March 6, 1951 | J. B. MALIN | 2,543,791

ENGINE GENERATION OF SYNTHESIS GAS

Filed Aug. 25, 1949 | 2 Sheets-Sheet 1

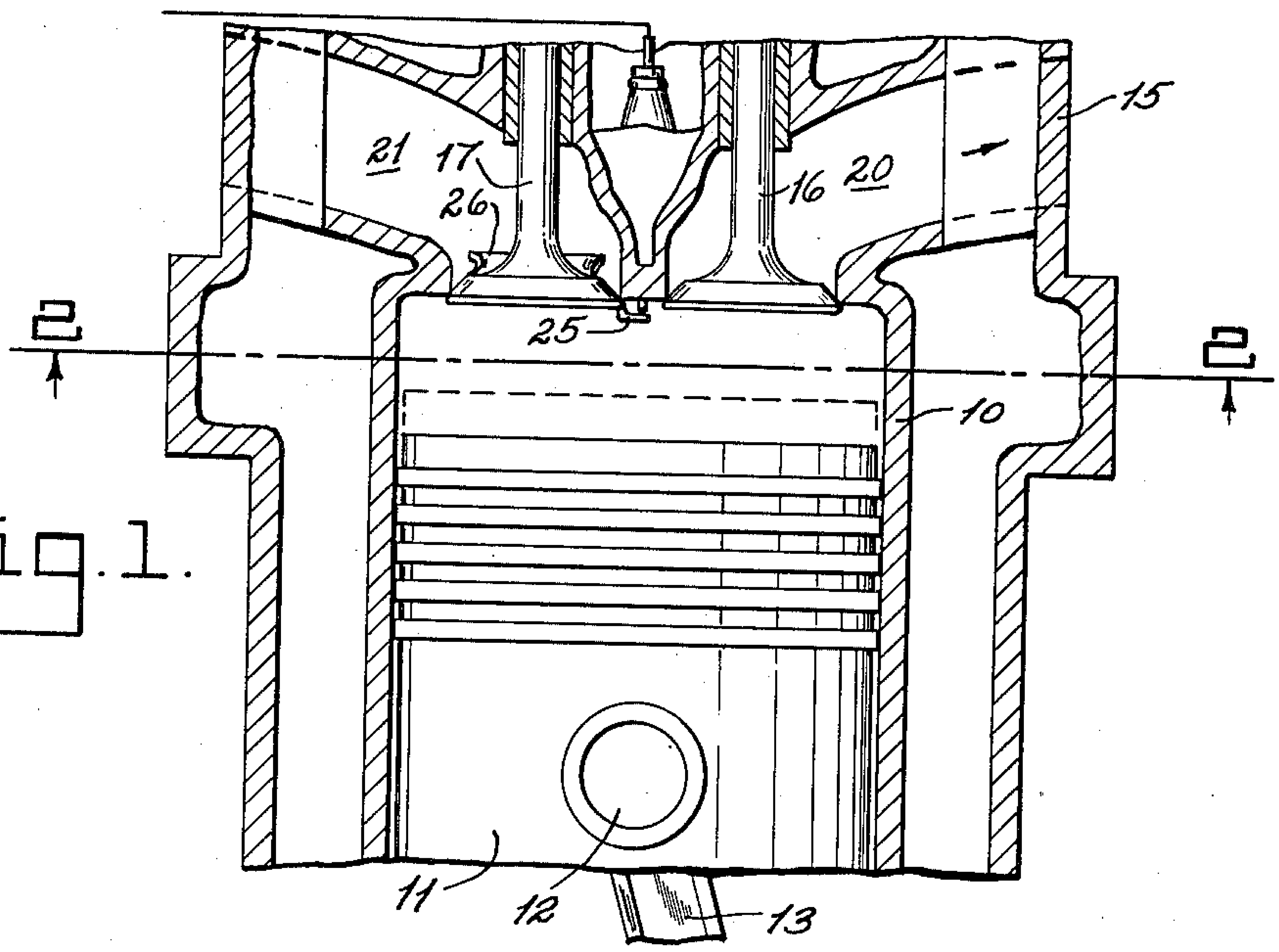

Fig. 1.

