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Experimental Comparison of Methods for Cleaning Car Exhaust Gas by Exposure Using Ultrasound and Laser Radiation

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Abstract. The article offers a comparison of the use of ultrasonic and laser exposure in a device for cleaning exhaust gases of internal combustion engines, in order to determine the most effective method to reduce their toxicity and improve the environmental safety of cities. The scheme of an experimental combined ultrasound-laser automobile muffler and the results of the experiment are presented, proving the possibility and effectiveness of using the process of ultrasonic coagulation of solid particles and photo-chemical reaction for cleaning exhaust gases of diesel cars. Dependences confirming the effectiveness of the ultrasound-laser car muffler were obtained. A comparison of methods for cleaning car exhaust gas by ultrasound, laser radiation and the combined effects of both methods is presented.

Keywords: car; internal combustion engine; ultrasonic cleaning; laser cleaning; car exhaust gases; coagulation.

Introduction

Toxic emissions in modern mufflers are reduced by installing exhaust gas purification and neutralization systems that operate on vehicles; devices operating on absorption, thermocatalytic methods, and thermal afterburning have become widespread [1].

An increase in the concentration of exhaust gases leads to an increase in diseases of the cardiovascular system and lungs. Reducing harmful emissions from automobile exhaust gases is an important task in solving the environmental problem of environmental pollution [2]. Prolonged contact with an environment poisoned by car exhaust gases weakens the human body. In addition, exhaust gases can cause the development of various diseases, such as: respiratory failure; sinusitis; bronchitis; lung cancer [3-6].

The authors propose an experimental comparison of methods for ultrasonic and laser cleaning of automobile exhaust gases, including installation of an ultrasonic emitter and laser inside the muffler. Research has been carried out on the purification and utilization of exhaust gases from motor vehicles, which have shown positive results [7-16].

Patents have been registered on the use of ultrasonic influence on vehicle exhaust gas, which have shown their effectiveness [17-19]. To conduct and prove research on exhaust gas purification with ultrasound, full-size ultrasonic stands in a polypropylene housing were developed and studies were carried out [7, 10].

The research hypothesis is the possibility of cleaning exhaust gases from an internal combustion engine with ultrasonic emitters and a laser built into the car muffler housing.

The goal is to substantiate the possibility of using ultrasonic influence, laser radiation or joint work to clean car exhaust gases.

The objectives of the research include: development of an experimental stand; research methodology; experimental study and analysis of the results obtained.

The option of creating a car muffler with the combined effect of ultrasound and laser radiation has a significant advantage: it can be equipped with both new and existing cars. The importance of the environmental problem of air purification, the level of technical solutions and patents, the results of theoretical and experimental studies on ultrasonic and laser effects on media allow us to consider the task of creating automobile mufflers with the complex effect of ultrasonic and laser radiation as relevant [20-39].

1. Methods and Experiments

To achieve the set goals, a full-scale experiment was conducted on the developed combined ultrasonic-laser automobile muffler (Figures 1-3). During the experiment, at the first stage, the degree of exhaust gas purification from harmful impurities was determined using a gas analyzer.

During the experiment, at the first stage, the content of CH, CO, CO_2, O_2 in the exhaust gas of a car was determined depending on the engine speed without ultrasound, under the influence of ultrasound at the frequencies of the ultrasonic generator 40, 25, 28 kHz, as well as under the influence of laser radiation and complex exposure to ultrasound and laser. At the second stage of the experiment, the smoke, temperature and humidity inside the muffler, the speed of the exhaust gas, the frequency in the ultrasonic laser car muffler measured by a frequency meter installed at a distance of 150 mm from the entrance to the muffler, as well as fuel consumption depending on the crankshaft speed of the car's internal combustion engine were determined.

