

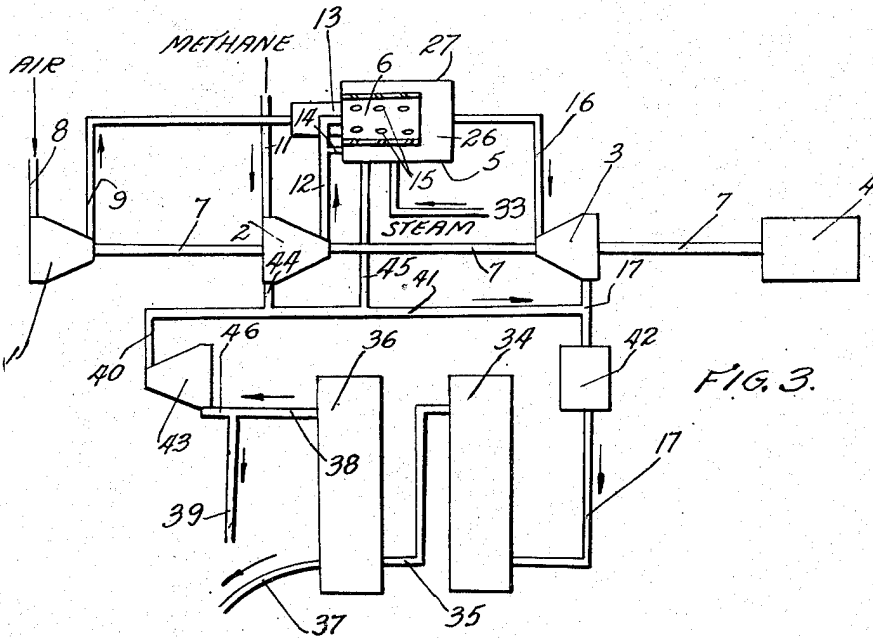
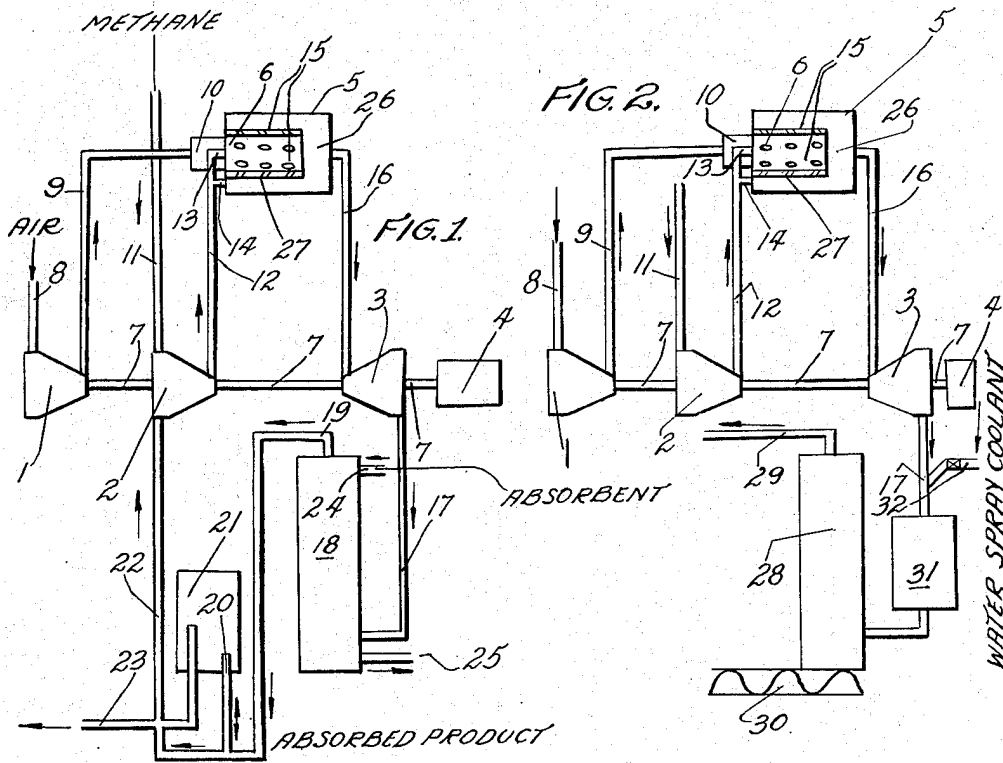
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GAS TURBINE CYCLE EMPLOYING SECONDARY FUEL AS A COOLANT

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# UNITED STATES PATENT OFFICE

2,660,032

## GAS TURBINE CYCLE EMPLOYING SECONDARY FUEL AS A COOLANT

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Application October 4, 1947, Serial No. 778,001

29 Claims. (Cl. 60—39.02)

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My invention relates to improvements in gas turbine cycles, and more particularly to gas turbine cycles in which valuable chemical by-products may be recovered from the exit gases of the turbine.