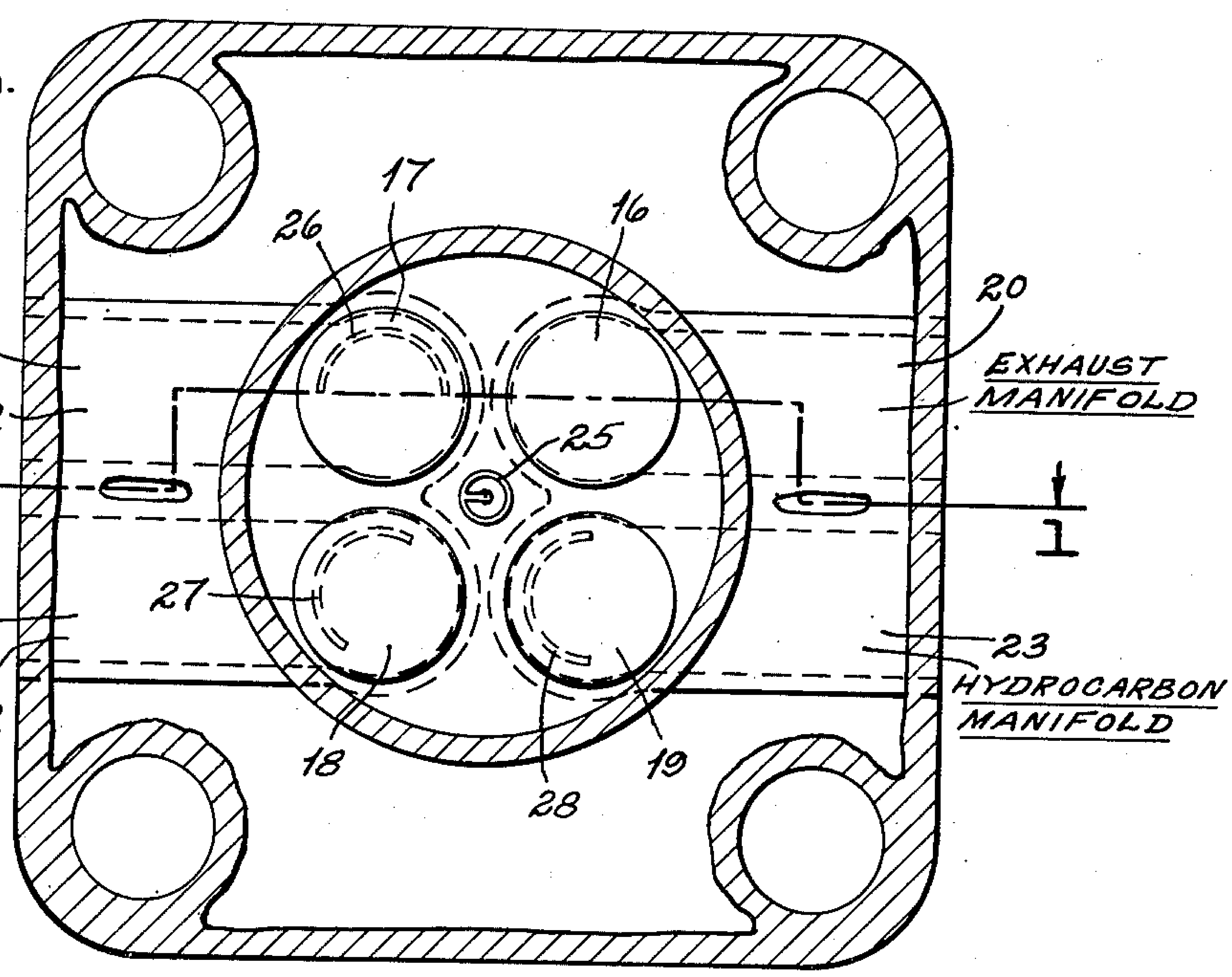

Fig. 2.

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Fig. 3.