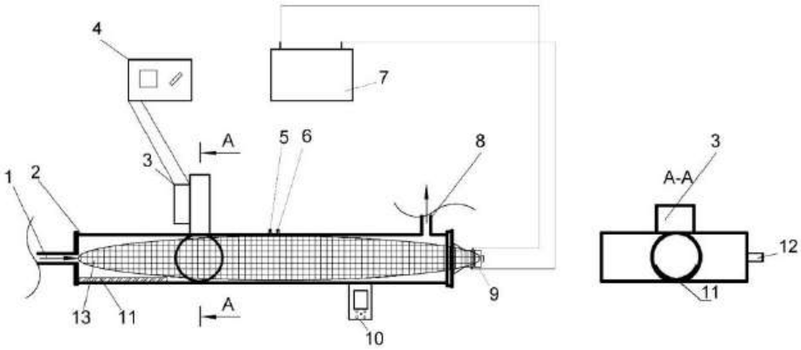
The experimental study was carried out as follows:

- tests were carried out without turning on and with turning on ultrasonic and laser equipment for one minute each;
- the study was carried out at engine crankshaft speeds of 1000, 1200, 1400 rpm. A laboratory diesel internal combustion engine "D245" was used (Fig. 1), engine capacity 4750 cc. cm., engine power 245 hp, automobile 4-component gas analyzer "Infrakar M-1.01", smoke meter "INFRAKAR-D 1-3.01", anemometer "UNI-T UT363" and digital frequency meter.

Fig. 1. – Laboratory diesel internal combustion engine "D245"

The exhaust gas from the car was supplied to the ultrasonic laser car muffler (further see Figures 2-3) through the inlet pipe 1 under pressure depending on the speed of the car's crankshaft. In the muffler, with the ultrasonic equipment turned on, for one minute at an ultrasonic generator frequency of 40, 25, 28 kHz, the exhaust gas was exposed to ultrasonic waves in the longitudinal direction 13, and laser radiation 3 also occurred. In the muffler, ultrasonic intensification of coagulation processes occurred [19, 20] and purification of exhaust gases due to sedimentation of enlarged particles of exhaust gas at the soot collection site 11, as well as photo-chemical processes occurred under the influence of a laser. The purified exhaust gas was discharged through the outlet pipe 8.

Fig. 2. – Ultrasound-laser car muffler



1 – inlet pipe; 2 – muffler body; 3 – laser; 4 – 12V rectifier;
5 – temperature sensor; 6 – moisture meter; 7 – ultrasonic generator; 8– outlet pipe;
9 – longitudinal ultrasonic emitter; 10 – thermometer-hygrometer; 11 – removable tray;
12 – microscope

Fig. 3. – Diagram of an ultrasonic laser car muffler

When the ultrasonic laser muffler was operating, readings were taken from a gas analyzer, smoke meter, thermoter-hygrometer, anemometer, and frequency meter. Also, the fuel consumption of the internal combustion engine was previously measured at speeds of 1000, 1200 and 1400 (Fig. 4-8) by supplying fuel from a measuring container. Photos and video recordings were made inside the ultrasonic silencer using a digital microscope 12. Photos are not shown due to unclear images during transfer.

Fig. 4. – Indications of the automobile 4-component gas analyzer “Infrakar M-1.01”

Fig. 5. – Readings of the smoke meter “INFRAKAR-D 1-3.01”

Fig. 6. – Electronic frequency meter readings

Fig. 7. – Process of measuring fuel consumption

Fig. 8. – Process of measuring exhaust gas velocity

3. Experimental Studies

Tables 1-3 show the experimental results, and Figures 9-12 show the dependences of the CO_2, O_2 content, smoke and frequency in the muffler on the engine speed without exposure, under the influence of ultrasound at frequencies of 40, 25, 28 kHz, as well as under the influence of a laser and the complex effect of ultrasound and laser at 1000, 1200, 1400 rpm of the internal combustion engine crankshaft.

Table 1. Experimental readings without exposure, under the influence of ultrasound and laser at 1000 rpm

Measurements time=60 sec	without impact	with ultrasound f= 25kHz	with ultrasound f= 28 kHz	with ultrasound f= 40 kHz	with laser	with laser and ultrasound
CH (ppm)	0,00	0,00	0,00	0,00	0,00	0,00
CO (%)	0,02	0,01	0,02	0,02	0,02	0,02
CO_2 (%)	1,38	1,36	1,38	1,36	1,33	1,32
O_2 (%)	18,66	18,63	18,67	18,70	18,87	18,87
Smokiness (%)	0,9	0,7	0,7	0,8	0.6	0.8
Temperature (°C)	47,6	48	43	43,1	48,2	48
Humidity (%)	10%	10%	15%	15%	10%	10%
Gas velocity (m/s)	Input 18 Output 10.3	Input 18 Output 10.3	Input 18 Output 10.3	Input 18 Output 10.3	Input 18 Output 10.3	Input 18 Output 10.3
f in the muffler at a distance of 150 mm from the input (Hz)	66-141	2100-2570	2400-2438	2800-2909	219-180	3600-3700
Fuel consumption (ml/min)	35	35	35	35	35	35