Due to the present state of the metallurgical art, the temperature of the gases entering gas turbines, as now operated, must be limited to the maximum temperature that can be safely handled with the metals as now used in the turbine construction. This temperature is now controlled by burning the heating fuel with a portion of the total air admitted to the combustion chamber and admitting sufficient secondary air to reduce the temperature of products of combustion to that which can be safely utilized by the turbine. This temperature is from 1000° F. to about 2000° F., depending upon the turbine construction.

I have discovered that the temperature of the turbine can be controlled by the addition of excess fuel or by some heat absorbing reaction, instead of by the addition of excess air, and that when the temperature is so controlled, valuable oxidation products may be recovered from the turbine exhaust. Moreover, the yield of such by-products is greater than can be obtained by other methods of direct oxidation, so far as I am aware. This may be explained by the rapidity with which the combustion products are cooled by adiabatic expansion in the turbine, particularly if a turbine of the impulse type is used.

However, my invention is applicable both to the impulse and reaction type turbines, as either type will give quicker cooling throughout the mass of the gaseous products than is obtained by other procedures. In the impulse turbine, this cooling will be from  $\frac{1}{16}$  to  $\frac{1}{2}$  milli-second, and in a reaction turbine, it will be from 1 to 4 milli-seconds. (This compares to approximately 20 to 100 milli-seconds in the usual internal combustion engine.) This quick cooling acts to prevent the oxidation of hydrocarbons, of a type resulting principally in the formation of carbon monoxide, carbon dioxide, and water vapor. Instead, the intermediate products of combustion can be retained, and, depending on the temperatures, the contact time, the fuel used, the relative quantity of fuel to air, the operating pressure, and on the catalysts selected in the combustion chamber, various products can be manufactured and can be recovered from the exhaust gases. Some of the products that can be thus obtained are alcohols, esters, aldehydes, ketones, acid anhydrides, organic acids, carbon black, etc. Also, if relatively heavy hydrocarbons, such as straw oil or gas oil, are used as fuel, the cycle can be operated to crack

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the excess fuel used for temperature control, and high grade motor fuel can be recovered from the turbine exhaust. The cycle is also applicable to the dehydrogenation of paraffines.

The oxidizing agent may be air, oxygen-enriched air, or substantially pure oxygen. Which of these is used will depend upon the particular circumstances, the material to be oxidized, and the reaction products desired. Also, as chlorination is chemically equivalent to an oxidation reaction, chlorine (or other halogens) may be used as the oxidizing material with the production and recovery of halogenated products.

Also under properly controlled conditions, the oxidation can be directed to result largely in dehydrogenation of the hydrocarbon fuel. In this manner, saturated hydrocarbons of the paraffine series may be converted into olefines and di-olefines. This reaction is favored by the use of boron fluoride as a gaseous catalyst. It will be noted that at the temperatures utilized in my turbine cycle, the boron fluoride will not be unduly corrosive, but care must be taken to prevent corrosion after the gases have left the turbine and the temperature is reduced.

Other gaseous catalysts may be used with my cycle, depending upon the desired end product. Thus, nitric oxide (NO), nitrogen tri-oxide (N<sub>2</sub>O<sub>3</sub>) and nitrogen tetra-oxide (N<sub>2</sub>O<sub>4</sub>) may be used to catalyze oxidation reactions. It will be noted that some of these materials will be formed in the high temperature zone of combustion, through the interaction of the nitrogen and the oxygen of the air, when air is used as the oxidizing medium. Some of these products will persist throughout the turbine, and appreciable quantities will remain where the time from the primary combustion zone to the turbine entrance is short, thus preventing reversion of the oxides to oxygen and nitrogen before the quick cooling in the turbine acts to deter the reversion.

Other gaseous catalysts are hydrofluoric acid, and formaldehyde. The latter acts to speed the oxidation of aliphatic hydrocarbons into intermediate oxidation products.

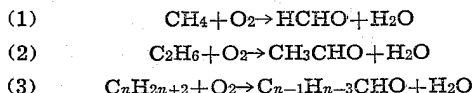
The objects of my invention are thus, in a gas turbine cycle to—

1. Obtain higher overall thermal efficiency than is obtained in a usual "air" cycle.
2. Produce useful products of reaction other than those of complete combustion together with the generation of power.
3. Produce synthetic chemicals as a by-product of power generation.

Other objects will be apparent from this specification.

Paraffine hydrocarbons, either straight or branched-chain, olefines, benzene, toluene, xylene, and other hydrocarbons may be used as the material to be oxidized, depending upon the desired products.

The reaction of paraffin hydrocarbons to produce aldehydes is typified by the following reactions

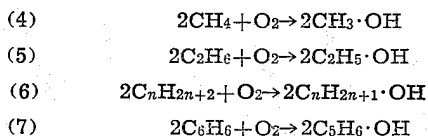


These reactions will take place at temperatures above 700° F. and at moderate pressures. The presence of oxides of chromium aids in these reactions. As these reactions usually will not go to completion, it will usually be desirable to recirculate the unreacted portion of the exhaust gases, after removal of the desired reaction products. If air is used as the oxidizing agent, the hydrocarbons issuing from the exhaust will be contaminated with the nitrogen from the air, so that if the material to be oxidized is gaseous, some portion of the exhaust must be vented from the system in order to prevent an excess build-up of nitrogen in the system. The gases so vented will be suitable for use in firing boilers and for other purposes. The use of oxygen-enriched air will reduce the amount of venting required, and the use of substantially pure oxygen will materially reduce the need for venting.

