

March 24, 1953

J. W. LATCHUM, JR.

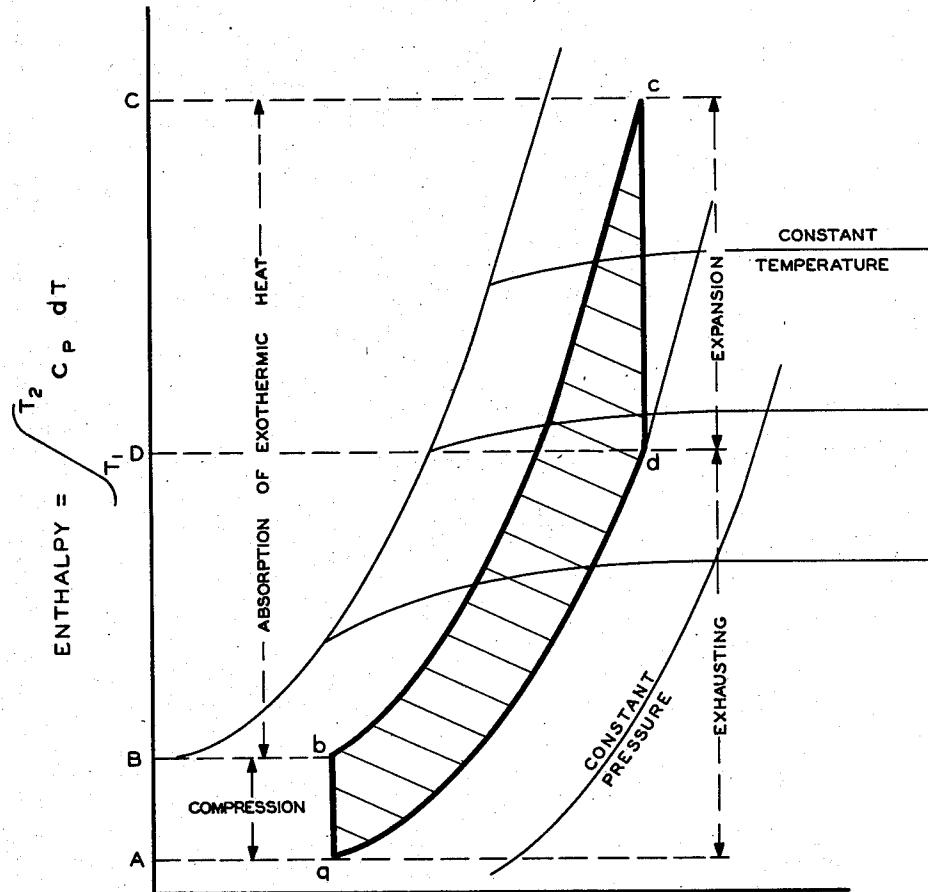
2,632,689

PROCESS AND APPARATUS FOR EFFECTING CHEMICAL REACTIONS

Filed Nov. 3, 1944

4 Sheets-Sheet 1

ENTHALPY-ENTROPY
DIAGRAM



$$\text{ENTROPY} = \int_{T_1}^{T_2} C_P \frac{dT}{T}$$

FIG. 1

INVENTOR
J.W. LATCHUM, JR.

BY *Hudson and Young*
ATTORNEYS

March 24, 1953

J. W. LATCHUM, JR

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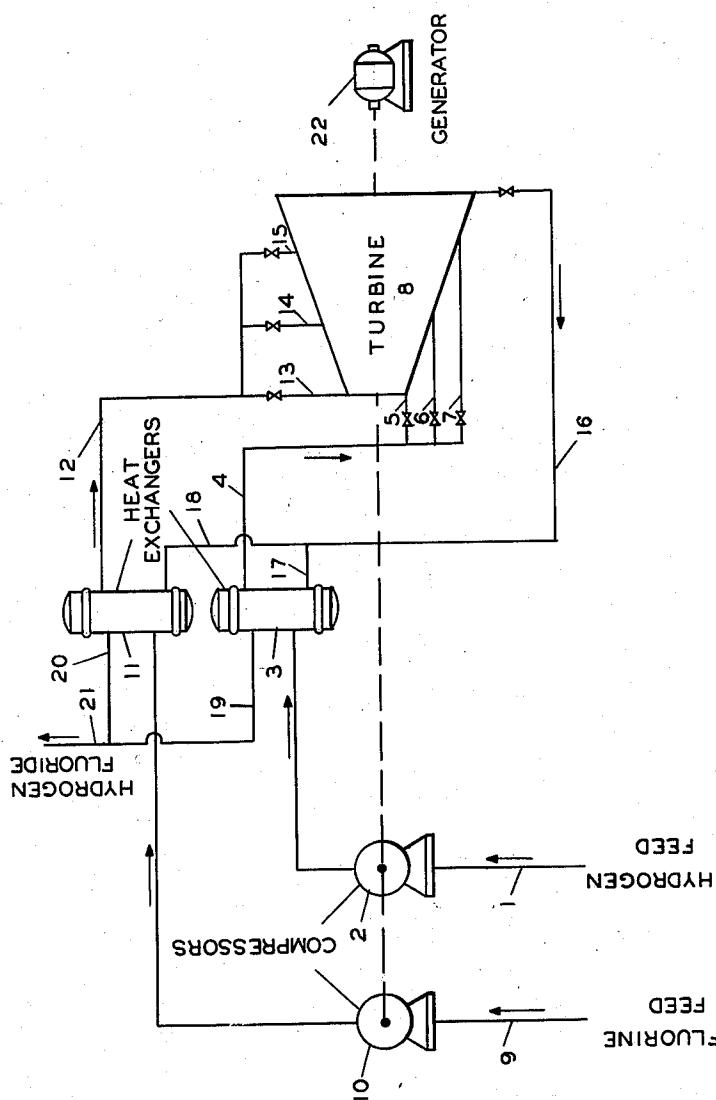


