption per hour.

During LPG fuel consumption measurement in the system of liquid phase injection, there is problem of fuel vaporization in supply system [1, 5]. Main ingredients of LPG fuel: propane and butane have low boiling temperatures. The boiling temperatures for this LPG components (about 231 K for propane and about 272.5 K for n-butane) are lower than average ambient temperatures next to the engine. This produce the increase of fuel temperature in the fuel system, creates fuel vaporization in the fuel pipes making vapour-lock phenomena. This produce disturbance, that required special solutions for fuel consumption measurement, differ to systems used for petrol and diesel fuel measurement.

2. Measurement system description

The object of research was turbo-charged spark ignition engine MD111 ET fuelled by multipoint sequential injection of LPG in the liquid phase to the suction manifold arms. For the engine Vialle LPG fuelling system was adopted (Fig. 2). In Tab. 1 the main parameters of tested engine are represented.

Receiving reliable results of experimental research always is connected with adequate state of technology and accuracy of measuring devices. On this matter special attention was focused. Made every endeavour to all components of measurement system was to meet high requirements. This was connected especially with fuel consumption measurement system. For that purpose measurement system with two flometering sensors of firm AVL was used. The main parameters of measuring sensors represent Tab. 2. Used sensors based on Coriolis phenomena. These type of flowmeters are using to direct measurement of: mass flow, total mass, fuel density and temperature, volumetric flow and total volume.

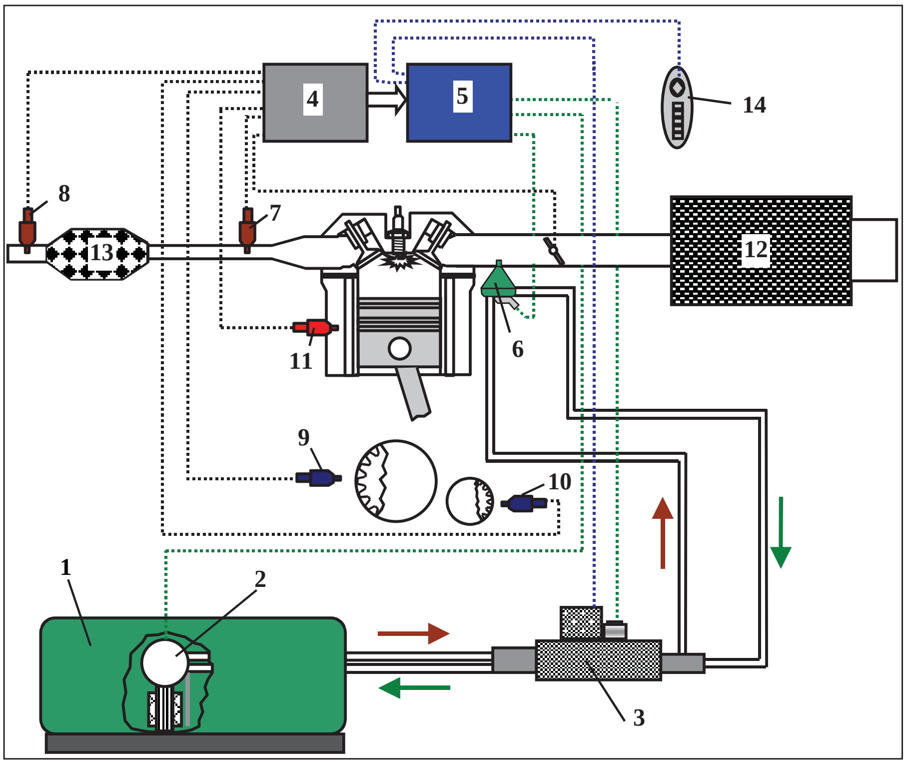

Fig. 2. Scheme of VIALLE system: 1 - LPG fuel tank, 2 - LPG pump, 3 - pressure regulator , 4 - petrol control unit, 5 - LPG control unit, 6 - LPG injector, 7 - first lambda sensor, 8 - second lambda sensor, 9 - rotational speed sensor, 10 - camshaft position sensor, 11 - coolant temperature sensor , 12 - air filter, 13 - exhaust gas catalyst, 14 - fuel selection switch