If the hydrocarbon oxidized contains three or more carbon atoms and if the operating temperatures are held within such limits so that the amount of cracking to gaseous products is limited with relation to the amount of material oxidized, the fuel in the exhaust may be readily separated from the nitrogen by known methods when air or oxygen-enriched air is used as the oxidizing medium. The nitrogen could be recovered and further purified for other chemical uses, such as the manufacture of ammonia, if desired. However, the use of substantially pure oxygen has certain advantages in the turbine cycle as will be explained.

When air or oxygen-enriched air is used as the oxidizing agent, these materials must be compressed to the inlet pressure of the turbine. The work required for this compression utilizes an appreciable portion of the work generated in the turbine. If substantially pure oxygen, in the liquid state, is used for oxidation, the required pressures can be generated without gaseous compression. This is particularly advantageous where the higher hydrocarbons are oxidized, as these can be brought up to the required pressure by pumping them in a liquid phase, or in some cases, by application of heat to the liquid, thus entirely eliminating the necessity for gaseous compression. Under this condition the gross energy delivered from the turbine is substantially the net energy of the cycle.

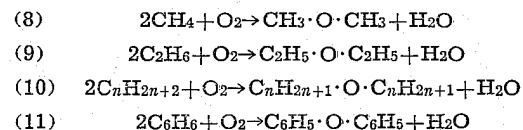
The above factors will enter into the cycle when producing other materials than aldehydes, as described above, as for instance, in the production of alcohol, according to the following equations:



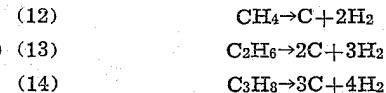
The reactions take place at temperatures in ex-

cess of 750° F., and are favored by the use of high pressures. This would require the use of compression in stages where gaseous fuel is used in combination with air. However, if the fuel has three or more carbon atoms, and oxygen, initially liquid, is used to support the combustion, any pressure required as favorable to the production of the alcohols, can readily be obtained without the necessity of gaseous compression, which, as has been explained, results in greater net energy output from the turbine cycle. The alcohol reactions are favored, not only by high pressures, but also by the presence of catalysts, including aluminum oxides, chromates and certain other oxides, and some metals.

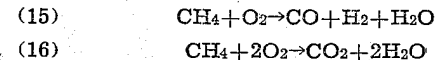
The production of ethers, like the production of alcohols, is favored by high pressures. The following reactions typify the cycle when ethers are the desired by-product



The production of carbon black in the turbine cycle is favored by low pressures, so that when using gaseous fuels and air to support combustion, a single stage compressor only, is required, as with the production of aldehydes. This reaction is favored by the presence of carbon and iron. Thus, when the cycle is in operation, the product acts as its own catalyst. If the reaction temperature is carried at plus 1800° F., the carbon black reaction may be brought practically to completion in accordance with the following reactions



Similar reactions occur if hydrocarbons of higher molecular weight are used in the cycle. The use of methane leads to the production of a "reinforcing" type of carbon black. The use of the higher hydrocarbons leads to the production of a "soft" type of carbon black. In order to provide heat for the above reactions, an oxidation as illustrated by the following equations, takes place substantially simultaneously with the reactions leading to the formation of carbon.



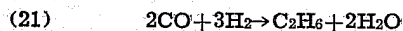
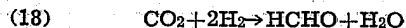
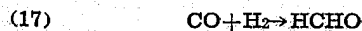
Similar reactions occur when higher hydrocarbons are used as fuel.

At lower temperatures than are desirable for carbon formation, heavy petroleum can be introduced into the combustion chamber of my turbine cycle, preferably as a fine spray, and lighter liquid hydrocarbons, such as gasoline, will be formed. An inlet temperature of 750° F. to 1100° F. at the turbine inlet is conducive to this reaction. Like the reaction for carbon formation, a portion of the fuel is combined with oxygen to supply the heat energy. Also, a single stage compressor may be used for compression, if air is used as the oxidizing medium. In order to hold the lower temperatures desired, a larger weight ratio of fuel to air is required for usual hydrocarbon cracking than is required for carbon black formation. Unlike the cracking to carbon black, this reaction does not go to completion, so that recovery and recycling of the

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unreacted fuel will be required when my cycle is operated with heavy hydrocarbon fuel for the recovery of motor fuel. Various catalysts known in the art may be used, depending upon the characteristics that are desired in the motor fuel recovered.

It will be understood that simultaneously with reactions similar to Equations 1 to 11 inclusive, reactions similar to 15 and 16 may take place in or near the zone of primary oxidation prior to the addition of the excess combustible. This will result in secondary reactions in the secondary zone which may be exemplified as follows



These and other similar reactions can thus be obtained, and synthesis of hydrocarbons may be promoted. The principal reaction may be predetermined by proper selection of the temperature, time in the primary and secondary reaction zones, relative amounts of oxygen and oxidizable substances, and presence of some particular catalyst.