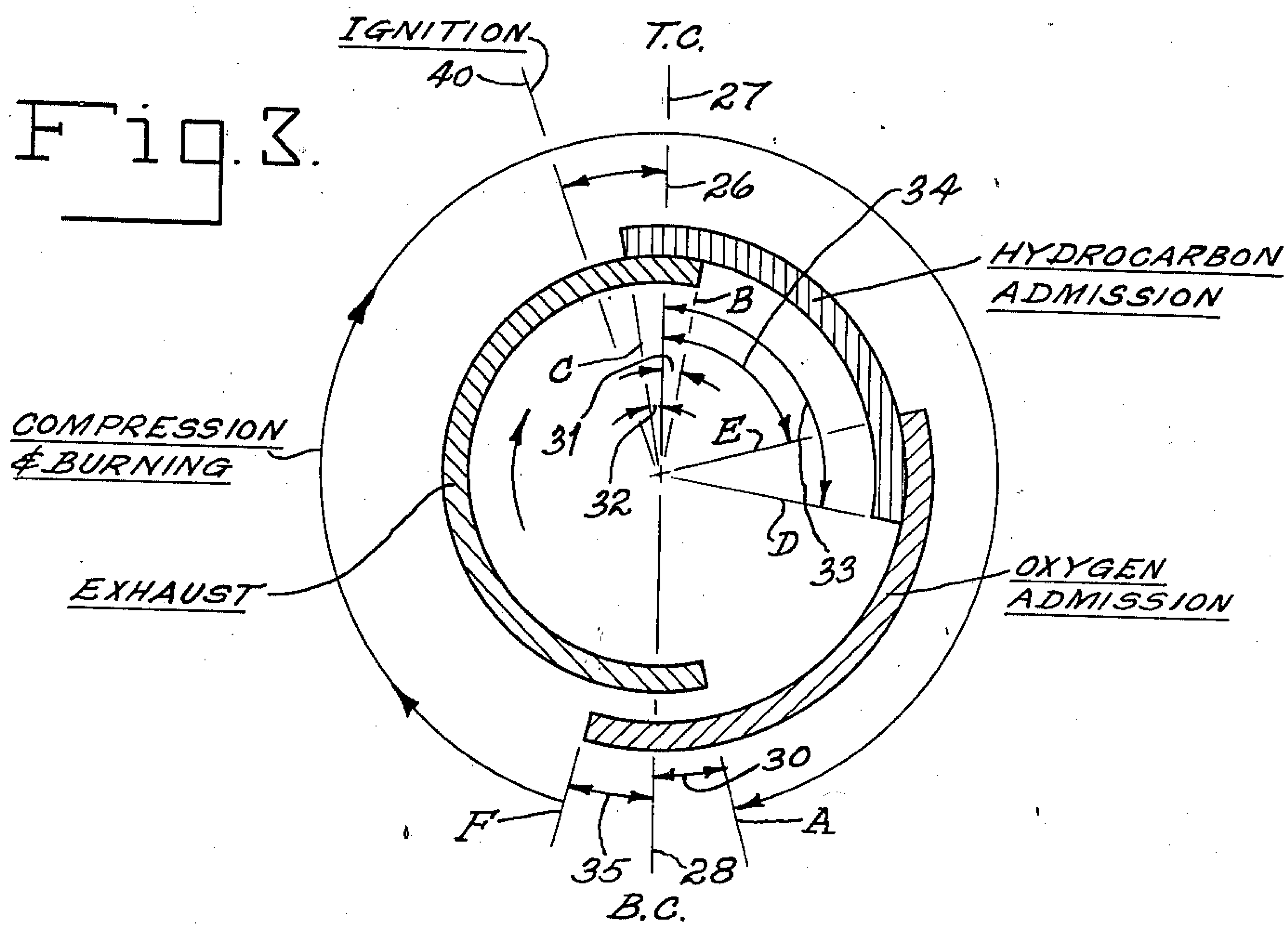
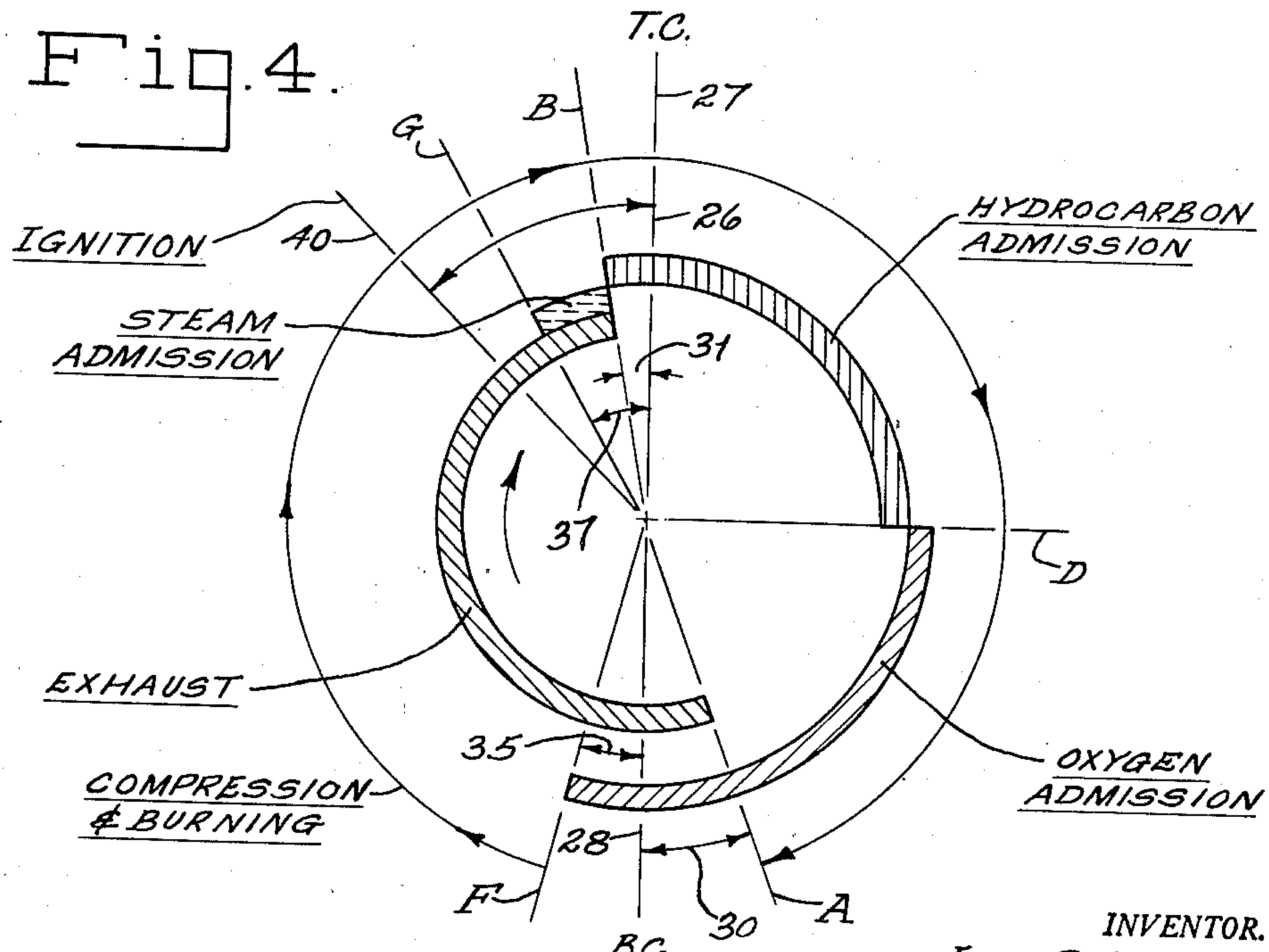


Fig. 4.



