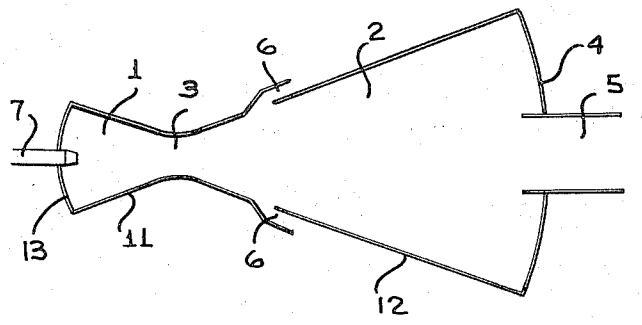
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METHOD AND APPARATUS FOR PRODUCING A HIGHLY COMPRESSED OPERATING GAS FOR HEAT ENGINES

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FIG. 1



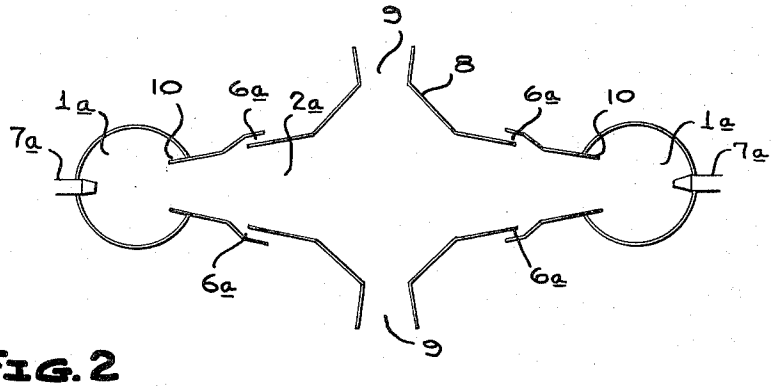


FIG. 2

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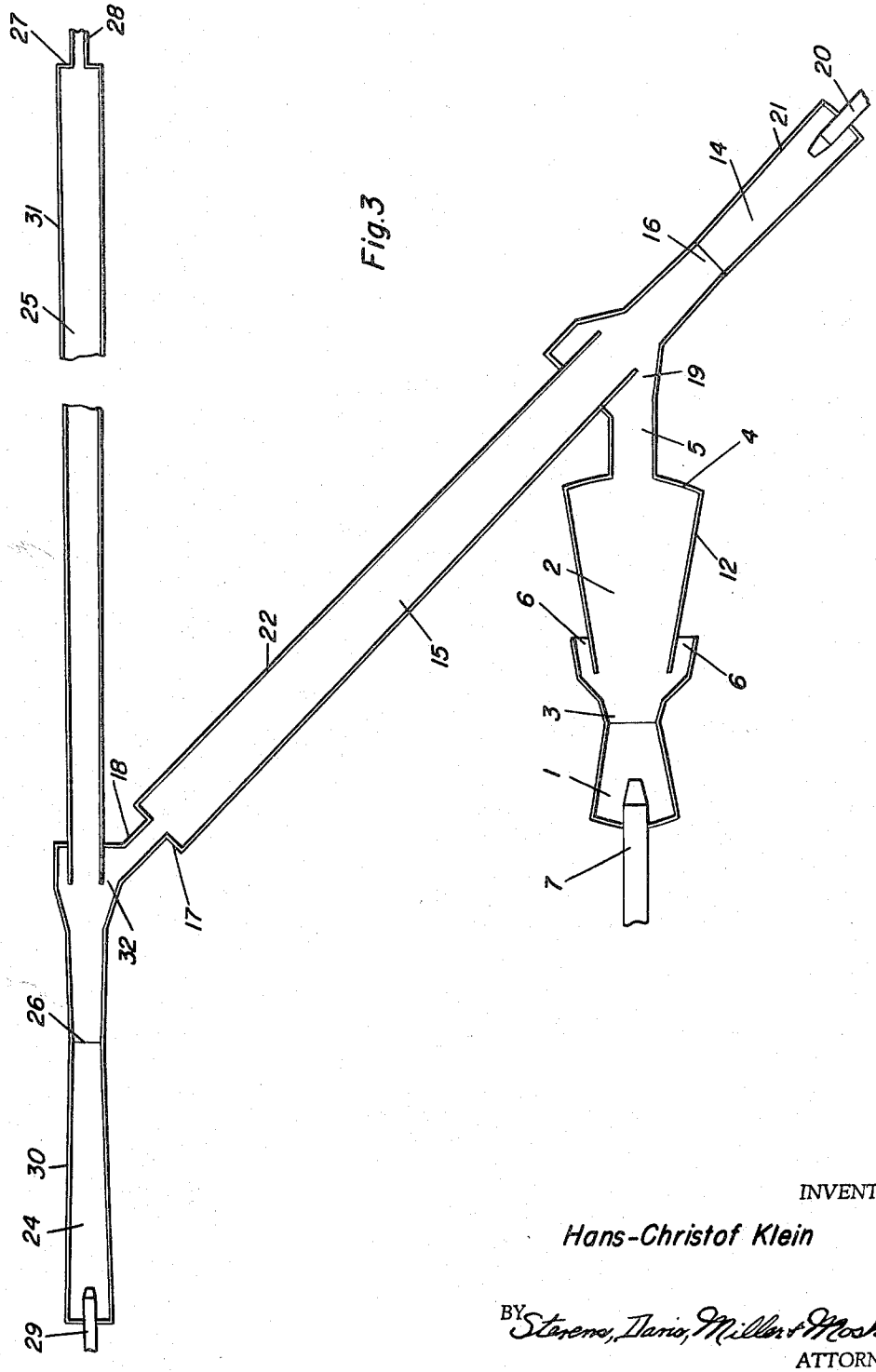
ATTORNEYS