It will further be understood that the above examples are illustrative only, as under proper conditions, the reactions can be carried out to result in other oxidation products, depending on the factors cited in the preceding paragraphs and upon the character of the oxidizable substance utilized. Also, some lesser amounts of other oxidation products in addition to the main product desired, will be obtained simultaneously with the main reactions, except in such instances as the substances may be reacted to substantial completion in a single cycle, as for instance, the reaction to carbon black. This will not appreciably affect the value of my process, as these products will have commercial value, and in most instances, they may be readily separated from the main desired product.

In certain instances, it may be desirable to supply more than one fuel (hydrocarbon) to the system. Such a condition would occur under the following circumstances:

(a) When heavy hydrocarbons are introduced for cracking to motor fuels as previously described. Here, the furnace fuel is itself a mixture of various chemical substances which may include recycled products.

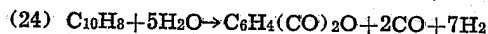
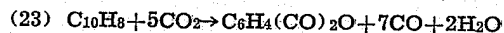
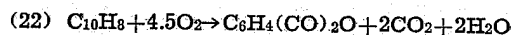
(b) When it is desired to obtain a specific chemical through the oxidation and interaction of two substantially pure hydrocarbons, as for example in the formation of a mixed ether.

(c) When a specific product requires the use of a relatively expensive hydrocarbon for its formation and it is desired to limit the use of this relatively expensive material in so far as is possible.

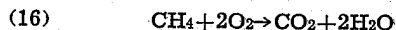
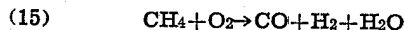
An example of the latter condition, methane may be reacted with oxygen in accordance with Equations 15 and 16 and vapors of naphthalene may be separately introduced into the furnace as a coolant for the reaction products of the methane combustion. If the proper conditions are maintained in the furnace, the naphthalene may be converted into phthalic anhydride by reactions

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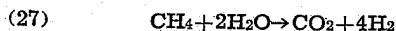
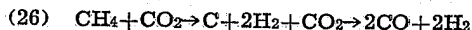
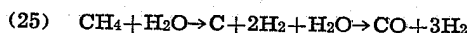
which include those shown by the following equations



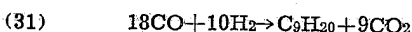
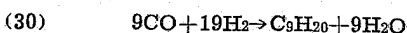
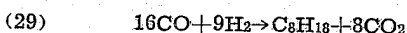
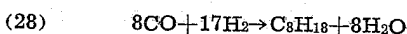
In a further modification of my cycle, the fuel may be reacted with oxygen in the primary zone of the furnace and the temperature of the products of combustion may be lowered by the introduction of steam or a water spray in the secondary zone in the furnace along with additional fuel. In the primary zone, the reactions are typified by



In the secondary zone the reactions may be typified by the following equations



Equations 25, 26, and 27 are favored by temperatures in excess of 1500° F. and Equations 25 and 27 are further favored by the presence of excess steam. These three equations represent endothermic reactions which assist in cooling the products of Equations 15 and 16 from the high temperatures attained from those latter reactions to the temperature required at the turbine inlet. In the passage through the turbine, these gases are so quickly cooled by the adiabatic expansion, as to prevent exothermic reversing of the carbon monoxide and hydrogen to carbon and water or to carbon and carbon dioxide. However, the temperature of the gases leaving the turbine is sufficiently high to promote the Fischer-Tropsch synthesis in the presence of a suitable catalyst. This latter reaction may be typified by the following equations



Attention is directed to the fact that in most instances the thermal efficiency of my turbine cycle is appreciably greater than can be obtained by control of temperature thru excess of air or oxygen, if due allowance is made for the heat units in the product recovered from the turbine exhaust. In other words, more kilowatt-hours can be recovered from the turbine shaft for any given expenditure of heat units in the cycle, if allowance is made for the heat of combustion in the recovered products. This is particularly true if liquid fuel and liquid oxygen are delivered to the system and fed to the combustion chamber as a vapor or spray, as in this case the gross power from the turbine is substantially the net power of the cycle. This is due to the fact that the compressor is eliminated.

The hot products leaving the turbine exhaust may be brought into heat exchange with the relatively cool materials entering the combustion chamber, and a gain in thermal efficiency of the cycle will result. Heating of the material to the combustion chamber by heat exchange with the hot exhaust gases is particularly desirable where liquid materials are used as fuel and are delivered

to the combustion chamber either as a spray or a vapor.

Where the gases leave the turbine at a temperature of from 950° F. to 1350° F., hydrocarbons may be introduced into the stream. The introduction of hydrocarbons having a molecular weight above 44, into the stream at these temperatures, will lead to their cracking. Relatively light hydrocarbons, such as butane, may be introduced as a vapor and heavy hydrocarbons such as straw oil may be introduced as a spray.

My invention may best be described by reference to the following drawing, in which

Fig. 1 illustrates diagrammatically, my invention as applied to the production of formaldehyde.

Fig. 2 similarly illustrates my invention as applied to the formation of carbon black.