Tab. 1. Main technical data of MD-111ET engine

Parameter	Value
Working cycle	Four-stroke engine
Diameter of cylinder	127 mm
Piston stroke	146 mm
Engine displacement	11097 cm^3
Number and configuration of cylinder	6-th cylinder, in-line
Firing order	1-5-3-6-2-4
Combustion system	Spark ignition
Compression ratio	9
Cooling system	liquid
Timing angles Inlet valve (opening, closing) Exhaust valve (opening, closing)	 8° befor TDC, 232° after TDC 134° after TDC, 20° before TDC
LPG fuelling system LPG tank Pump Pump driving motor Pressure regulator Injectors Resistance of injector coil Injectors fasten Control unit	injection wit multipoint sequential injection of liquid LPG to the suction manifold - pressure vessel of Stako firm - membrane pump of VIALLE - brushless, alternating current - with mechanical part of pressure regulation and solenoid cut-off valve stay constant over fuelling pressure 0.5 MPa in relation to pressure in the LPG fuel tank - solenoid of VIALLE, - 1.8 Ω - in corpus with adapter - control unit of VIALLE with system of injection control of Delta Tech Electronics firm

View of test stand with flowmetering system for fuel consumption measurement is shown on the Fig. 3. Time of injection, LPG pressure, rotational speed of LPG pump, rotational speed of engine and the other parameters describing work of fuelling system were analyzed with the use of diagnosis program DPD of Vialle. On the Fig. 4 example window of PROLINK II program for fuel sensors service is presented.

Measurements of fuel consumption were realized for two method of sensors position in the system (Fig. 5 and Fig. 6). In the first case (Fig. 5), one sensor was placed before pressure regulator and the other sensor was placed on the return fuel pipe, after pressure regulator. In the second case (Fig. 6), sensors were placed in the injectors' circuit. First sensor was located after pressure regulator and before first LPG injector, while the other sensor was located after sixth LPG injector and before pressure regulator.

Tab. 2. Basic technical data of fuel flowmeters

Flowmeter to measuring fuel flow to the engine		
No.	Parameter	Value
1	Type	CMF025M
2	Measuring method	Coriolis sensor
3	Range of engine power	to 500 kW
4	Measuring range	0...125 Nm^3/h (for gaseous phase fuel)
5	Measuring accuracy	≤ 0.5 % of measured value
6	Repeatability of measurements	0.25 %
7	Pressure of fuel	to 100 bar
8	Range of fuel temperatures	-40 ... +120 ºC
Flowmeter to measuring fuel flow from the engine		
No.	Parameter	Value
1	Type	CMF010M
2	Measuring method	Coriolis sensor
3	Measuring range	0...100 kg/h
4	Measuring accuracy	≤ 0.1 % of measured value
5	Repeatability of measurements	0.03 %
6	Pressure of fuel	to 30 bar
7	Range of fuel temperatures	-50 ... +125 ºC
8	Software	PROLINK II

Fig. 3. View of test stand with flowmetering system of fuel consumption measurement: 1 - flowmeter to measure of fuel flow rate to the engine, 2 - flowmeter to measure of fuel flow rate from the engine