FIG. 2

INVENTOR
J. W. LATCHUM, JR.
BY *Hudson and Young*
ATTORNEYS

March 24, 1953

J. W. LATCHUM, JR

2,632,689

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4 Sheets-Sheet 3

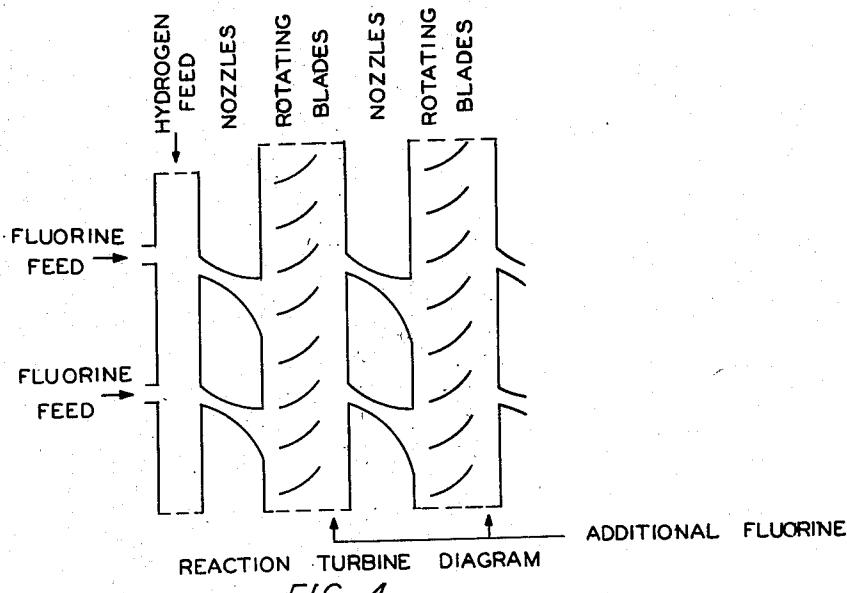


FIG. 4

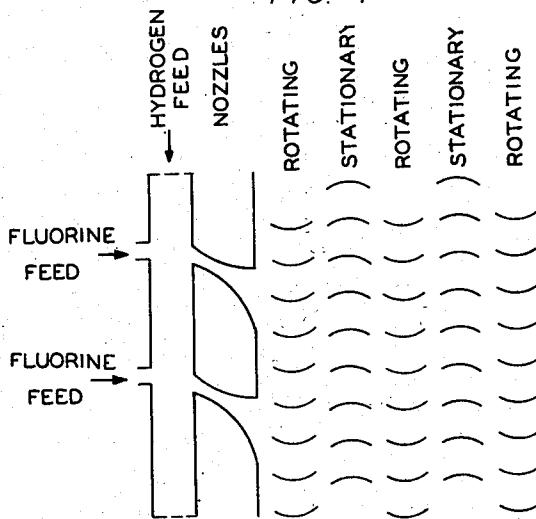


FIG. 3

INVENTOR
J.W. LATCHUM, JR.