Fig. 3 diagrammatically illustrates my invention as applied to the production of motor fuel thru the synthesis from carbon-monoxide and hydrogen.

It will be recognized that these examples are merely illustrative of my invention, as slightly different diagrams may be desirable for the production of other products than formaldehyde, carbon black, or motor fuel. Also for the production of formaldehyde or carbon black, modifications may be made in the details of the cycles illustrated, without departing from the spirit of my invention. This will be readily understood by one skilled in the art.

Referring to Figure 1: the air compressor 1, and the methane compressor 2 are mechanically connected to each other and to gas turbine 3 and the electric generator (or other load) 4, by means of the shaft 7. The gas turbine 3 is preferably an impulse type turbine. Air from the atmosphere enters the compressor 1 by means of pipe 8, and the compressed air from the compressor 1 is delivered by pipe 9 to the primary reaction chamber 6 of the furnace 5 through the enlarged portion 10 of the pipe 9. Methane is delivered to the compressor 2 by means of the pipe 11, simultaneously with return gas by means of the pipe 22, as will be explained later. The compressed gas is delivered to the primary reaction chamber 6 of the furnace 5 by means of pipes 12 and 13, and to the secondary reaction chamber 26 of the furnace 5 by means of pipes 12 and 14. The enlarged portion 10 of pipe 9 permits the pipe 13 to be placed within the stream of incoming air so that the combustible is surrounded by air as the two are delivered to the primary reaction chamber 6. Gas from the secondary chamber 26 may also enter the primary chamber 6 by the ports 15 in the partition 27, separating the secondary chamber from the primary chamber. The partition 27 and the furnace 5 are preferably made of chromium upon which a layer of oxide has been built up to assist in the conversion to formaldehyde. The ratio of gas to air in the primary chamber is adjusted to maintain continuous ignition of the methane. The quantity of methane added in the secondary chamber is adjusted to reduce the temperature of the combustion products entering the turbine to the desired amount and to promote the desired reaction. The heated gas, after reaction is led to the turbine 3 by means of the pipe 16. In the turbine, the gas is expanded while doing work, which effectively reduces the temperature to an amount which substantially prevents further chemical reactions in the gas stream. The expanded gas is led from the turbine 3 by the pipe 17, to the recovery system

18, which in this instance is shown as a counter-current scrubber, to which cold water or other absorbent is introduced thru the pipe 24, and the solution of formaldehyde is removed by the pipe 25 to any suitable form of concentration system (not shown). The scrubbed gas, substantially free from formaldehyde, is withdrawn from the scrubber 18 by the pipes 19 and 20 to the gas holder 21, from which it may be withdrawn by pipes 20 and 22, and returned to the compressor 2 or by pipe 23, by which it is withdrawn from the system. To prevent an excessive build-up of nitrogen, which is introduced into the system in air thru pipe 8, some withdrawal must be made of the reacted gases thru pipe 23. If there are other uses for heating gas, all of the gas rejected by the scrubber 18 may be withdrawn from the system by the pipe 23. In this instance, no methane would be delivered to the compressor 2 by the pipe 22, and the entire supply of methane would be delivered to the system by the pipe 11. The following example is based upon the latter operation as computed for possible yields:

Temperature of air to compressor	60° F.=520° R.
Temperature of methane to compressor	60° F.=520° R.
Pressure at compressor inlet	15 p. s. i.—abs.
Pressure at compressor outlet	90 p. s. i.—abs.
Temperature of gas entering turbine	1500° F.=1960° R.
Temperature of gas leaving nozzle	825° F.=1285° R.
Temperature of gas leaving turbine	1025° F.=1485° R.
Pounds methane consumed as fuel per pound methane to the system.	.107.
Pounds of air per pound methane to system.	1.
Pounds formaldehyde per pound total methane to system.	.20.
Pounds formaldehyde per day per 1000 kw. output of turbine.	95,000.
Total methane per day per 1000 kw. output (cu. ft.).	11,540 M.
Consumed methane per day (as fuel) per 1000 kw. (cu. ft.) output.	1,230 M.
Heating value of gas from scrubber (cu. ft.).	500 B. t. u.
Efficiency of turbine cycle, based on heat of combustion of entering methane, less heat of combustion of exhaust products.	18.8%.
Efficiency of air cycle turbine having same temperature and pressure ratios.	16.2%.

The above data are based upon the use of a well-known single stage impulse turbine in which the entire adiabatic expansion takes place in a single stage nozzle placed within the turbine immediately following the turbine entrance.

If methyl alcohol were the desired product, a cycle similar to that shown in Fig. 1 would be applicable. However, the production of alcohol is favored by higher pressures. One method of attaining such higher pressure is that compressors 1 and 2 be two-stage compressors and that the turbine be a single-stage unit. Air would enter the first stage of the air compressor, methane would enter the first stage of the methane compressor, but the return gas thru pipe 22 would enter the second stage of the methane compressor. The scrubber 18 and holder 21 are thus operated under pressure and the pressure of the furnace 5 and turbine 3 is greater than when formaldehyde is the desired product. The ratio of methane to air is also adjusted as required.