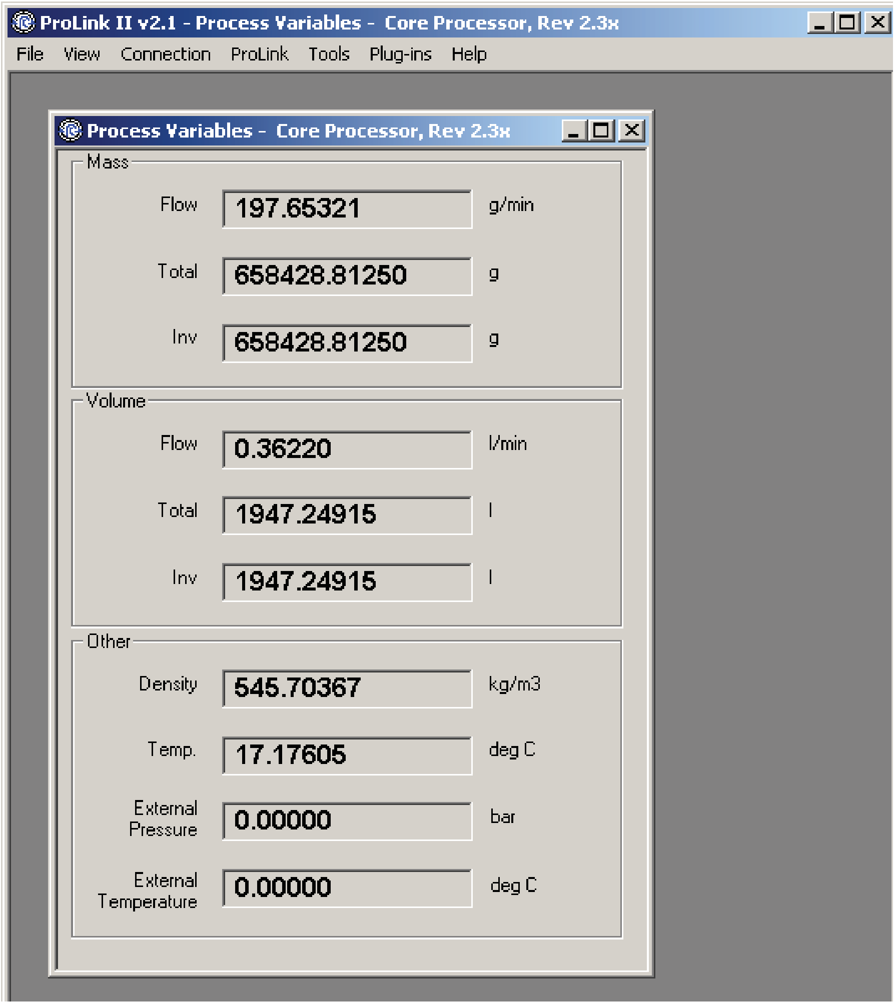

Fig. 4. View of example window of program for service of flowmetering system of fuel consumption measurement (parameters: LPG mass flow, LPG volumetric flow, density of LPG and temperature of LPG)