BY *Hudson and Young*
ATTORNEYS

March 24, 1953

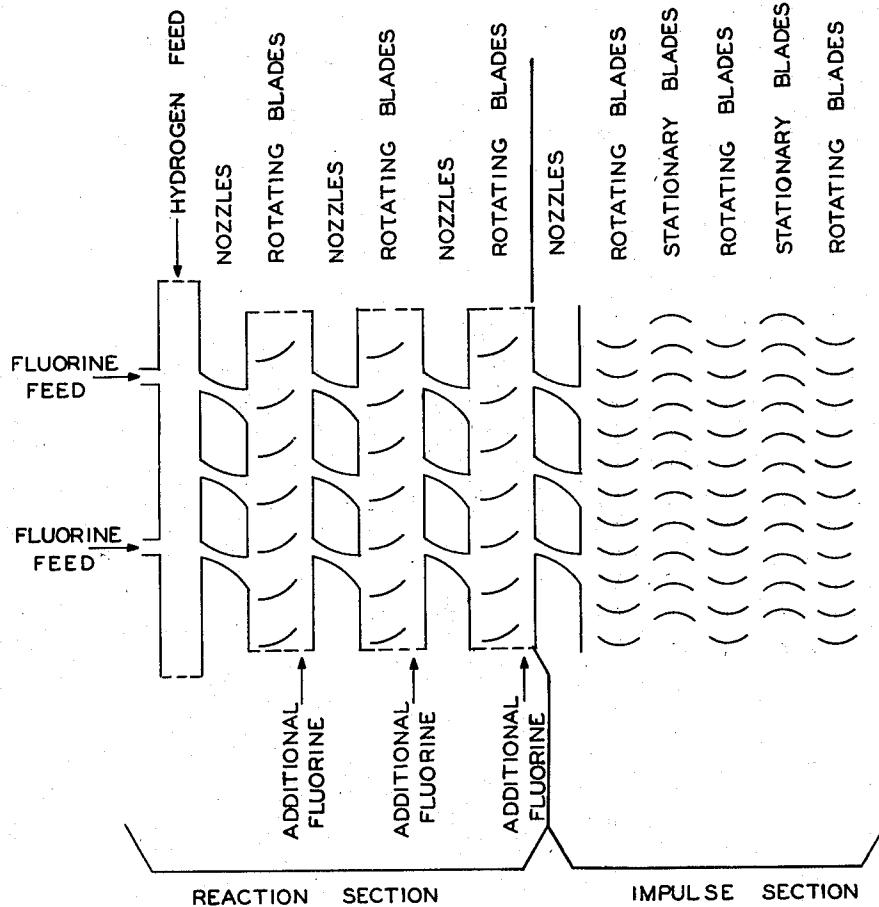
J. W. LATCHUM, JR.

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4 Sheets-Sheet 4



REACTION-IMPULSE TURBINE DIAGRAM

FIG. 5

INVENTOR
J. W. LATCHUM, JR.

BY *Hudson and Young*
ATTORNEYS

UNITED STATES PATENT OFFICE

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PROCESS AND APPARATUS FOR EFFECTING
CHEMICAL REACTIONS

John W. Latchum, Jr., Bartlesville, Okla., assignor to Phillips Petroleum Company, a corporation of Delaware

Application November 3, 1944, Serial No. 561,753

12 Claims. (Cl. 23—153)

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This invention relates to a process for generating power and conducting a chemical reaction. More specifically, this invention relates to a process for effecting chemical reactions within the casing of a power-producing turbine whereby available energy and reaction products are recovered. In one embodiment of this invention the heat released from exothermic chemical reactions is utilized as a source of power.

In general, the use of gas turbines for generating mechanical work by the expansion of hot gases is not uncommon. In both the petroleum industry and in iron smelting, gas turbines have been installed to recover available energy by the expansion of hot gases therein which otherwise would be lost by the expansion and cooling of the gases to atmospheric conditions.

The catalytic cracking of petroleum oils involves the regeneration of the catalyst with large volumes of regenerating gas under high temperatures and pressures. After the regenerating gas has burned the carbonaceous materials deposited on the catalyst during the cracking of the petroleum oils, the hot gases are expanded through a gas turbine to recover some of the energy therefrom. The mechanical work thus obtained from the gas turbine is often used to compress the regenerating gas prior to the combustion of the carbonaceous deposits.

Similarly, the process of reducing iron ore in a blast furnace involves large volumes of hot air and gases under moderate pressure. The hot exit gases from the blast furnace are often conveyed to a gas turbine where the gases release some of their available energy in the form of mechanical work. Essentially, these turbines utilize the expansion of hot gases whose potential energy, in the form of heat and pressure, was obtained elsewhere than in the turbine itself. In all of these processes, the high temperature of the gases is the result of the result of exothermic heat of reaction of the oxidation of carbonaceous materials prior to the introduction of the gases into the turbine.

The use of gas turbines in this manner is more or less a means for recovering energy as a by-product and by no means represents an efficient utilization of all the available energy of the entire process. Obviously, much energy is lost in effecting the process reactions separately from the gas turbine itself and in conveying the hot gases to the power-producing turbine.

It is the object of this invention to provide a power-producing device.

A further object of this invention is to com-

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bine a chemical process and a power-producing turbine in such manner as to recover the available energy from the chemical process as well as the products of reaction.

5 Another object is to improve the efficiency of chemical processes and decrease the cost thereof. Still another object is to utilize the exothermic heat of reaction of chemical reactions as a source of power.

10 Other objects and advantages of the present invention will become obvious to one skilled in the art from the accompanying disclosure.

In the present process, a novel use of a power-producing turbine has been found which enables the generation of power from energy available in chemical processes. In this respect, the chemical reactions comprising a chemical process are effected under gas or vapor forming conditions in the casing of a gas turbine acting both as the reaction chamber of the process and as a means of generating power.