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METHOD AND APPARATUS FOR PRODUCING A HIGHLY COMPRESSED OPERATING GAS FOR HEAT ENGINES

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Fig.3



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METHOD AND APPARATUS FOR PRODUCING A HIGHLY COMPRESSED OPERATING GAS FOR HEAT ENGINES

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15 Claims. (Cl. 60—39.02)

The present invention relates to a method and apparatus for producing a highly compressed operating gas for heat engines.

As is known, there are provided highly compressed operating gases for heat engines, gases which are first compressed and thereupon fed heat. The compression is effected in piston or turbine engines: in the case of the former, generally in the same chamber as the combustion and expansion. Heat is fed indirectly in heat exchangers or directly by combustion of fuels with or in the highly compressed gas. They can be fed in enclosed or traversed chambers at the same pressure or together with an expansion. The combustion phenomena are propagated in the case of heat transformations in internal combustion engines with the velocity of ignition which is dependent on the specific fuel-air mixture, and the geometrical and flow conditions of the combustion chamber. Detonations propagated at the much higher detonation velocity are prevented. While in the explosive-like combustions in internal combustion engines, the unburned mixture is brought to ignition temperature by heat conduction, this is effected, in case of detonation, by adiabatic compression in the pressure wave produced by the detonation. The detonation must accordingly propagate itself at least with the speed of sound which corresponds to the high temperature and the high pressure of the gases upon the detonation. A specific detonation velocity which is typical of the mixture in question is always established. In the case of pulsating combustion, the operating gases are brought into oscillations which increase the ignition velocity and the efficiency of the thermal transformation. As a result of such combustion oscillations, pressure waves having pressure amplitudes of less than 1 kilogram per square centimeter are produced in the combustion chamber which is developed as an oscillation tube. A known device, the Schmidt tube, which is of similar construction and operates with periodic pulse ignition, has maximum pressures of up to 6 kg./cm.^{2}. The combustion can be carried out continuously in traversed combustion chambers or periodically, for instance in reciprocating internal combustion engines or oscillation tubes. With continuous combustion, the flame front is maintained at the same place by special measures. In the case of periodic combustion, ignition of the fuel/air mixture is in each case necessary. Ignition by electric spark, incandescent bodies and pressure waves is known. Pressure waves can be produced by mechanical devices or can be the result of a preceding explosion. The pressure oscillations described can extend up into the feed and discharge lines of the combustion chambers and induce resonance oscillations therein, the feeding of unburned fuel-air mixture being effected at times of high pressure.