Referring to Figure 2, the air and gas compressors 1 and 2, turbine 3, electric generator 4, furnace 5, with primary reaction chamber 6, and secondary reaction chamber 26 and shaft 7 are the same as has been explained in connection with Fig. 1. Also, pipes 8, 9, 11, 12, 13, 14, and 16 are used in the same manner as described in Figure 1. Pipe 17 leads from the turbine exhaust to the carbon black collecting system, which is indicated as cooler 31, and as electrostatic precipitator 28. Pipe 29 is used for removing the gas

exhausted from the precipitator. In this instance all the gas is rejected from the cycle after the removal of the carbon black by the precipitator. Carbon is removed from the system by the conveyor 33. In the production of carbon black, the temperature of the furnace is preferably held at approximately 1800° F. or in excess thereof. No catalyst is required for this operation as the carbon produced is in itself a catalyst for the reaction to carbon. The following figures are pertinent to this operation, based on complete methane conversion.

Pounds of air per pound of methane----- 2.65.  
 Pounds of carbon black produced per pound of methane to system. 23.  
 Cu. ft. of methane per day per 1000 kw. out- 330 M. put.  
 Pounds carbon black per day per 1000 kw. out- 75,000. put.  
 Exhaust gas per day per 1000 kw. output 11,700 M. (cu. ft.).  
 Heating value of gas from precipitator 189. (B. t. u./cu. ft.).  
 Efficiency of turbine cycle, based on heat of combustion of entering methane less heat of combustion of exhaust products. 62.5%.

Referring to Figure 3, the air and gas compressors 1 and 2, turbine 3, electric generator 4, furnace 5, with primary reaction chamber 6, and secondary reaction chamber 26, and shaft 7, are the same as has been explained in connection with Figure 1. However, the steam pipe 33 is provided in Figure 3 to furnish a source of steam to the secondary reaction chamber 26. Pipes 8, 9, 11, 12, 13, 14 and 16 are used in Figure 3, in the same manner as was described in connection with Figure 1.

Pipe 17 leads from the turbine exhaust to the catalytic reaction chamber 34, which can be any type of conversion chamber suitable for promoting hydrocarbon synthesis reactions from CO and H<sub>2</sub>. The gas stream from the conversion chamber 34 passes by conduit 35 to the cooling and separating system 36, in which the readily condensable reaction products are removed from the stream through conduit 37. The uncondensed gases pass from the cooling and separating system by the conduit 38. These gases may be discharged from the system by conduit 39, or they may be re-circulated back to the system. Thus, they may be led into a compressor 43 by pipe 46, where they are compressed, and led by pipes 40 and 41 back into pipe 17 where they are used to cool the gases from the turbine 3, and are re-circulated back thru reaction chamber 34. The gases from the compressor 43 may alternatively be passed by pipes 40 and 44 back into the system thru the inlet of compressor 2. Both of these methods of returning the gases back to the system are applicable when the compressor 43 is suitable for delivering low pressure gas.

If compressor 43 is suitable for delivering gas at high pressure, the gases from the separating system 36 may be passed back to the combustion chamber by pipes 38 and 46, compressor 43 and pipes 40 and 45. It will be understood that suitable valving is necessary for control of the distribution of the gases where more than one method of returning the gases is alternatively provided in the piping system. As an alternative method of controlling the temperature of the gases entering reaction chamber 34, a cooler 42 may be provided in pipe 17 for conducting gas from the turbine 3 to the reaction chamber 34.

Now having described my process in a manner that may be readily understood by one skilled in the art, I claim:

1. A process for making valuable products of incomplete oxidation of a fluid-fuel in conjunction with the operation of a gas turbine, which

includes the steps comprising, passing under superatmospheric pressure a combustible fluid to be oxidized as a stream into a primary reaction zone, confined in a reaction chamber, also under superatmospheric pressure passing an oxidant of the class consisting of oxygen, halogens and air into said zone as a stream, promoting exothermic reactions of said combustible fluid with said oxidant in said zone at a high temperature, above 2000° F., passing the hot reaction products thus made directly and continuously from said zone to a secondary reaction zone of said chamber immediately mixing it therein with an additional excess amount of said combustible fluid thereby promoting chemical endothermic reaction in the mixture while lowering the temperature of the reacting fluid mixture below 2000° but above 750° F., passing the thus cooled reacting mixture immediately into a gas turbine and therein materially reducing the temperature of the latter mixture while simultaneously reducing its pressure in a period of time less than 20 milli-seconds, thereby forming at least one valuable product of incomplete oxidation of said combustible fluid; said excess amount of combustible fluid being at least in excess of the amount adapted to be completely oxidized by said oxidant.

2. The process described in claim 1 in which some of the products of reaction are removed from the stream discharged from said turbine and some of the residue therefrom is recycled back to said secondary reaction zone.

3. The process described in claim 1 in which at least one of the products of reaction is returned to the said combustion chamber, one portion being fed to the primary combustion zone and another portion being fed to the secondary reaction zone thereof.

4. The process described in claim 1 in which steam is also introduced continuously into the said secondary reaction zone as both a reactant and coolant, the amount of steam being so limited that the temperature of the reacting gaseous mixture as discharged from the latter zone into the turbine is higher than 750° F. but lower than about 2000° F.