15 Preheated reactants are injected separately into a turbine, generally at a superatmospheric pressure. The reactants are intimately mixed and chemical reactions occur within the turbine forming a gaseous or vaporous product. Simultaneously with the chemical reaction, the reactants and gaseous products are allowed to expand within the turbine, giving up energy in the form of mechanical work. The gaseous effluents of the reactions are recovered from the exhaust of the turbine as valuable products or for further treatment in their preparation as products of the process.

20 A more comprehensive understanding of the invention may be obtained from a consideration of the drawing of which Figure 1 is an enthalpy-entropy diagram of the theoretical thermodynamic cycle involved in the process of the invention. Figure 2 is a diagrammatic illustration of a preferred arrangement of apparatus for effecting the reaction of fluorine with hydrogen to produce hydrogen fluoride in a multi-stage turbine.

25 Figure 3 is a diagrammatic illustration of a multi-stage impulse type turbine showing the method of injecting multiple reactants. Figure 4 is a diagrammatic illustration of a multi-stage reaction type turbine showing the introduction of multiple reactants of a reaction chamber preceding the first set of nozzles and additional injection of one of the reactants directly to successive stages of the turbine, and Figure 5 illustrates diagrammatically the preferred arrangement of the apparatus of the invention in which a reac-

tion type turbine precedes an impulse type turbine.

In the application to an exothermic chemical reaction, Figure 1 represents the theoretical thermodynamic cycle involved in the present process. The ordinate of the enthalpy-entropy diagram of Figure 1 is enthalpy,

$$\Delta h = \int_{T_1}^{T_2} C_p dT$$

and the abscissa is entropy,

$$\Delta S = \int_{T_1}^{T_2} C_p \frac{dT}{T}$$

The complete cycle is represented in the diagram of Figure 1 by *abcd*; the area within the cycle *abcd* is the theoretical excess energy. The first step of the process is compression of the reactant gases or vapors (when fed to the process as gases) which requires energy in the form of mechanical work. The compression step is from *a* to *b* on the enthalpy-entropy diagram and utilizes *B*—*A* units of enthalpy. The heat released by the exothermic reaction raises the temperature and volume of the gas along the path *bc* at constant pressure at the expense of *C*—*B* units of enthalpy liberated in the reaction. In expanding the gases through the turbine along path *cd* of the cycle, *C*—*D* units of enthalpy in useful mechanical work is realized. The exhaust gases carry away *D*—*A* units of enthalpy along the path *da* of the cycle.

In practice, especially in exothermic processes, the quantity of mechanical work realized from the expansion of the gases in the turbine is greatly in excess of that needed to compress the reactants in the first step. This excess mechanical work is a convenient source of power to be treated as a product or to be consumed in other phases of the process.

Chemical processes applicable to the present invention are preferably those involving high pressure, high temperature gas or vapor-forming reactions of the exothermic type and/or where the volume of the reaction products is greater than the volume of reactants. As an example of a high temperature, high pressure, exothermic process, the noncatalytic alkylation of hydrocarbons may be effected within the casing of a power-producing turbine where the exothermic heat of reaction could be substantially recovered in the form of mechanical work. In noncatalytic alkylation, selected olefin-paraffin mixtures are subjected to a temperature from about 900° F. to about 1100° F. and pressures as high as about 2,500 to 5,000 or 10,000 pounds per square inch gage. Under such conditions the combination of the constituents is effected in the vapor phase without the use of a catalyst. Such hydrocarbons as ethene, propene, n-butene, isobutene, propane, n-butane, isobutane and pentane react readily in this process.

Noncatalytic polymerization of petroleum fractions may be an exothermic process which also could be carried out by the process of the present invention. In practice, temperatures of about 850° F. to about 1150° F. and pressures of about 1,000 to 2,000 pounds per square inch gage are preferred in producing noncatalytic polymerization of C₂, C₃, and C₄ olefins in the vapor phase when diluted with paraffins.

Other exothermic processes to which this present invention is applicable when the product formed is in the vapor or gaseous state include chlorination of cyclohexane, ethylene, and other petroleum derivatives, the formation of hydrogen chloride from hydrogen and chlorine, and the

formation of hydrogen fluoride from hydrogen and fluorine.

This invention is adaptable to catalytic as well as noncatalytic chemical processes. It is preferred to have the catalyst present as a vapor or finely divided solid or liquid admitted as a mist with the reactants. Examples of catalysts which may be used in the form of a mist or vapor at the temperature of the chemical process are the hydrogen halides, the metal halides, boron halides, sulfuric acid, phosphoric acid, the oxides of nitrogen, and some metal sulfides and sulfates. Other catalysts which may be a finely divided solid introduced as a mist are the chromates and metal oxides. Since the invention applies to chemical processes in general, no attempt is made to list all of the catalysts which might be used.

The application of this invention to the formation of hydrogen fluoride gas from hydrogen and fluorine is diagrammatically illustrated in Figure 2.