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2,543,791

UNITED STATES PATENT OFFICE

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ENGINE GENERATION OF SYNTHESIS GAS

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Application August 25, 1949, Serial No. 112,326

12 Claims. (Cl. 48—212)

The present invention relates to the generation of synthesis gas comprising hydrogen and carbon monoxide by the partial combustion of a hydrocarbon with free oxygen in the combustion space of a cyclically operating, internal combustion engine.

More specifically, the present invention concerns the process of separately introducing the reactants to the engine combustion zone during the intake stroke or portion of the engine cycle, effecting their admixture in the proper proportion for partial combustion to hydrogen and carbon monoxide, subjecting the mixture to substantial compression, and thereafter igniting the compressed mixture and causing it to burn with ensuing expansion of combustion products.

The product gas is withdrawn or exhausted, preferably during contraction of the combustion zone, and the cycle continuously repeated to insure a continuing supply of product composed essentially of hydrogen and carbon monoxide.

The present invention contemplates separately charging or introducing the reactants, in relatively pure condition, into the engine combustion zone, preferably during movement of the piston away from the cylinder head, in consecutive order such that substantial admission of the hydrocarbon takes place prior to initiating the admission of free oxygen.

The admission of the reactants may take place consecutively over separate periods of time such that admission of the hydrocarbon ceases prior to admission of the oxygen.

However, it has been found permissible and advantageous from the standpoint of reducing somewhat the pressure drop across the inlet valves, to continue hydrocarbon admission during the initial portion, at least, of the free oxygen admission. This follows from the fact that overlap of reactant admission is not materially objectionable where the initiation of oxygen admission is preceded by substantial charge of hydrocarbon to the combustion chamber. It is particularly true where the overlap occurs during the intermediate portion of the intake stroke; that is to say, where simultaneous admission of hydrocarbon and oxygen occurs in the region between about 45° after top center and about 45° before bottom center, in which the piston reaches its maximum range of velocity away from the cylinder head. Accordingly, simultaneous introduction of the reactants within approximately 45° of top and bottom center is advantageously avoided.

The invention additionally contemplates overlapping the exhaust or product withdrawal por-

tion of the cycle with the admission of hydrocarbon, or alternatively, with the injection of water vapor or steam to effect substantial purging of the product gases from the combustion space and thereby materially improve the volumetric efficiency of the engine. The use of steam is outstandingly advantageous in this connection, first, because water vapor constitutes a beneficial reactant in regulated, predetermined proportions, and second, because any excess will simply carry into the product gases, where it is readily removable by condensation. As a result, excessively acute metering of the steam injection is not mandatory, and in a reciprocating engine of the type contemplated, the proportion of water vapor thus retained in the reaction space for admixture with the hydrocarbon and oxygen charge is readily maintainable in close approximation to the desired, predetermined value.

The outstanding feature of the present invention is that is overcomes the irregular and uncertain operation of combustion engine synthesis gas generators which has been variously described as backfiring, detonation and preignition. In general, such operations are characterized by an interruption or misfire in the nature of a backfire in which the engine loses several cycles until something approaching regular operation is reached, at which time the difficulty tends to reoccur. The net result is a continuing irregularity of operation with material loss in developed mechanical energy and an inferior yield and purity of the synthesis gas product.

This problem is believed, on the basis of theory developed from actual observation, to be due to a number of factors:

First, simultaneous, separate injection or admission of the reactant gases during the intake portion of the cycle results in a contact of the pure, highly reactive, molecular oxygen with highly combustible, residual product gas, which frequently is still in the final stages of partial combustion and under the influence of the high explosion temperature. Manifestly, under these conditions, misfiring will always be imminent;

Second, near top and bottom dead center, when the pressure drop into the cylinder reaches a minimum, simultaneous injection of the reactants is affected by relatively small differences in the manifold pressures of the reactants. Actually, it appears that under ordinary operating differences in manifold pressure, the higher pressure reactant may tend to move reversely through the valve or port provided for the admission of the complementary reactant. In such case, mixture of the reactants occurs in the manifolding, in advance of the combustion zone providing an ignitable mixture, the ignition of which interrupts the feed to the cylinder and, in any event, causes undesired disproportioning of the feed mixture reaching the cylinder. Even where careful precautions are taken to maintain identical pressures in the oxygen and hydrocarbon gas manifolds, differences in pressure invariably tend to occur and contribute to the difficulty.