These known methods of producing an operating gas for heat engines require special compression devices for piston engines, in order to produce sufficiently high final compression pressures, and gas producers as well as turbocompressors are examples thereof. Piston engines have the disadvantage of a larger mechanical expenditure for driving mechanism and control, and the presence of oscillating inertia forces, but the advantage of a high final compression pressure. Turbocompressors with their in

part costly blading have the disadvantage of lower final compression pressures and less favorable partial load efficiencies. The simpler mechanical construction, the absence of oscillating inertia forces, and the simple possibility of cooling the operating gas between individual compression stages are advantageous. With the two devices, economically feasible over-all efficiencies are obtained. Compression devices which are based on the utilization of the above-described combustion oscillations would give very poor over-all efficiencies due to the low final compression pressures and therefore do not enter into consideration for use in heat-engines.

The object of the present invention is to provide a method of producing a highly compressed operating gas for heat engines, the parts of which are characterized by extremely simple mechanical construction, and the absence of oscillating driving and control parts. This result is obtained in accordance with the invention in the manner that the pressure wave which results from a detonation in a chamber is reflected in adjacent chambers connected with the detonation chamber on stationary walls or special projections thereof, a part of the pressure wave being masked off by suitable arrangement of these walls and protrusions and being fed to the next cycle of the operating process of a heat engine, while the rest of the pressure wave is thrown back into the detonation chamber, and compresses the fresh air which has flowed in same as a result of the detonation over-expansion and the fuel to such a high value that a further detonation is automatically produced, and another cycle of the compression process commences and continues periodically in the same manner.

As a variant of this inventive concept, the method can also be carried out in the manner that two detonation chambers are connected by an intermediate space in which the discharge of the highly compressed operating gases takes place, and the pressure wave proceeding from a detonation in a detonation chamber compresses the air including fuel present in the other detonation chamber to such a high value that another detonation is brought about from which a new pressure wave proceeds, which compresses the fresh air which has flowed into the first detonation chamber as a result of the detonation over-expansion and the fuel fed to such a high value that another detonation is automatically produced, and another cycle of the compression process commences and continues periodically in the same manner.

In the simplest case, the detonations take place in the smaller of two connected chambers of rotational symmetry, the shape and size of which are particularly adapted to each other. It is advisable for the smaller of the two interconnected chambers to have the shape of a spherical sector and for the edge of the larger space to be so adapted in axial section to the change in condition taking place upon the passage of the pressure wave through same that a quasi-stationary wave is produced in said chamber upon the periodic detonations.

In general, two or more identical chambers are preferably arranged in star shape around a detonation chamber, or a plurality of pairs of detonation chambers are arranged in star shape around a common intermediate space. The transition between detonation chamber and adjacent chamber is formed by a nozzle-like intermediate piece which passes continuously into the edges of the chambers and has a passage cross-section which at first decreases and then remains constant, and then increases again.

By the separation of the detonation chamber, there is obtained the possibility of developing it in such a stable manner it can withstand the stresses due to the detonations. The very high detonation pressures are restricted to the detonation chamber. In the adjacent chambers, they decrease with the distance from the focus of the detonation. The final compression pressure obtained is de-

termined by the shape of these chambers. As a result of the constant detonation velocity, stable resonance conditions are present, and permit an unequivocal determination of the chamber shapes. From the interaction between the said chambers, there result gas-dynamic oscillatory processes which lead to gas pressures which are variable with respect to place and time.

On the basis of these relationships, the outlet is arranged at those points of the chambers adjacent the detonation chamber where the largest average value with respect to time of the pressure occurs, and the air inlet is arranged at those places where the smallest average value with respect to time of the pressure occurs, and which lie in the shadow of the detonation wave and furthermore, in such a manner that the returning reflected pressure waves exert a suction action. Both control members can therefore be developed as aerodynamic valves, the former also as an aperture when the outlet lies in the impingement region of the detonation pressure wave. The aperture is in this connection advantageously so developed that on the inlet side there is brought about at the sharp edges a series of slight oblique compression pulses as a result of which the masked-out pressure wave is delayed.