Hydrogen for use in the process may be obtained as a by-product in the dehydrogenation of petroleum fractions, or recovered from the effluent gases in the regeneration of catalysts upon which carbonaceous materials have been deposited during the conversion of hydrocarbons. Fluorine can be obtained from any suitable source, as from the electrolysis of potassium or calcium fluoride in a copper cell, which acts as a cathode, with a graphite rod serving as the anode.

Dry hydrogen enters compressor 2 from line 35 1 and is compressed to a pressure between about 10 and about 1,000 pounds per square inch gage, preferably a pressure between about 20 and about 70 pounds per square inch gage. The hydrogen passes from compressor 2 to heat exchanger 3 where it is preheated to a temperature between about 300° F. and about 600° F. and passes from heat exchanger 3 into turbine 8 through lines 4, 5, 6, and 7. Simultaneously, dry fluorine enters compressor 10 from line 9 where the fluorine also is compressed to a pressure between about 10 and about 1,000 pounds per square inch gage, and preferably to a pressure between about 20 and 70 pounds per square inch gage. The fluorine then passes from compressor 10 to heat exchanger 11 where it is preheated to a temperature between about 300° F. and about 600° F. and passes from heat exchanger 11 through lines 12, 13, 14, and 15 into turbine 8. The hydrogen and fluorine are injected at various points along the length of the turbine in a manner more fully described below.

The formation of hydrogen fluoride within the turbine liberates about 5,750 B. t. u. of heat per pound of hydrogen fluoride formed. After or during the liberation of heat which raises the 60 temperature, the gases are expanded in the turbine to furnish mechanical work, a part of this work is utilized to compress the hydrogen and fluorine, and the remainder may be available to generate power in generator 22 as an additional 65 product of the process.

The effluent, having been expanded to about atmospheric pressure, is discharged from the turbine through line 16 and passes through lines 17 and 18 to heat exchangers 3 and 11. The effluents are then recovered via lines 19, 20 and 21 for the separation of the hydrogen fluoride product, and the recycling of the unreacted hydrogen or fluorine.

The thermal efficiency of a turbine operated

according to this invention is about 21 per cent when the temperature of the gases within the turbine is about 1,000° F., while with operations at about 1,200° F. an efficiency of 25 per cent may be realized. By using heat exchangers as illustrated in Figure 2, the efficiency may be raised 3 or 4 per cent. At 1,500° F. this basic unit could deliver power at 28 per cent thermal efficiency, with 31 per cent easily attainable with the use of heat exchangers. The use of heat exchangers transfers some of the heat from the relatively hot exhaust gases of the turbine to the reactants, hydrogen and fluorine, before they enter the turbine to react. The economic size of heat exchanger will limit the recovery of heat from exhaust gases, at 1,200° F., to approximately 75 per cent recovery of the heat available from the turbine exhaust gases.

Thermal efficiency may be further improved in some instances when intercooling is added to heat exchanging or regeneration. Intercooling removes the heat of compression from the air passing through the compressor. Water circulating through the intercooler coils between the stages of the compression cools the compressed fluid. By intercooling, the compressor work is reduced because the cooler compressed fluid has a smaller volume. Other conditions remaining the same, one stage of intercooling will reduce the compressor work about 15 per cent. This increases the portion of the turbine capacity available as useful output and improves the efficiency as much as 2 to 3 per cent.

A portion of the gaseous reaction products may be recycled before or after the heat exchange to aid in control of the power output of the turbine.

A speed governor, regulating the supply of reactant and thereby the quantity of heat liberated, affords a convenient method of controlling the turbine temperature.

Generally, the construction of the turbine may comprise a casing in which are machined grooves for the turbine nozzles and stationary blades, a turbine spindle on whose periphery are the moving blades, gas inlet and exhaust passages, roller bearings for the supports of the turbine spindle and a suitable number of nozzles and stationary and moving blades. The turbine casing, split on the horizontal center line, is preferably a cast carbon-molybdenum steel having good corrosion resistance and other physical properties. The gas inlet and exhaust passages are cast integrally with their respective casing halves. A solid non-corrosive chrome-nickel-steel forging may comprise the turbine spindle. The nozzles or stationary blades, preferably made from a straight rolled section of 15 per cent nickel-steel of high corrosion and wear resistance have their inlet edges hardened to prevent erosion and are fastened in the grooves of the casing by the engaging of a projecting ring in the groove with a slot in the blade and close fitting spacer pieces. The tapered and twisted moving blades, preferably milled from 14 per cent chrome, 9 per cent nickel steel containing relatively small amounts of tungsten, molybdenum, titanium, and columbium to give a quality of high corrosion resistance, are securely held in place in the spindle by engaging the upset end of the blades with serrated spacer pieces.

Conventional turbine structures, particularly with respect to nozzle blades, casings, rotors, etc., may be utilized with modifications of design dictated by the particular reaction to be performed in the turbine, but, of course, with the novel

features such as inlet conduits or nozzles leading directly into separate stages of the turbine. For instance, the preferred modification of the apparatus of the invention which is a combination reaction-impulse turbine of the multi-stage type, may comprise a conventional multi-stage reaction turbine in combination with a conventional impulse turbine downstream of the reaction turbine on the same or on separate shafts but preferably the former.