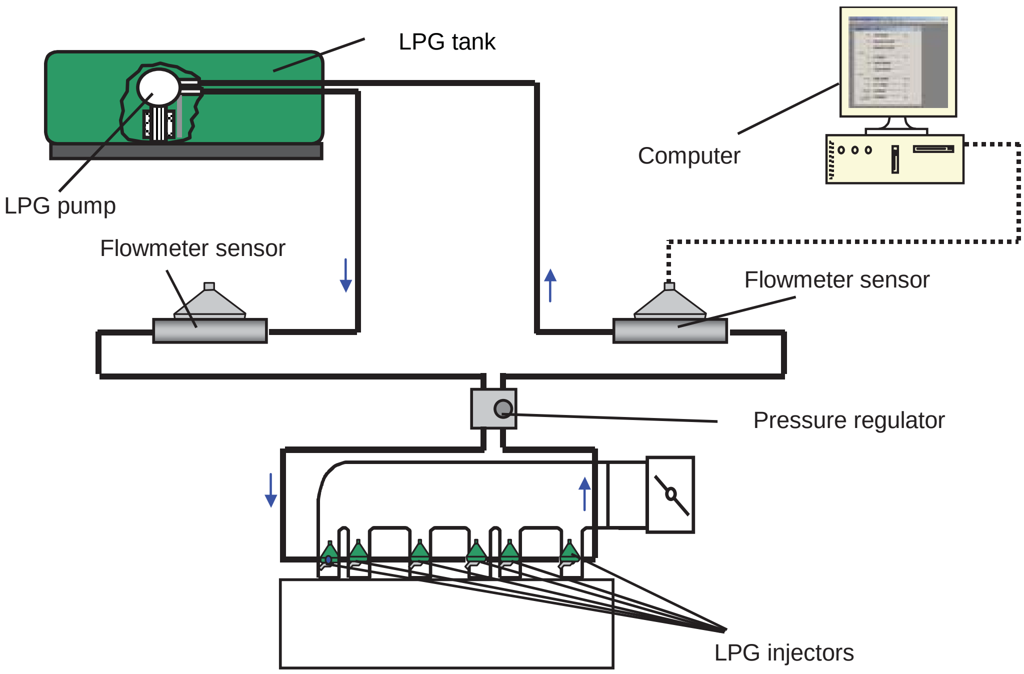

Fig. 5. Schema of flowmeter sensors location in the first case

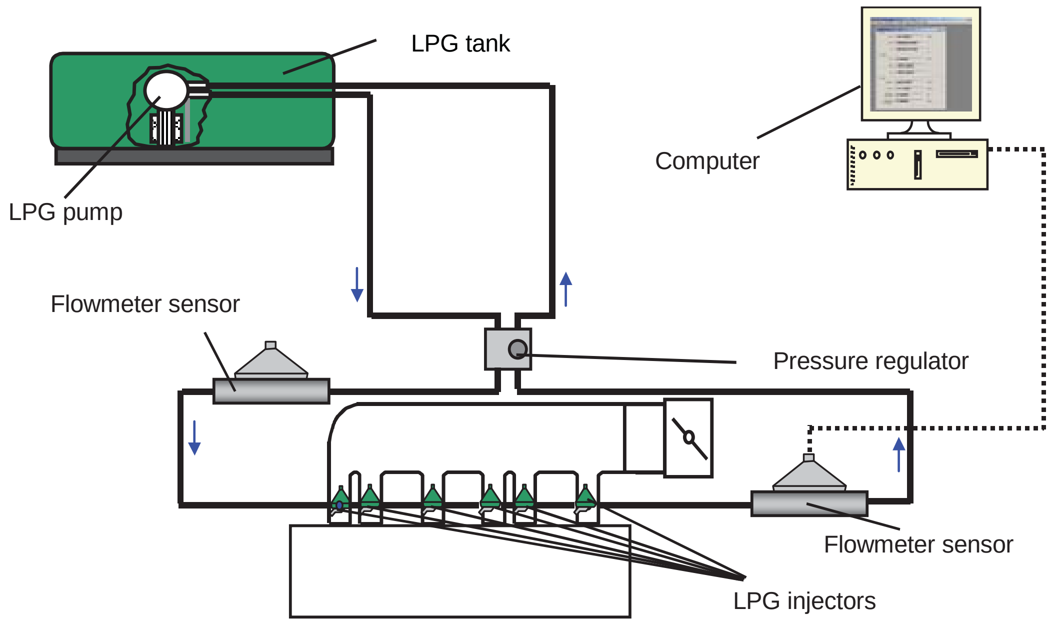

Fig. 6. Schema of flowmeter sensors location in the second case

3. Results of research

Results of research for the first case of flowmeter sensors location show Tab. 3. As we can see, the change of LPG density in the return fuel fuel pipe and flowmeter sensor measured flow of fuel from the engine are significant. Decrease of density indicates that part of fuel vaporizes in the fuel pipe and there is the two-phase flow (liquid+gaseous) in the return fuel pipe and flowmeter sensor. This effect changes measured mass flow and fuel consumption per hour. Maximum difference between indications of mass flow in the return flowmeter was equal about 10 g/min. Average relative difference of measured fuel consumption per hour δG_h exceeded 7%.

Tab. 3. Some research results for the first position of flowmeter sensors

Mo [Nm]	t_{wv} [ms]	p_{LPG} [kPa]	n_p [obr/min]	Q_{palD} [g/min]	ΔQ_{palD} [g/min]	Q_{palZ} [g/min]	ΔQ_{palZ} [g/min]	G_h [kg/h]	δG_h [%]	ρ_{LPG} [kg/m^3]	t_{LPG} [°C]
26.2	4.2	1111	1000	391 383	8	245 248	3	8.76 8.10	7.8	534.0 434.0	18.0 19.1
75.6	4.6	1105	1000	394.0 392.8	1.2	234.0 236.0	2	9.60 9.41	2.0	534.7 391.0	18.0 18.9
120.6	5.6	1100	1000	396.0 393.0	3	206.0 216.0	10	11.40 10.62	7.1	534.0 362.0	18.0 19.1
331.5	9.4	1069	1000	394.0 393.5	0.5	122.0 131.0	9	16.32 15.75	3.5	534.0 326	17.0 17.7
422.9	11.4	1042	1000	394.0 393.5	0.5	82.0 89.0	7	18.72 18.27	2.4	534.0 242.0	19.0 19.8
600.0	15.6	975	1500	619.9 620.8	0.9	140.0 150.0	10	28.79 28.25	1.9	545.0 194.0	17.2 18.3
688	15.6	1015	2000	766.9 765.0	1.9	217.0 207.0	10	32.99 33.48	1.5	543.0 216.0	17.9 18.7