The predominant part of the primaray detonation pressure wave is reflected on surfaces which are perpendicular to it, and thrown back into the detonation chamber, or passes directly into the opposite detonation chamber. As a result of this the pressure increase in the latter is so high that even conventional gaseous or liquid fuels are caused to detonate. In order to prevent the fuel leaving the detonation chamber before the detonation, it is introduced centrally in an atomized condition and with twist into the detonation chamber, or sprayed as liquid fuel against the walls of the detonation chamber. The amount of fuel fed is so controlled in accordance with the size of the chambers which are in communication with each other that the highly compressed operating gas leaving the compression chamber still contains oxygen for a further combustion. In this way, the feeding of heat is divided into a heat feed at mach numbers above 1.0 upon the detonation and a heat feed advantageously after delay of the pressure wave at mach numbers between 0.8 and 1.0 with decreasing temperature. In this way, the thermal stress on the combustion chamber is reduced.

In order to place the compression device in operation, a detonatable mixture is electrically ignited in a pre-heatable special detonation chamber provided only for the initial operation thereof, or else in a detonation chamber provided for continuous operation. The pressure wave proceeding from this detonation compresses the air-fuel mixture introduced into the operating detonation chamber to such a high pressure that another detonation is released which is periodically continued by reflection of pressure waves or in resonance with other operating-detonation chambers in the intended manner.

A pre-compression of the fresh air fed by conventional methods is advisable whereby the end compression pressures obtained in mixtures with low detonation pressures, are increased. It is particularly advantageous in such cases to arrange a plurality of independent detonation compression devices one behind the other. The connection is advisedly such that the final pressure obtained in the preceding stage is the starting pressure of the subsequent stage and that the highest pressure at the outlet of the preceding stage is the same as the smallest pressure at the air inlet of the following stage.

The compact construction of the detonation compression device operating in accordance with the method of the invention makes it obvious to arrange same in the rotor of an expansion turbine. In this connection, the rotor axis is advantageously one of the axes of symmetry of the compression operating chambers. In the case of detonation chambers arranged around the rotor axis, the fuel is advisedly introduced axially and centrally and in this connection thrown by the centrifugal force against the walls thereof.

The fuel feed lines are sealed by contact-free seals from the walls of the detonation chambers. They can advantageously be developed as rigid or adjustable core of the aerodynamic valves of the air inlets. The electrical energy required for ignition and preheating upon the placing into operation of the compression devices are transmitted without slip rings to the rotor. The torque exerted in this way on the rotor can be utilized to accelerate it in the intended direction of rotation until reaching the starting speed of the compression device.

Three embodiments of the invention are described in further detail below with reference to the schematic showings in the drawings. FIGURE 1 shows a side elevational schematical view of a longitudinal cross-section through the simplest construction of a detonation compression device.

FIG. 2 shows a side elevational schematical view of a cross-section through a further embodiment of this invention comprising two oppositely located detonation compression devices.

FIG. 3 is a side elevational schematical view of a cross-section through a third embodiment of this invention wherein detonation compression devices are connected in series.

Referring now in detail to the drawings, the device of FIG. 1 has a small chamber **1**, the detonation chamber, which is connected with a larger adjacent chamber **2** by a nozzle-like intermediate piece **3**. The chambers **1** and **2** have side walls **11** and **12**, respectively, in the form of truncated cones. An arched rear wall **4** closes off the space **2**. In the rear wall **4** there is an outlet opening **5**, the edge of which projects into the chamber **2**. In the side wall **12** of the chamber **2**, there are circumferentially spaced inlet openings **6** which open in the direction toward the chamber **1**.