Table 2. Experimental readings without exposure, under the influence of ultrasound and laser at 1200 rpm

Measurements time=60 sec	without impact	with ultrasound f= 25kHz	with ultrasound f= 28 kHz	with ultrasound f= 40 kHz	with laser	with laser and ultrasound
CH (ppm)	0,00	0,00	0,00	0,00	0,00	0,00
CO (%)	0,02	0,02	0,02	0,02	0,02	0,02
CO_2 (%)	1,39	1,36	1,38	1,37	1,35	1,36
O_2 (%)	18,97	18,98	18,97	18,97	19,01	19,01
Smokiness (%)	3,1	2,9	2,8	2,9	2,5	2,5
Temperature (°C)	49	49,1	51,2	48,7	48,9	47,8
Humidity (%)	10%	10%	12%	13%	10%	10%
Gas velocity (m/s)	Input 20,8 Output 11	Input 20,8 Output 11	Input 20,8 Output 11	Input 20,8 Output 11	Input 20,8 Output 11	Input 20,8 Output 11
f in the muffler at a distance of 150 mm from the input (Hz)	117-151	2200-2615	2450-2465	2915-2930	220-350	3650-3700
Fuel consumption (ml/min)	50	50	50	50	50	50

Table 3. Experimental readings without exposure, under the influence of ultrasound and laser at 1400 rpm

Measurements time=60 sec	without impact	with ultrasound f= 25kHz	with ultrasound f= 28 kHz	with ultrasound f= 40 kHz	with laser	with laser and ultrasound
CH (ppm)	0,02	0,02	0,02	0,02	0,04	0,04
CO (%)	0,01	0,01	0,01	0,01	0,01	0,01
CO_2 (%)	1,40	1,39	1,40	1,40	1,38	1,4
O_2 (%)	18,56	18,50	18,56	18,53	18,43	18,36
Smokiness (%)	0,8	0,7	0,7	0,5	0,6	0,6
Temperature (°C)	49,2	45,8	48	48,1	48	49,2
Humidity (%)	12%	12%	12%	12%	12%	12%
Gas velocity (m/s)	Input 21,5 Output 12,9	Input 21,5 Output 12,9	Input 21,5 Output 12,9	Input 21,5 Output 12,9	Input 21,5 Output 12,9	Input 21,5 Output 12,9
f in the muffler at a distance of 150 mm from the input (Hz)	130-185	2351-2300	2455-2465	2920-2935	250-451	3750-3960
Fuel consumption (ml/min)	65	65	65	65	65	65