The chemical reactions of the processes applicable to the present invention may be effected in a single or multistage turbine of either an impulse type or a reaction type or a combination reaction-impulse type. When the impulse type turbine is used the reactants may be injected separately into the annular space immediately preceding the inlet to the nozzle, as illustrated in Fig. 3, in which the exothermic reaction occurs and the temperature of the gases increases rapidly. The gaseous reaction products expand in the nozzle to attain a substantially high velocity. Theoretically the velocity of the gases is decreased only in the rotating or moving blades immediately following the nozzles, and the pressure is reduced only in the nozzles. In practical application the greatest part of the temperature drop occurs in the nozzles. In the impulse type turbine, because of friction and the change of enthalpy into kinetic energy, the temperature drops a substantial amount in the nozzles while the gases are expanding and results in a much more rapid temperature decrease in the nozzles than in the reaction turbine. This quick temperature drop is desirable in some cases and is an advantage in processing where short reaction time and fast cooling are required.

Since heat is removed by work done in the expanding of the reactants and products, the cooling of the gas is achieved with more rapidity than by conventional heat exchange methods. Thus, the application of this invention to reactions requiring a quick quench (cooling) of the gases to stop the reaction as in the case of many petroleum processes is very suitable.

In the multistage reaction turbine, illustrated in Figure 4, where the gases are expanded successively after each set of moving blades, the temperature drop will theoretically be the same on each set of moving blades with only a very small temperature drop in the nozzles. The temperature drop per stage is relatively less in this type of turbine than in the impulse type turbine previously described. The pressure drop per stage is also relatively lower in the reaction turbine than in the impulse turbine. Therefore, where longer reaction times and better control of reaction conditions, such as temperature and pressure, are required to assure a high yield of the desired reaction products, the reaction turbine should be used rather than the impulse turbine.

A preferred set-up for the practice of this invention is the use of a combination reaction-impulse type multistage turbine to form the reaction chamber of a chemical process. The combination reaction-impulse turbine is illustrated in Figure 5. The turbine comprises two sections. In the first or reaction section the blades are designed to utilize the kinetic energy due to the expansion of the fluid, in the second or impulse section the blades are designed to utilize the kinetic energy due to velocity of the fluid. The reactants are injected separately into the annular space before the inlet to the first set of nozzles of the reaction section of the turbine. Additional

reactants also may be injected immediately preceding the next successive set of nozzles and so on through the entire reaction section. By successive injections of one of the reactants as indicated, the gases are reheated in successive stages on passing through the turbine, which effectively increases the efficiency of the turbine while simultaneously increasing the yield of chemical product. The reaction type section of the turbine, because of the relatively small decrease in temperature, allows time for the chemical reactions to proceed toward completion, and the impulse-type section of the turbine where the temperature drop is relatively large and more rapid, acts as a quick quench for the chemical reaction so that the formation of excess side products is prevented. If the time for passage of the gases through the reaction section of the turbine is insufficient for the desired amount of reaction of the gases, an additional chamber may be inserted between the reaction section and the impulse section of the turbine. In this additional chamber the gases will have more time for reacting thereby enabling an increase in yield of the chemical product. The reaction and impulse section of the turbine also may be entirely separate units interconnected by suitable means for the conveyance of gases. These methods permit closer control of reaction conditions than attainable in a conventional reaction chamber followed by a quench in separate equipment.

Preferably the reactants are injected at right angles to each other and this may be effected in the annular space preceding the nozzles by injecting through stationary inlets, or one of the reactants may be injected from rotating arms or blades attached to the turbine spindle. These rotating arms have orifices therein through which one of the reactants may be injected at right angles to the flow of the gases within the turbine. The reactant may pass to the rotating arms by entering the turbine through the rotating shaft of the spindle or some like manner. Either of these methods of injection assures intimate and thorough mixing of the reactants in preparation for effecting the chemical reaction. In carrying out the reactions within the turbine it is preferable to have an excess of one of the reactants present at all times, especially when the other reactant is introduced at a plurality of points along the length of the turbine casing.

The desired products manufactured by this process are recovered from the exhaust effluent by methods not new in the field of chemical technology. The methods may include absorption in a solvent, adsorption on a solid, chemical combination with other reactants, fractional condensation and distillation or a combination thereof. In almost all cases it is desirable to cool the hot products rapidly after discharge from the turbine.

The present invention has application in many chemical processes, preferably those processes in which pressure is not a controlling factor in the yield of the desired product. However, all processes of high and low pressure may be conveniently adapted to the present invention providing the products of reaction are formed and maintained in the gaseous or vaporous state while expanding through the turbine. In other words, the conditions of temperature and pressure within the turbine must be such that the resulting products of reaction are in the gaseous state in the turbine although the products characteristically may be liquids under atmospheric condi-

tions. Although exothermic reactions in general are preferred, the use of processes characterized by endothermic reactions where the heat of reaction is supplied by a supplementary source such as a furnace or superheated steam is also within the scope of this invention.