5. The process described in claim 1 in which the oxidant contains free oxygen in excess of 20 per cent.

6. The process described in claim 1 in which the said combustible fluid comprises hydrocarbon substance.

7. The process described in claim 1 in which the temperature of the reacting gas stream as discharged from the combustion chamber to the turbine is maintained below 2000° F. but sufficiently high so that the turbine exhaust gas has a temperature of the order of 950° to 1350° F.

8. In a gas turbine cycle adapted for the generation of power in a suitably connected gas turbine unit, in which gasiform products of incomplete oxidation are produced, the steps comprising, continuously introducing under superatmospheric pressure into the primary reaction zone of the combustion chamber of said unit both a stream initially containing vapor phase fuel and a stream of gasiform fluid containing free oxygen, initiating and promoting the complete combustion of said stream of fuel in said oxygen containing stream in said zone, the amount of said oxygen being sufficient for the complete combustion of said fuel, thereby raising the temperature of the combined stream considerably above 2000° F., continuously passing the hot products of the combustion while under pressure into a secondary reaction zone of said chamber simultaneously in-

roducing a predetermined additional amount of said fuel in a stream under superatmospheric pressure and a temperature considerably below that of the stream from the primary reaction zone into the said secondary reaction zone and mixing it therein with the said hot products of the combustion thereby causing the latter fuel to react endothermically with the said products of combustion lowering the temperature of the latter, passing the gaseous mixture while reactions are still occurring therein, into the turbine of said unit and substantially adiabatically expanding and cooling it therein, thereby producing incompletely oxidized products of said fuel and retaining them in the gas discharged from said turbine; said predetermined additional amount of fuel being that required to maintain the temperature of said mixture as discharged into said turbine at a level below 2000° F. and above 750° F.

9. The cycle described in claim 8 in which said fuel is a vapor phase hydrocarbon material.

10. In a gas turbine cycle of a suitably connected gas turbine unit, the steps comprising passing a stream initially containing a combustible material into the primary reaction zone of the combustion chamber of said unit and substantially completely burning said material therein, thus raising the temperature of said stream above 2000° F., introducing additional combustible material as a second separate stream into a secondary reaction zone of said chamber, passing the thus heated first mentioned stream into said secondary reaction zone and mixing it with the second stream therein, thereby promoting endothermic reaction of said combustible material in the latter stream and lowering the temperature of the reacting mixture somewhat below 2000° F., then substantially immediately passing the hot reacting mixture into a gas turbine and lowering its temperature by substantially immediate adiabatic expansion, whereby the hot reacting mixture is effectively cooled in a time of substantially less than 20 milli-seconds.

11. The process described in claim 10 in which some of the products of reaction are removed from the stream discharged from said turbine and some of the residue therefrom is recycled back to said secondary reaction zone.

12. The process described in claim 10 in which at least one of the products of reaction is returned to the combustion chamber, one portion being fed to the secondary reaction zone thereof.

13. The process described in claim 10 in which steam is also introduced continuously into the said secondary reaction zone as both a reactant and coolant, the amount of steam being so limited that the temperature of the reacting gaseous mixture as discharged from the latter zone into the turbine is higher than 750° F. but lower than about 2000° F.

14. The process described in claim 10 in which the oxidant contains free oxygen in excess of 20 per cent.

15. The process described in claim 10 in which the said combustible fluid comprises hydrocarbon substance.

16. The process described in claim 10 in which the temperature of the reacting gas stream as discharged from the combustion chamber to the turbine is maintained below 2000° F. but sufficiently high so that the turbine exhaust gas has a temperature of the order of 950° F. to 1350° F.

17. In a gas turbine cycle of a suitably connected gas turbine unit, the steps comprising, passing a gaseous stream initially containing a

combustible material into the primary reaction zone of the combustion chamber of said unit under superatmospheric pressure, promoting substantially complete combustion of said material therein to raise the temperature of said gaseous stream above 2000° F., introducing a second stream of combustible material also under superatmospheric pressure at a lower temperature than 2000° F. into a secondary reaction zone of said chamber, passing the thus heated first mentioned gaseous stream while at a temperature above about 2000° F. into said secondary reaction zone and mixing it with said second stream of combustible material therein thereby promoting endothermic reaction of the latter material in the mixture, the rate of feed of said second stream being so regulated that the temperature of the mixture is lowered below about 2000° F. but above 750° F., then substantially immediately passing the hot reacting gaseous mixture in the latter temperature range into the turbine of said unit and lowering its temperature immediately by substantially adiabatic expansion therein, whereby the hot reacting mixture is effectively further cooled.

18. A gas turbine cycle as described in claim 17 in which the temperature of the hot gases passing to the turbine is controlled and maintained within a range of 1000° F. to 2000° F. by regulating the relative amount of said second stream mixed with the said hot products of combustion in said secondary reaction zone.

19. A gas turbine cycle as described in claim 17 in which power is generated and valuable partly oxidized products are simultaneously formed, and in which the temperature of the gas mixture exiting from said secondary reaction zone to the turbine is controlled within the range of 1000° F. to about 2000° F.