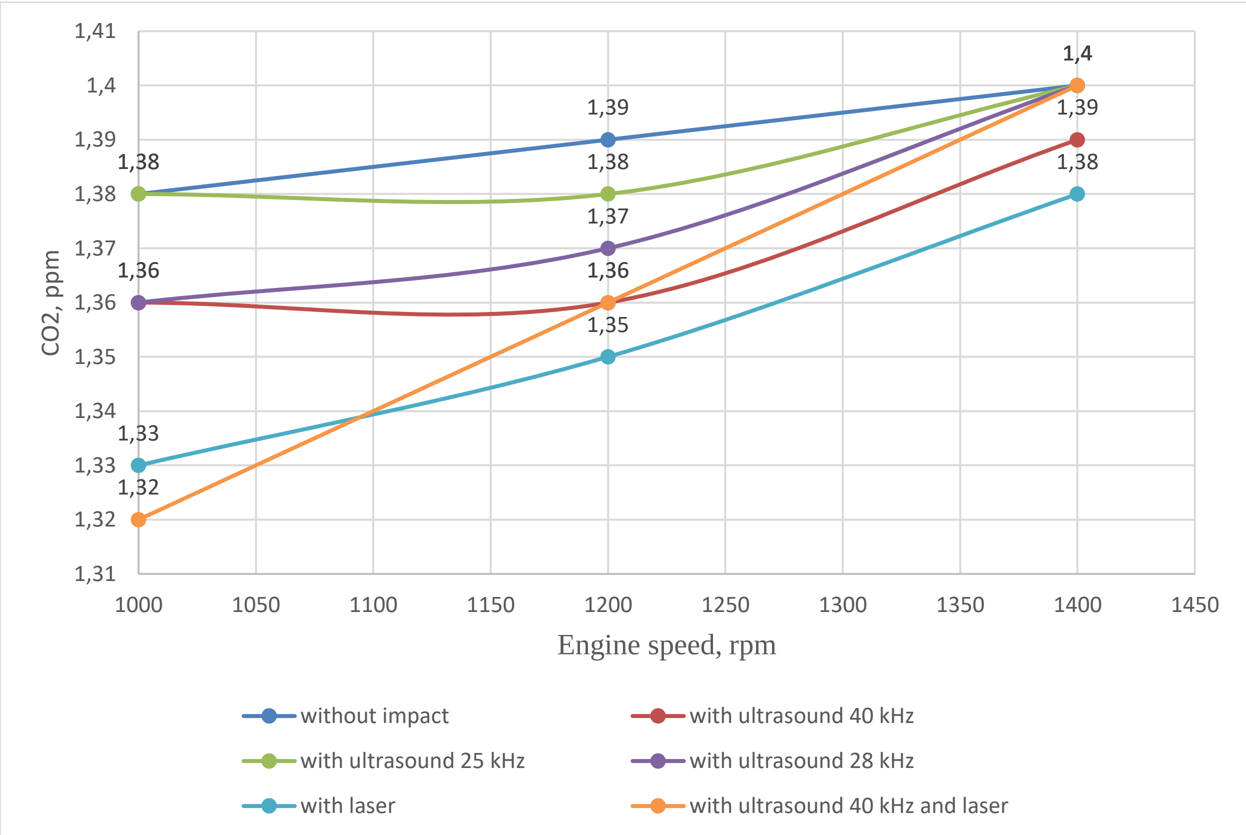


Fig. 9. – Dependence of CO_2 content on engine speed without impact and under the influence of ultrasound at frequencies of 40, 25, 28 kHz and laser