In accordance with the present invention, however, the residual hot combustion product gases make first contact exclusively with the fresh hydrocarbon for a period during which substantial cooling occurs. Therefore, when the stream of free oxygen is subsequently admitted, temperatures are sufficiently below the combustion range to prevent uncontrolled burning of the mixture.

Similarly, reverse flow or leakage of one reactant into the manifold provided for the other reactant is positively prevented near top dead center, and preferably also at bottom dead center, where cylinder suction is low. As indicated above, however, during the intermediate portion of the suction stroke, when the combustion space is rapidly expanding with creation of a suction and maintenance of a comparatively great pressure drop across the intake valves, the simultaneous admission of the reactants is permissible. This has the advantage of permitting a substantial angle of admission to assure adequate charging of the reactants without excessive positive pressures in the intake manifolds.

In order to more specifically disclose the present invention in greater detail, reference is had to the attached drawing, wherein Figures 1 and 2 show respectively vertical and horizontal sectional views of a combustion engine cylinder embodying the principles of the present invention, and Figures 3 and 4 are diagrammatic representations of typical operating cycles.

In the engine disclosed in Figures 1 and 2, which may be of a multicylinder type, an individual cylinder designated by the reference numeral **10** receives a vertically reciprocating piston **11**, attached through pin **12** and connecting rod **13** to a crank shaft not disclosed, which delivers the available mechanical energy. A cylinder head **15** is provided, wherein four separate valves **16**, **17**, **18** and **19** lead respectively to individual manifolds **20**, **21**, **22** and **23**.

In the embodiment disclosed, manifold **20** receives a product synthesis gas through outlet valve **16**. Manifolds **21** and **23** respectively supply a stream of pure oxygen and a stream of gaseous hydrocarbon. Manifold **22** supplies steam under pressure through valve **18**.

Ignition is effected by means of a spark plug **25** connected with electrical igniting means not shown and timed as will hereinafter be disclosed in greater detail.

Valves **17**, **18** and **19** are preferably shrouded as indicated at **26**, **27** and **28** with annularly disposed projections arranged to insure high turbulence and therefore complete mixing of the admitted reactants by effecting admission or injection in about the same rotational direction with reference to the axis of the cylinder. It will be understood that the exact arrangement or construction of the mixing shrouds does not, per se, form an essential part of the present invention, and accordingly, this construction is not shown in detail. Actually, it has been found that shrouds extending annularly through 90–180° of the valve are effective when faced in generally the same rotational direction. However, this construction may obviously be varied widely to secure adequate mixing and alternatively, provision of directional intake ports and/or turbulence producing cylinder head arrangements may be substituted for this purpose.

In accordance with one embodiment of the present invention, provision, not shown, is made for timing the operation of the valves and ignition means in accordance with the diagram set forth in Figure 3.

Therein, progressing in a clockwise direction from the point A there is symbolized the complete cycle of operation in the case of a typical four-stroke cycle reciprocating engine. The vertical line **26** symbolizes the angular position of the combustion engine cylinder axis. Therefore, point **27** represents top dead center and point **28** bottom dead center. Accordingly, the angular movement on the right hand side of the line **26** covers the approximate intake and combustion or burning portions of the cycle, whereas the opposite side of the diagram relates, in general, to the compression and outlet or exhaust regions.

Beginning with the exhaust or outlet portion of the cycle at the angular position A the exhaust valve opens, preferably though not necessarily, somewhat in advance of bottom dead center, and remains open throughout approximately the entire exhaust stroke, as represented by the shaded area entitled "Exhaust," during which the product gas produced in a previous cycle of operation flows through outlet valve **16** into the exhaust manifold **20**. In the cycle shown, exhaust valve opening takes place at 14° before bottom center, and closing occurs at 10° after top center as indicated by the angular distances **30** and **31** respectively.

At approximately top dead center, and preferably somewhat in advance thereof, at the angular position C, the hydrocarbon inlet valve opens so the feed hydrocarbon under pressure enters from manifold **23** through inlet valve **19**. Admission of the hydrocarbon gas, in the specific embodiment selected, takes place an angular distance **32** of 10° before top center and continues throughout the shaded portion of the cycle entitled "Hydrocarbon Admission" to the angular position D, located 100° after top center, as indicated by arc **33**. Closing position of valve **19** may vary widely from that shown, preferably being about or somewhere after the first half of the inlet down stroke.

Continuing the first circle of rotation, the oxygen valve **17** opens at angular position E, at least about 45° after top center, and specifically 75° ATC in the selected embodiment (see arc **34**), admitting oxygen under pressure from manifold **21** through valve **17** and continuing such admission through a substantial angular period represented by the shaded area entitled "Oxygen Admission" which terminates at angular position F, preferably about or slightly after bottom dead center, and specifically 15° after bottom dead center as indicated by arc **35**.

Following this point, with the valves closed, the engine goes through almost a complete revolution in which the mixed gases are compressed, subjected to ignition at point **40**, and thereafter burned as indicated in the line designated as "Compression and Burning" which continues to angular position A, at which the four-stroke cycle of operation is repeated.