The manner of operation of the device of FIGURE 1 is as follows: Air is present in chambers **1** and **2** before the starting of operation. A detonatable mixture is introduced into the chamber **1** through a nozzle **7** carried by an arched rear wall **13** of the chamber **1**. Before this mixture can flow through the intermediate piece **3** into the chamber **2**, it is caused to detonate by a spark plug, not shown in the drawing. The detonation pressure wave is propagated through the intermediate piece **3** into the chamber **2**. The detonation pressure wave cannot leave the chamber **2** through the inlet openings **6** since the latter lie in the shadow of the intermediate piece **3**. At the curved rear wall **4**, the greater part of the detonation pressure wave is reflected. Only a small portion leaves the chamber **2** through the outlet opening **5**. Since the movement of the gas from chamber **1** to chamber **2** continues as a result of the inertia of the gases even after the outlet pressure has been reached, a vacuum is produced in the chamber **1**. In this way, fresh air is drawn in through the inlet openings **6**. The reflected portion of the pressure wave moves into this process and supports the drawing-in of fresh air by suction upon passing the inlet openings **6**. The fresh air drawn in is compressed in the chamber **1** together with the fuel introduced through the nozzle **7**, by the pressure wave which continues to move back and is thus caused to detonate whereupon the process described is repeated.

A detonation compression device having two detonation chambers lying opposite each other with a common intermediate space is shown in FIGURE 2. In this case, two detonation chambers **1***a* are adjacent the same chamber **2***a*. The chambers **1***a* and **2***a*, which are in rotational symmetry, have a common axis. The chamber **2***a* has a second axis of symmetry at right angles to the common axis. The arrangement of the chambers **1***a* is also symmetrical with respect to said second axis of symmetry. In the side wall of the chamber **2***a*, there are inlet openings **6***a* which open in the direction toward the nearest

chamber 1*a*. Each chamber 1*a* has a nozzle 7*a*. Around the second axis of symmetry of the chamber 2*a*, there are arranged surfaces 8 which are inclined to the second axis and which terminate into outlet openings 9. Instead of a nozzle-like intermediate piece 3, a part 10 of the edge of the chamber 2*a* extends in this case into the chamber 1*a*.

The device of FIGURE 2 operates in the following manner:

The detonation pressure wave coming from a detonation chamber 1*a* reaches, to the greater part, the opposite chamber 1*a*, compresses the fuel/air mixture present therein and produces another detonation. A small portion of the first detonation pressure wave is deflected at the surfaces 8 into the outlet openings 9 and leaves the chamber 2*a*. Over-expansion, the drawing-in of fresh air, as well as renewed compression and production of detonation in the first chamber 1, takes place in the same manner as in the device of FIGURE 1 previously described. The advantage of the device shown schematically in FIGURE 2 resides in the direct action of the detonation pressure waves on the fuel-air mixture of the opposite detonation chamber. It is therefore particularly useful in connection with mixtures which are difficult to detonate.

FIG. 3 represents an embodiment of this invention, wherein the device of FIG. 1 forms a first stage coupled to a second stage formed by a subsequent, similar device, which in turn is connected to a third similar stage. The reference numerals of stage 1 are identical with corresponding numerals used in FIG. 1. The second stage has the detonation chamber 14 operation chamber 15, a throat section 16, reflecting wall 17, outlet 18, air inlet 19, fuel nozzle 20, detonation chamber wall 21, and operating chamber wall 22. Similarly, the device used for the third stage has the detonation and operating chambers 24 and 25, separated by the throat section 26; reflecting wall 27; outlet 28, fuel inlet 29, walls 30 and 31 for the detonation and operating chambers, and the air inlet 32.

As evident from the drawing, the outlet 5 of the first stage is connected to the air inlet 19 of the second stage, so that the final pressure obtained in the first stage is the starting pressure of the following second stage, and that the greatest pressure at the outlet of the first stage is identical with the smallest pressure at the air inlet of the second stage. The same is true for the connection of the second stage to the third stage by means of outlet 18 and air inlet 32.