20. A gas turbine cycle as described in claim 17 in which control of the temperature of the hot gases passing to said turbine is effected in part by addition of H<sub>2</sub>O in suitable form both as a reactant and coolant, to said hot mixture prior to introducing it into said turbine.

21. A gas turbine cycle as described in claim 17 in which said combustible material comprises a hydrocarbon compound.

22. A gas turbine cycle as described in claim 17 in which a portion of the combustible exhaust gases from the turbine is returned to the system as combustible material.

23. A gas turbine cycle as described in claim 17 in which control of the temperature of the hot gases to the turbine is effected in part by addition of such an amount of H<sub>2</sub>O in a suitable form as a reactant to the hot gases from the primary reaction zone that considerable amounts of carbon monoxide and hydrogen are formed.

24. A gas turbine cycle as described in claim 17 in which said combustible material is a hydrocarbon substance and in which control of the temperature of the hot gases to the turbine is effected in part by addition of steam as a reactant to the reacting excess hydrocarbon material in such amount that considerable amounts of carbon monoxide and hydrogen are formed as steam hydrocarbon reaction products, and in which the temperature of the gases passing to said turbine is of the order of 1500° F. to 2000° F.

25. A gas turbine cycle as described in claim 17 in which the turbine exhaust gases while still at an elevated temperature are brought into reacting contact with a catalyst for sufficient time



for reaction products present in said exhaust gases to react with one another catalytically whereby at least one valuable by-product is produced.

26. A gas turbine cycle as described in claim 17 in which the combustible material used for controlling the temperature of the reacting material to the turbine is a different combustible material from that supplied for supporting combustion.

27. In a gas turbine cycle adapted for the generation of power in a suitably connected gas turbine unit in which gasiform products of incomplete oxidation are produced, the steps comprising, continuously introducing under superatmospheric pressure into the reaction zone of said unit both a stream of fuel and a stream of gasiform fluid containing oxygen in such proportion as to supply complete oxidation of said fuel, initiating and promoting oxidation in an oxidation phase, whereby at least a portion of the fuel is completely oxidized and the temperature of the resulting reaction products is raised to above 2000° F., continuously withdrawing the gas stream of oxidized products from the oxidation phase and substantially immediately passing said gaseous stream into a reduction phase with the addition of a second stream of combustible material under superatmospheric pressure and a temperature substantially less than 2000° F., whereby the hot products from the oxidation phase are cooled and a portion of the highly oxidized products of the oxidation phase are reduced to lower oxides by reactions with said second stream of combustible material, continuously withdrawing the reacting products in a gaseous stream from the reduction phase at a temperature below 2000° F. but above 1200° F. and substantially immediately discharging said latter stream into the turbine of said unit and substantially adiabatically expanding and cooling it therein, thereby producing partially oxidized products of said fuel and retaining them in the gas discharged from said turbine.

28. A gas turbine cycle for the generation of power comprising the steps consisting of a stage in which a gasiform fluid is compressed with increase in pressure; a substantially constant pressure stage in which a substantial amount of heat is added to said gasiform fluid and its temperature raised, the final temperature in the latter stage being attained and controlled by the substantially complete combustion of fuel in a primary combustion zone to a temperature substantially in excess of 2000° F. and by the addition thereto in a secondary reaction zone of an amount of fuel substantially in excess of the theoretical requirements for complete combustion and in an amount to reduce the temperature to below 2000° F. in part by endothermic reactions; substantially immediately passing the reacting gaseous mixture from the substantially constant pressure stage into an expansion stage in which latter stage the reacting gaseous mixture is expanded with a decrease in pressure, whereby intermediate combustion products formed in the substantially constant pressure stage are quickly cooled adiabatically with the retention of such intermediate products; and finally a substantially constant pressure stage in which a substantial amount of heat is with-

drawn from the exhaust products of the turbine and the temperature of the products is thus further reduced, thereby completing the cycle with the generation of power.

29. A gas turbine cycle for the generation of power, comprising of the steps consisting of a stage in which a gasiform fluid containing free oxygen is compressed with increase in pressure; a substantially constant pressure stage in which a substantial amount of heat is added to said gasiform fluid and its temperature raised, the final temperature in the latter stage being attained and controlled by the substantially complete combustion of a hydrocarbon fuel with said gasiform fluid in a primary combustion zone to a temperature substantially in excess of 2000° F. and by the addition thereto in a secondary reaction zone of an amount of hydrocarbon fuel substantially in excess of the theoretical requirements for complete combustion with the amount of oxygen present, and in an amount to reduce the temperature to below 2000° F. in part by endothermic reactions; substantially immediately passing the reacting gaseous mixture from the substantially constant pressure stage into an expansion stage in which latter stage the reacting gaseous mixture is expanded with a decrease in pressure, whereby intermediate combustion products formed in the substantially constant pressure stage are quickly cooled adiabatically with the retention of such intermediate products; and finally a substantially constant pressure stage in which a substantial amount of heat is withdrawn from the exhaust products of the turbine and the temperature of the products is further reduced, thereby completing the cycle with the generation of power.

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