It will be noted that hydrocarbon admission takes place over a substantial angular distance before the oxygen stream is admitted. Also, oxygen admission is initiated at a point between the top and bottom dead centers, at which time the combustion cylinder is under substantial suction to prevent backflow of reactant through the inlet port or ports. Likewise, the hydrocarbon admission is terminated considerably in advance of bottom dead center for substantially the same reason.

It is to be understood, as intimated above, that overlap of the hydrocarbon admission and the oxygen admission periods is not essential, and therefore, the angular position D may coincide with or be slightly in advance of the angular position E so that the two inlet valves are not simultaneously open.

However, as stated above, the indicated overlap is not materially disadvantageous to engine operation and tends to improve volumetric engine efficiency somewhat by facilitating charging of the cylinder without excessive manifold reactant pressures.

Attention is specifically directed to the slight angular valve overlap near top dead center, as between the outlet valve 16 and the hydrocarbon admission valve 19. As a result of this arrangement, the clearance space or pocket of the cylinder is purged or swept with a predetermined amount of hydrocarbon gas which carries before it the product gas. Since the clearance space may amount to 40% of the cylinder displacement volume, a substantial improvement in volumetric engine efficiency is thus realized.

Manifestly, the overlap between the angular positions C and B is so selected as to prevent any material contamination of the withdrawn product gas with feed hydrocarbon. In other words, the overlap is such as to effect an approximate metering of purging gas with due regard to engine design, so that the product is forced out of the cylinder substantially free from contamination by purging gas.

However, in its broadest aspect, the invention contemplates omitting this overlap between outlet and inlet valves in instances where cylinder purging is not desired, in which case the angular position B may precede position C so that the outlet valve closes at or before the time the hydrocarbon admission valve opens.

Therefore, in operation the engine continuously goes through an exhaust period followed by a substantial period of hydrocarbon admission before subsequent admission of oxygen during or after which the reactants are thoroughly mixed, compressed, ignited at the point 40 and subjected to burning to produce a gas composed essentially of hydrogen and carbon monoxide.

Figure 4 of the drawing sets forth in similar form a diagram of an alternative preferred cycle of operation wherein the cylinder is scavenged or purged at the end of the exhaust stroke by injection of steam or water vapor. To this end, the exhaust period starts with the opening of the exhaust valve at the angular position A, in this case, 20° before bottom center, continuing to about 10° before top dead center, where it terminates by closures of valve 16 at angular position B.

However, at a point of angular position G 30° before top center, that is, 20° before the exhaust valve is closed, steam injection valve 18 opens, sweeping the residual product gas through outlet valve 16.

As above indicated, the period of opening of the steam injection valve is not extremely critical since any small amounts of steam or water vapor carried off with the product gas through the outlet manifold 20 are readily removable by condensation. The valve 18 remains open during the period represented by the shaded area entitled "Steam Admission." Thereafter, hydrocarbon admission is effected through the major portion of the down-stroke, as indicated, to the line D about 90° after top center, at which time oxygen admission is initiated and continues through to the angular position F 15° after bottom center. In this embodiment, compression, ignition and burning proceed as before, while the engine cyclically delivers substantially pure synthesis gas.

It is to be understood that there is a wide permissible variation of valve and ignition timing from those disclosed in the above embodiments. For example, opening of the exhaust valve usually takes place anywhere from 40° before to 40° after bottom center, but preferably, at least 10° in advance of bottom center. While the exhaust valve normally closes at about top dead center, it may have adjusted in accordance with engine characteristics to close from 20° in advance to 20° beyond top center.

In order to effect efficient charging of reactants, the hydrocarbon gas valve advantageously opens about or before top center, as for example, as much as 20° in advance. Advantageously, it does not close until 90° after top center, preferably as indicated, somewhat before bottom center. Similarly, the oxygen valve opens at least 45° after top center, for example, from 75 to 102° after top center, and may close above or preferably somewhat after bottom center, as for example, 10° or up to 20° thereafter. The ignition point 40 depends on known principles of engine design and operation which, per se, form no part of the present invention. Therefore, spark timing is preferably adjusted for development of maximum mechanical energy with due regard to engine speed and other engine characteristics.

In accordance with one example of actual operation of an engine constructed as above, wherein separate feeds of Montebello natural gas and a rectified oxygen stream of about 99.5% purity are supplied, the following cycle of timing was observed:

Exhaust valve opens	14°	BBC
Exhaust valve closes	20°	BTC
Natural gas valve opens		TDC
Natural gas valve closes	90°	ATC
Oxygen valve opens	102°	ATC
Oxygen valve closes	12°	ABC

BBC—before bottom center. ABC—after bottom center. BTC—before top center. ATC—after top center. TDC—top dead center.