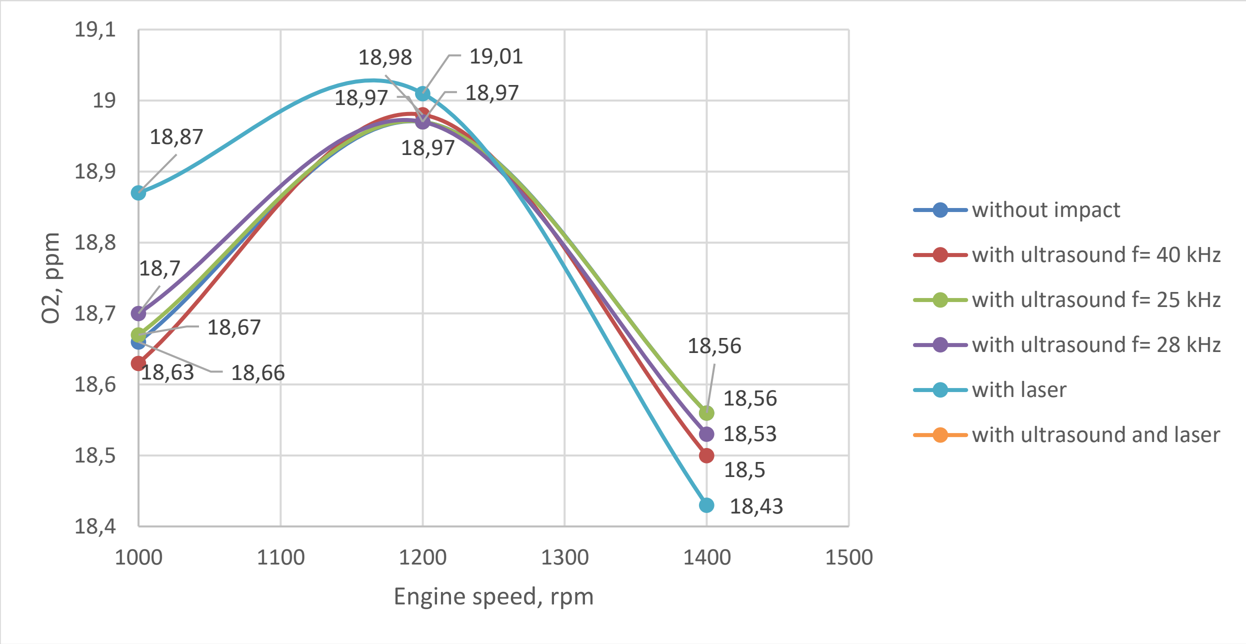


Fig. 10. – Dependence of oxygen content on engine speed without impact and under the influence of ultrasound at frequencies of 40, 25, 28 kHz and laser

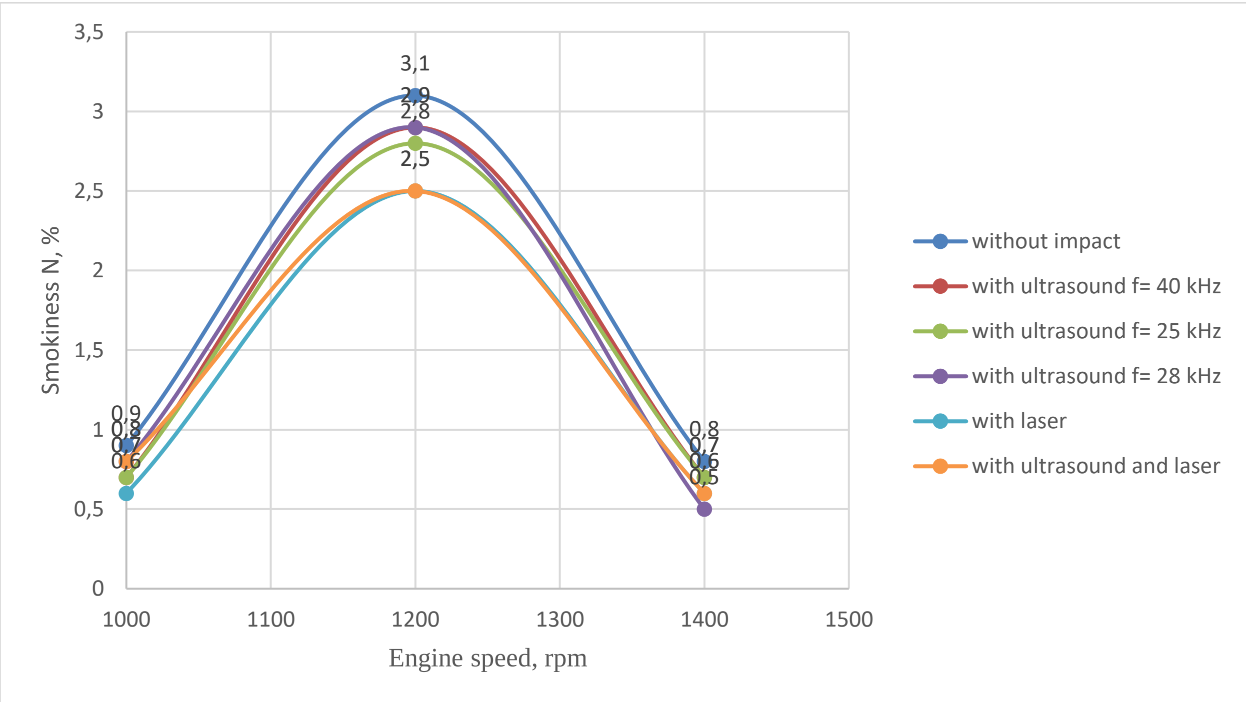


Fig.11. – Dependence of exhaust gas smokiness on engine speed without impact and under the influence of ultrasound at frequencies of 40, 25, 28 kHz and laser

As can be seen from the given dependencies, the decrease in CO_2 concentration and smoke, with an increase in O_2 confirms the hypothesis about the effective operation of ultrasonic and laser cleaning of exhaust gas. Laser radiation works more effectively than ultrasound, since the speed of light is faster than the speed of sound. The energy transmitted by the laser is instantly transferred to solid particles in the exhaust gas and there is a decrease in smoke, as well as an increase in oxygen. The combined operation of ultrasound and laser provides the maximum reduction of CO_2. This complex process has not been fully studied and requires additional theoretical and experimental research.