The cracking of isobutane in the vapor phase is an example of an endothermic process to which this invention can be adapted. In this case, the isobutane feed is compressed to about 4,000 to 5,000 pounds per square inch gage, and then passed through a preheater where the isobutane is rapidly vaporized at a temperature of about 1,000° F. to about 1,200° F. without effecting substantial decomposition thereof. The vaporized feed is injected into a heated turbine where it is expanded to a pressure of about 2,000 to about 2,500 pounds per square inch gage in a reaction type section of a combination reaction-impulse type turbine. The flow of the feed is regulated so that the isobutane has the desired residence time for the cracking reaction. Supplementary heat can be added to the reaction type section through the turbine casing by means of a superheated steam jacket surrounding the turbine. After expansion in the reaction type section of the turbine, the gases containing isobutane and reaction products are further expanded in the impulse type section of the turbine. The gases are cooled rapidly in the latter section preventing excessive formation of side products at the lower pressures. The available mechanical work realized from the turbine would be considerably more than that required to pump the liquid feed.

The excess mechanical work may be used to generate electric power or the like. Products of reaction are recovered from the exhaust effluent for separation and further treatment if desired. Certain conditions of temperature and pressure can be chosen so that the actual heat input for vaporization at high pressures is less than that required at low pressures.

Although the invention has been described with particular reference to specific types of chemical processes carried out in a particular manner, various modifications will occur to one skilled in the art which may be practiced without departing from the scope of the invention.

I claim:

1. A continuous process for cracking isobutane in the vapor phase and generating power from the resulting gases, which comprises compressing isobutane to a pressure of about 4,000 to about 5,000 pounds per square inch gage, rapidly preheating said isobutane to a temperature of about 1,000° F. to about 1,200° F. without effecting substantial decomposition thereof and vaporizing the same, injecting said vaporized isobutane into the reaction turbine section of a combination reaction-impulse turbine wherein a reaction turbine section comprising alternate sets of stationary gas directing elements and rotating elements is followed by an impulse turbine section comprising alternate sets of stationary gas directing elements and rotating elements interconnecting therewith, under conditions such that at least a portion of said isobutane forms cracked products, adding supplementary heat to said reaction turbine section so as to continue the cracking therein, expanding said isobutane and cracked products within said reaction turbine section to a pressure of about 2,000 to about 2,500 pounds per square inch gage, subsequently further expanding said isobutane and cracked products into said impulse turbine section of said turbine

whereby the isobutane is cooled rapidly and the formation of cracked products is substantially stopped, generating power by the expansion and velocity of said isobutane and cracked products in said turbine, and recovering an effluent from said turbine for the separation of said cracked products therefrom.

2. A continuous process for the manufacture of hydrogen fluoride and generation of power from the resulting gases, which comprises separately injecting hydrogen and fluorine under superatmospheric pressure into at least the first stage of a combination gas turbine in which a multi-stage reaction turbine section is followed by an impulse turbine section, a stage comprising alternate sets of stationary gas directing elements and rotor elements, effecting chemical interaction between said fluorine and said hydrogen so as to produce gaseous hydrogen fluoride in successive stages of said reaction turbine, translating resulting gas pressure in said reaction turbine into rotary movement thereof, expanding gaseous effluent from said reaction turbine into said impulse turbine and therein translating kinetic energy of said effluent into rotary movement of said turbine, thereby rapidly quenching said effluent and stopping further interaction, and recovering hydrogen fluoride from the turbine effluent.

3. In a process for effecting exothermic chemical reactions requiring accurate control of the reaction time the improvement which comprises separately injecting gaseous reactants under superatmospheric pressure into the reaction section of a power-producing combination turbine wherein a multi-stage reaction type turbine is followed by an impulse type turbine, a stage comprising alternate sets of stationary gas directing elements and rotor elements, effecting a chemical reaction between said reactants under conditions such that gaseous product is formed in said reaction type turbine, expanding said gaseous reactants and product and continuing the reaction in stages in said reaction type turbine, subsequently further expanding and utilizing the velocity of the resulting gaseous stream to rotate said impulse type turbine whereby said reactants and product are cooled rapidly and said reaction is substantially stopped, and recovering said product from the effluent from said turbine.

4. A continuous process for effecting exothermic chemical reactions and generating power, which comprises separately injecting a plurality of gaseous reactants under superatmospheric pressure at a plurality of points into an enclosed space immediately preceding the first stage of a combination reaction type-impulse type gas turbine in which a multi-stage reaction type turbine is followed by an impulse type turbine under conditions such that said reactants spontaneously react to form a gaseous produce in said space and in successive stages of said reaction type turbine, a stage comprising alternate sets of stationary gas directing elements and rotor elements, simultaneously directly injecting from outside of said turbine at least one of the reactants to successive stages of said reaction type turbine, translating resulting gas pressure in said reaction type turbine into rotation thereof, further expanding the resulting partially expanded gaseous effluent into said impulse type turbine and therein translating kinetic energy of said effluent into rotation of said turbine, and recovering a product from the turbine effluent.