Denotation: Mo- engine torque, t_{wv} - LPG injection signal time, p_{LPG} - LPG pressure, n_p - rotational speed of LPG pump, Q_{palD} - fuel flow rate to the engine, ΔQ_{palD} - absolute change of fuel flow rate to the engine, Q_{palZ} - fuel flow rate from the engine (return), ΔQ_{palD} - absolute change of fuel flow rate from the engine, G_h - fuel consumption per hour, δG_h - average difference of measured fuel consumption per hour, ρ_{LPG} - density of LPG, t_{LPG} - temperature of LPG

Tab. 4. Some research results for the second position of flowmeter sensors

Mo [Nm]	t_{wv} [ms]	p_{LPG} [kPa]	n_p [obr/min]	Q_{palD} [g/min]	ΔQ_{palD} [g/min]	Q_{palZ} [g/min]	ΔQ_{palZ} [g/min]	G_h [kg/h]	δG_h [%]	ρ_{LPG} [kg/m^3]	t_{LPG} [°C]
62.7	4.4	1311	1500	547.5 546.6	0.9	402.8 402.1	0.7	8.68 8.67	0.13	511.3 510.9	34.1 35.3
201.3	6.6	1310	1500	548.4 548.0	0.4	334.6 335.7	1.1	12.83 12.74	0.7	511.4 510.7	36.1 36.9
180.3	6.8	1209	1000	386.0 385.3	0.7	181.4 180.9	0.5	12.28 12.26	0.1	515.9 515.3	30.4 31.6
303.2	8.4	1307	1500	547.9 548.3	0.4	280.9 280.0	0.9	16.02 16.10	0.49	511.2 509.7	37.3 38.0
395.5	10.4	1232	1500	560.2 560.5	0.3	254.2 250.0	4.2	18.36 18.63	1.46	515.1 514.2	33.5 34.8
572	14.2	1229	1500	558.5 559.9	1.4	151.7 151.9	0.2	24.41 24.48	0.29	513.5 511.7	33.5 35.5
668.5	17.2	1212	1500	558.6 557.7	1.1	105.3 100.3	5.0	27.20 27.44	0.9	507.2 506.7	37.3 38.2

Denotation: according to Tab. 3

In connection with above results was decided, that flowmeter sensors should be installed in the injector circuit. Results of research for the second case of flowmeter sensors location show Tab. 4. In this case changes of mass flow rate of fuel are considerable lower than for first case of sensor locations. Maximum difference between indications of mass flow in the return flowmeter was equal about 5 g/min. Average relative difference of measured fuel consumption per hour δG_h did not exceeded 1.5%.

4. Conclusions

On the base of research results the following conclusions have been formulated:

1. Significant problem in the liquid phase injection system fuelling engine is the measuring of fuel consumption. This required of LPG pump installed of the proper rate of delivery, in order to reduce vaporization of fuel.
2. Installation of flowmeter sensors according to the first method (Fig. 5) was connected with lowering of measuring accuracy. This was connected with fluctuations of fuel flow with pressure regulator working, as well as a result of fuel vaporization in the return fuel line and two-phase flow for the return fuel flowmeter sensor.
3. Measurement of fuel consumption of engine fuelled by sequential liquid phase injection of LPG required two flowmeter sensors located in the injector circuit (Fig. 6). This localization of flowmeter sensors reduces effect of fuel fluctuations with pressure regulator, as well as enables one-phase measurement of liquid phase.
4. Average relative difference of measured fuel consumption per hour δG_h, for location of flowmeter sensors in the injectors circuit did not exceeded 2%.

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