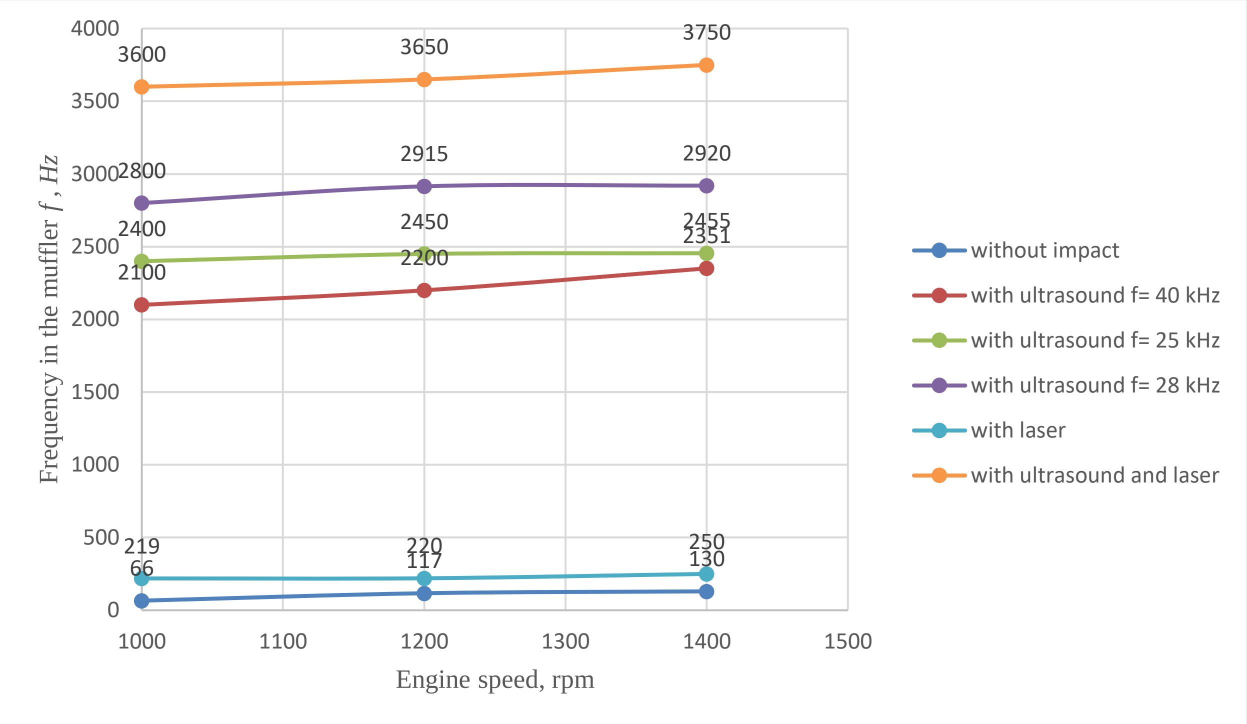


Fig. 12 – Dependence of frequency in an ultrasonic muffler on engine speed without impact and under the influence of ultrasound at frequencies of 40, 25, 28 kHz and laser

4. Conclusion

In order to reduce harmful emissions from motor vehicle engines, with minimal costs and maximum efficiency of the complex effect of ultrasound and laser radiation for cleaning from solid soot particles and harmful impurities, an experimental study was conducted on the developed ultrasound-laser automobile muffler. The efficiency of the complex effect on the exhaust gases of motor vehicles was proven during the experiment and has promising development of this direction of cleaning aerosols from harmful impurities by the proposed method.

Hydrodynamic coagulation is superior in efficiency to orthokinetic cleaning, and laser cleaning is superior to ultrasound. The experimental study showed an increase in the mass of coagulated particles (soot) under the influence of ultrasound by more than 2 times.

The article proves the hypothesis of reducing harmful emissions due to the use of ultrasound and laser radiation. The direction of complex effects on the exhaust gas of cars has promising development and requires additional research. The conducted experimental studies are the basis for the creation of an engineering calculation method during the development of experimental samples of combined ultrasonic-laser mufflers.

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