The precompressed air entering through the air inlet 19 of the second stage furnishes, in combination with the fuel fed through nozzle 20, the detonatable air-fuel mixture for the second stage; in the same manner the even more highly compressed air at outlet 18 is mixed with fuel fed through nozzle 29, the mixture detonates in the chamber 24, the pressure wave thereby generated travels through operating chamber 25, escapes partially through outlet 28 and partly is reflected at wall 27. Since pressure and temperature are different for each stage, the dimensions of these stages vary accordingly, i.e., the diameter of a subsequent stage is reduced and the lengths of detonation and operating chambers of a subsequent stage are increased with respect to a preceding stage.

What is claimed as new:

1. An apparatus for producing highly compressed gases comprising a first detonation chamber, a second operating chamber and a throat section, said first and said second chamber each terminating into opposite ends of said throat section, the inner diameters of said throat section and said chambers being identical in respective terminating zones, means for supplying fuel to said first chamber, a reflecting wall substantially normal to the main axis of said second chamber and defining said second chamber at one end remote from said throat, a continuously open outlet arranged in said reflecting wall, and at least one continuously open aerodynamic valve for supplying air to said first chamber, said valve opening into said second chamber toward said throat section.

2. An apparatus as set forth in claim 1, a first such apparatus being arranged in series with at least one following similar apparatus in a manner that the outlet of the first apparatus is connected to the next following similar apparatus, so that the final pressure obtained in the preceding stage is the starting pressure of the following stage and that the greatest pressure of the outlet in the preceding stage is identical with the smallest pressure at the air inlet of the following stage.

3. The apparatus of claim 1 wherein said chambers are arranged in symmetry about said axis.

4. The apparatus of claim 1 wherein said first chamber is of a smaller size than said second chamber.

5. The apparatus of claim 1 wherein said fuel supplying means are in the form of a nozzle projecting into said first chamber along said axis.

6. The apparatus of claim 3 wherein said outlet is in alignment with said axis and projects into said operating chamber for limiting the discharge of compressed gases to those moving in direct alignment with and towards said compressed gas outlet.

7. A method of producing highly compressed operating gases comprising the steps of generating a detonation pressure wave by igniting a predetermined amount of a detonatable air/fuel mixture, conducting gases forming said wave away from the place of ignition thereby creating a subatmospheric pressure in the ignition zone and drawing atmospheric air thereto, feeding a fresh fuel charge to said ignition zone, separating one portion of said detonation pressure wave to furnish energy, and returning another portion of said detonation pressure wave to the ignition zone, thereby compressing the mixture constituted by the fresh fuel and air charge to ignite the same whereby a new detonation pressure wave is produced and a new cycle is initiated.

8. A method as set forth in claim 7, wherein a second gas stream is generated under like conditions as said first gas stream but opposed to said first gas stream, and said other part of the first gas stream is reflected back to the place of ignition by means of said second opposed gas stream.

9. An apparatus according to claim 1, wherein said first and said second chamber each have a conical side wall diverging from said throat section.

10. An apparatus for the production of highly compressed operating gases comprising a centrally located operating chamber, said chamber having two symmetrical portions diverging toward the center of said chamber, two substantially equally shaped detonation chambers, each of said detonation chambers being connected to one of the narrower ends of said diverging portions, said detonation chambers having a common axis with said operation chamber, said narrower ends protruding into said detonation chambers, guiding walls diverging with respect to said common axis toward said center and terminating into the wider ends of said diverging portions, outlets being located substantially in the middle between said detonation chambers and extending with their main axes substantially perpendicularly to said common axis, and the wider ends of said guiding walls terminating into said outlets, means for supplying fuel to each of said detonation chambers, permanently open aerodynamic valves, each of said diverging portions of said operation chamber being provided with at least one of said valves, said valves opening into said diverging portions toward said detonation chambers.

11. An apparatus according to claim 10 wherein said chambers are symmetrical about said axis.

12. The apparatus of claim 10 wherein said chambers are symmetrically arranged about an axis disposed normal to said axis.

13. The apparatus of claim 10 wherein each of said detonating chambers is of a spherical configuration.

14. A method according to claim 7 wherein the ratio of fuel to air in the fuel/air mixture has an excess of air produced containing oxygen for further combustion.

15. A method according to claim 7 wherein the fuel is a liquid fuel sprayed against hot walls of the detonation chamber.

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