5. A process for effecting chemical reactions

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which comprises injecting a gaseous reactant under superatmospheric pressure into the first stage of a combination gas turbine having a multi-stage reaction section followed by an impulse section under spontaneous reaction conditions whereby only a portion of said reactant is converted to gaseous product, passing the resulting effluent through and continuing the reaction in at least one successive stage, a stage comprising alternate sets of stationary gas directing elements and rotor elements, translating resulting gas pressure in said reaction turbine section into rotation of said turbine, expanding gaseous effluent from said reaction turbine section into said impulse turbine section and therein translating kinetic energy of said effluent into rotation of said turbine, and recovering said product from the turbine effluent.

6. The process of claim 5 in which fresh reactant is injected directly from outside of said turbine into successive stages of said reaction turbine section.

7. A combination gas turbine for effecting vapor phase chemical reactions, comprising a multi-stage reaction type turbine connected in series with an impulse type turbine downstream thereof and arranged for gas flow therebetween; a rotor in said reaction type turbine having a set of blades for each stage mounted thereon adapted predominantly for translating expansive force of gas under pressure into rotation of said rotor; expansion nozzles preceding each set of blades on the reaction type rotor disposed so as to direct gas against said blades and effect rotation of aforesaid rotor; a rotor in said impulse type turbine having a set of blades mounted thereon adapted predominantly for translating kinetic energy of a stream of gas into rotation of said rotor; a plurality of nozzles in said impulse type turbine disposed so as to direct gas against the blades therein and effect rotation of the rotor therein; conduits opening directly into each stage of said reaction type turbine from a feed source outside thereof and conduits opening into a reaction chamber preceding the first set of nozzles of said reaction turbine adapted for introduction of gaseous reactants thereto; and outlet means for discharging an effluent from said impulse type turbine.

8. The apparatus of claim 7 in which said impulse type turbine is multi-stage, having a stationary nozzle section followed by alternate rotating and stationary blades.

9. A continuous process for generating power in the production of hydrogen fluoride which comprises separately injecting hydrogen and fluorine under a pressure of 20 to 70 pounds per square inch gauge at a plurality of points into the first stage of a multi-stage gas turbine in which each stage comprises a set of stationary gas directing members followed by a set of rotor members, under reaction conditions such as to convert only a portion of the reactants to gaseous hydrogen fluoride, passing the resulting mixture of reactants and product into succeeding stages of said turbine, and continuing the reaction therein, translating the resulting gas pressure and gas velocity into rotation of said gas turbine, and recovering hydrogen fluoride from the turbine effluent.

10. The process of claim 9 in which a stoichiometric excess of one of the reactants is injected into the first stage and the other reactant is directly injected into succeeding stages of the turbine.

11. Apparatus for effecting chemical reactions

in the gas phase and translating potential energy of the resulting gases into mechanical energy, comprising in combination on a common shaft a multi-stage reaction type turbine in which each stage comprises alternate sets of stationary gas directing elements and rotor elements arranged so as to translate pressure of expanding gases into rotation of said rotor elements; a reaction chamber in said turbine communicating with the first stage of said turbine through a set of nozzles; inlet conduits around the periphery of said turbine in communication with a plurality of stages directly from a feed supply outside of said turbine for injecting fresh reactants thereto; a multi-stage impulse type 15 turbine downstream of aforesaid turbine in communication therewith in parallel flow through a set of expansion nozzles, each stage of said impulse type turbine comprising a set of gas directing elements and rotor elements arranged so as to translate gas velocity into rotation of said rotor elements.

12. Gas turbine apparatus for effecting chemical reactions and generating power which comprises a combination multi-stage reaction type 25 turbine housed on a common shaft with a multi-stage impulse type turbine and arranged for parallel gas flow through said turbines in the order named; a reaction type rotor in said reaction turbine having parallel sets of blades spaced apart thereon along the line of flow; sets of stationary nozzles alternating with said sets of blades and disposed so as to direct gas flow against said blades and translate gas pressure into rotation of said rotor; a reaction chamber in said reaction turbine preceding the first set of nozzles and in communication therewith; gas inlets to said chamber for introducing reactants thereto; gas inlet conduits communicating directly with the space surrounding at least one set of blades adapted for separately introducing reactant gases to said space directly from a feed source outside of said reaction turbine; a multi-stage impulse type rotor in said impulse turbine having peripheral sets of blades spaced apart 30

5 along the line of flow; a set of stator blades in each space between the impulse rotor blades adapted so as to direct gas flow against said impulse rotor blades and translate gas velocity into rotation of said impulse rotor; a plurality of compressors on said common shaft for compressing a plurality of reactants and having inlet and outlet conduits connected therewith, the latter being connected also with inlet conduits 10 to said reaction type turbine; and exhaust outlet means in the downstream end of said impulse type turbine.

JOHN W. LATCHUM, JR.

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