The Montebello natural gas contained over 80% methane. Inlet manifold pressures were maintained continuously at about 62 p. s. i. g. The natural gas and oxygen streams were fed in the relative ratio of about 1.21 O/C. Operation was continuous, uninterrupted and regular over long periods of time, yielding a product synthesis gas of the following approximate composition on a dry basis:

CO	35.51
CO_2	2.85
H_2	59.64
CH_4	1.18
C_2H_6	0.04
N_2	0.79

In accordance with another example, the engine timing was set as follows:

Exhaust valve opens	40°	BBC
Exhaust valve closes	20°	ATC
Natural gas valve opens	20°	BTC
Natural gas valve closes	90°	ATC
Oxygen valve opens	75°	ATC
Oxygen valve closes	15°	ABC

The composition of the product gas did not vary materially from that set forth in the previous example. However, there was a material and definite increase in the total production of synthesis gas, due, presumably, to the purging effect realized as the result of the overlap between the open period of the natural gas valve and that of the exhaust valve. As previously intimated, the effect of sweeping product gas from the clearance space of the cylinder is to increase total gas production. In the case of the engine employed in the above examples, the increase is about 6–10%.

Engine operation was likewise continuous and uninterrupted over long periods.

It is important to note that substantially identical results, as regards engine operation and volumetric efficiency may be realized by terminating the overlap between the natural gas and exhaust valves, and, in lieu thereof, injecting steam during the end of the exhaust period. For example, in an engine otherwise operating identically as above, the exhaust valve closes and the natural gas valve opens at top dead center. Valve 18 opens at about 20° BTC and closes at top dead center, admitting purging steam at about 60 p. s. i. g. to sweep the cylinder substantially free of residual gases. Aside from a somewhat increased proportion of free hydrogen in the final product gas, the advantageous features of the present invention, evident from the previous examples, are all experienced.

As above indicated, the invention especially contemplates feeding the engine with a normally gaseous hydrocarbon such as methane, and the C_2–C_4 hydrocarbons, such, for example, as are found in natural gas. Broadly, however, the feed may include gasiform or vaporform hydrocarbons, for instance, normally liquid hydrocarbons which are fed in a gasiform condition under a substantial preheat.

Actually, preheating of either or all the reactants to temperatures of 300–600° F. and higher is specifically contemplated as a means of improving thermal efficiency. It is to be understood that in spite of the preheating, the temperature of the feed hydrocarbon is usually substantially lower than that of the residual combustion mixture so that an initial cooling or quenching occurs to a range at which uncontrolled ignition is inhibited. Therefore, it is manifest that the present process enables a substantial and desirable preheating of the reactants without the misfiring or preignition tendency which otherwise would accompany the simultaneous introduction of relatively high temperature methane and oxygen streams into the combustion zone.

The feed stream of oxygen is, as previously emphasized, advantageously enriched or rectified gas composed predominantly of molecular or free oxygen. Preferably, it contains over 80% and desirably over 90–95% oxygen. As a result, the product comprises a high purity mixture of hydrogen and carbon monoxide substantially free from difficultly removable contaminating gases such as nitrogen.

The ratio of oxygen to hydrocarbon for the production of the desired synthesis gas forms, per se, no part of the present invention, but is determined in general by the stoichiometric proportions indicated for partial combustion to form maximum hydrogen and carbon monoxide. However, as is known in the production of combustion engine generator gas, from the standpoint of yield, a slight excess of oxygen is usually advantageous. The preferred range of feed proportioning to achieve these objectives is best explained in terms of the atomic O/C ratio of the total reactants supplied. Optimum yield for a typical engine ordinarily occurs with an O/C feed ratio of about 1.0:1 to about 2.5:1. In each instance, however, the most appropriate ratio for maximum yield depends upon the specific characteristics of the engine and is best determined by actual trial and error.

In spite of the fact that the detailed examples have been given in terms of a four-stroke cycle engine, it should be apparent that the disclosure in its broadest aspect is not so limited since sequential injection of the reactants may be effected prior to, during, or after compression and before ignition, in accordance with known engine practice. For example, provision may be made for separately injecting methane and oxygen at the bottom of the exhaust stroke in a two-cycle engine such that the oxygen is admitted only after substantial methane injection. Alternatively, in this type of engine, the hydrocarbon may be injected and compressed to either or wholly or partly before pressure of the oxygen.

The injection of the steam, as in a previous example, results in metered inclusion of a predetermined amount of water vapor in the reactant mixture, which is subjected to ignition. Alternatively, as also shown, steam injection may be omitted. However, supplemental addition of minor proportions of water vapor or steam are usually beneficial, and even where separate steam injection is omitted, it is desirable to include small proportions of water vapor or steam with the hydrocarbon gas or oxygen steam supplied to the engine. In general, the proportion of water vapor which may be included may range up to about 50% of the molal volume of free molecular oxygen supplied to the engine.

In the illustrated descriptions above, the preferred valve shrouding is aligned to produce a unidirectional swirl. As there intimated, however, the highly desirable intimate admixing of the reactants may be realized by arranging the valve shrouds in rotationally opposed directions so as to induce opposing swirling of the introduced reactants. By such means, for example, the hydrocarbon swirl is established first in one direction whereas the later admitted oxygen is caused to swirl in the opposite direction. Actually, it appears at the present time that opposed swirling provides somewhat more thorough mixing. Accordingly, the invention contemplates any combination of swirling actions effective to realize the desired mixing and combustion.

Obviously, many modifications and variations of the invention as hereinbefore set forth may be made without departing from the spirit and scope thereof, and therefore only such limitations should be imposed as are indicated in the appended claims.

I claim:

1. In the combustion engine generation of syn-

thesis gas by the reaction of a gasiform hydrocarbon with free oxygen wherein said reactants are separately charged into the combustion space of a cyclically operating, internal combustion engine in approximate relative proportions for the formation of a partial combustion product composed essentially of hydrogen and carbon monoxide, mixed and compressed therein, subjected to internal combustion with the generation of mechanical energy, and the product hydrogen and carbon monoxide is thereafter withdrawn as a relatively pure stream, the improvement which comprises charging such reactants to the combustion space in consecutive order such that the gasiform hydrocarbon is first admitted and the admission of the free oxygen later initiated after substantial prior admission of the hydrogen.

2. The method according to claim 1, wherein the reactants include water vapor.

3. The method according to claim 1, wherein water vapor is admitted to said combustion space during the latter portion at least of the withdrawal of the products of reaction from a prior cycle, thereby causing substantial purging of the desired gasiform reaction products from the combustion space.

4. The method according to claim 1, wherein the reactants include hydrocarbon gas.

5. In the combustion engine generation of synthesis gas by the reaction of a gasiform hydrocarbon with free oxygen wherein said reactants are charged to the combustion space of a cyclically operating, internal combustion engine in approximate relative proportions for the formation of a partial combustion product composed essentially of hydrogen and carbon monoxide, compressed therein, subjected to internal combustion with the generation of mechanical energy, and the product hydrogen and carbon monoxide thereafter withdrawn as a relatively pure stream, the improvement which comprises separately charging the reactants in the combustion space by steps including first initiating the admission of said hydrocarbon, initiating the admission of the oxygen after substantial admission of said hydrocarbon, and terminating admission of the hydrocarbon substantially prior to termination of the admission of said oxygen.

6. In the combustion engine generation of synthesis gas by the reaction of a gasiform hydrocarbon with free oxygen wherein said reactants are charged to the combustion space of a cyclically operating, internal combustion engine in approximate relative proportions for the formation of a partial combustion product composed essentially of hydrogen and carbon monoxide, compressed therein, subjected to internal combustion with the generation of mechanical energy, and the product hydrogen and carbon monoxide thereafter withdrawn as a relatively pure stream, the improvement which comprises separately charging said reactants to the combustion space in relative order such that the hydrocarbon gas is first admitted and the oxygen is later admitted and forming a substantial admixture of said introduced gas prior to combustion thereof within the combustion space.

7. In the combustion engine generation of synthesis gas by the reaction of a gasiform hydrocarbon with free oxygen in a cyclically operating, reciprocating, internal combustion engine wherein said reactants are separately charged to the combustion space of the internal combustion engine in approximate relative proportion for the formation of a partial combustion product composed essentially of hydrogen and carbon monoxide and wherein the separately introduced reactants are mixed, compressed, subjected to internal combustion therein with the generation of mechanical energy and the product hydrogen and carbon monoxide thereafter exhausted as a relatively pure stream, the improvement which comprises charging said reactants to the combustion space subsequent to exhaustion therefrom of the major portion at least of the reaction product gases resulting from prior cyclic operation, in such relative order that a substantial proportion of the hydrocarbon is admitted before admission of the oxygen and terminating admission of the hydrocarbon prior to termination of the admission of the oxygen.

8. The method according to claim 7, wherein the reactants include water vapor.

9. The method according to claim 7, wherein water vapor is admitted to said combustion space during the latter portion at least of the period in which the products of reaction are being exhausted therefrom, thereby effecting a purging of the desired gasiform reaction products from the combustion space.

10. The method according to claim 7, wherein the reactants include hydrocarbon gas.

11. In the combustion engine generation of synthesis gas by the reaction of a gasiform hydrocarbon with free oxygen wherein said reactants are separately charged into the combustion space of a cyclically operating, internal combustion engine in approximate relative proportions for the formation of a partial combustion product composed essentially of hydrogen and carbon monoxide, mixed and compressed therein, subjected to internal combustion with the generation of mechanical energy, and the product hydrogen and carbon monoxide is thereafter withdrawn as a relatively pure stream, the improvement which comprises charging such reactants to the combustion space in consecutive order such that the gasiform hydrocarbon is first admitted under pressure during the latter portion of said withdrawal of the product hydrogen and carbon monoxide such that the residual products of reaction are positively swept from the combustion space by the admitted hydrocarbon, and thereafter admitting oxygen to the combustion space.

12. The method according to claim 11, wherein the reactants include water vapor.

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No references cited.

Certificate of Correction

Patent No. 2,543,791 **March 6, 1951**

JAY B. MALIN

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows:

Column 8, line 47, for the word "steam" read *stream*; column 9, line 18, for "hydrogen" read *hydrocarbon*;

and that the said Letters Patent should be read as corrected above, so that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 8th day of May, A. D. 1951.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.