Dec. 22, 1942. G. JENDRASSIK 2,305,785

WORKING PROCESS AND MECHANICAL EQUIPMENT FOR GAS TURBINES

Filed May 18, 1938 5 Sheets-Sheet 1

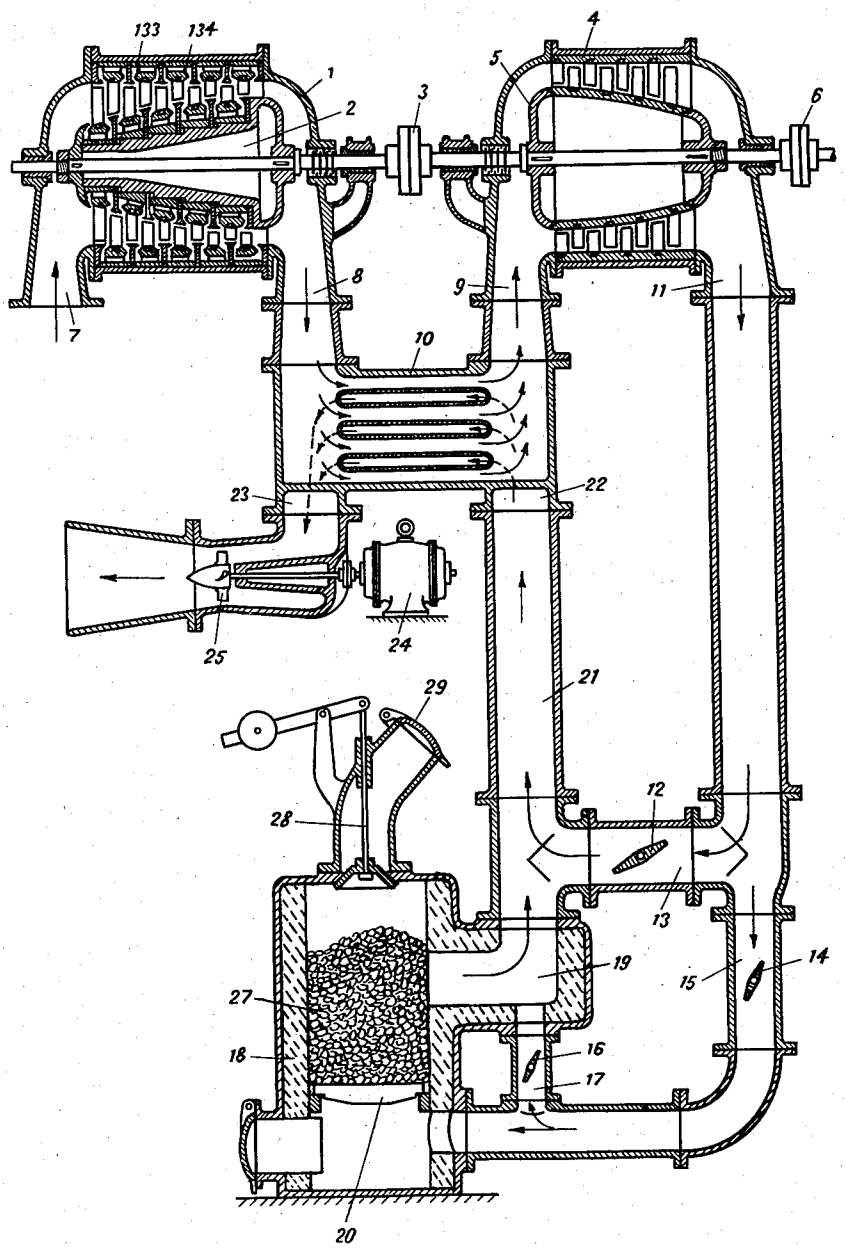


Fig. 1.

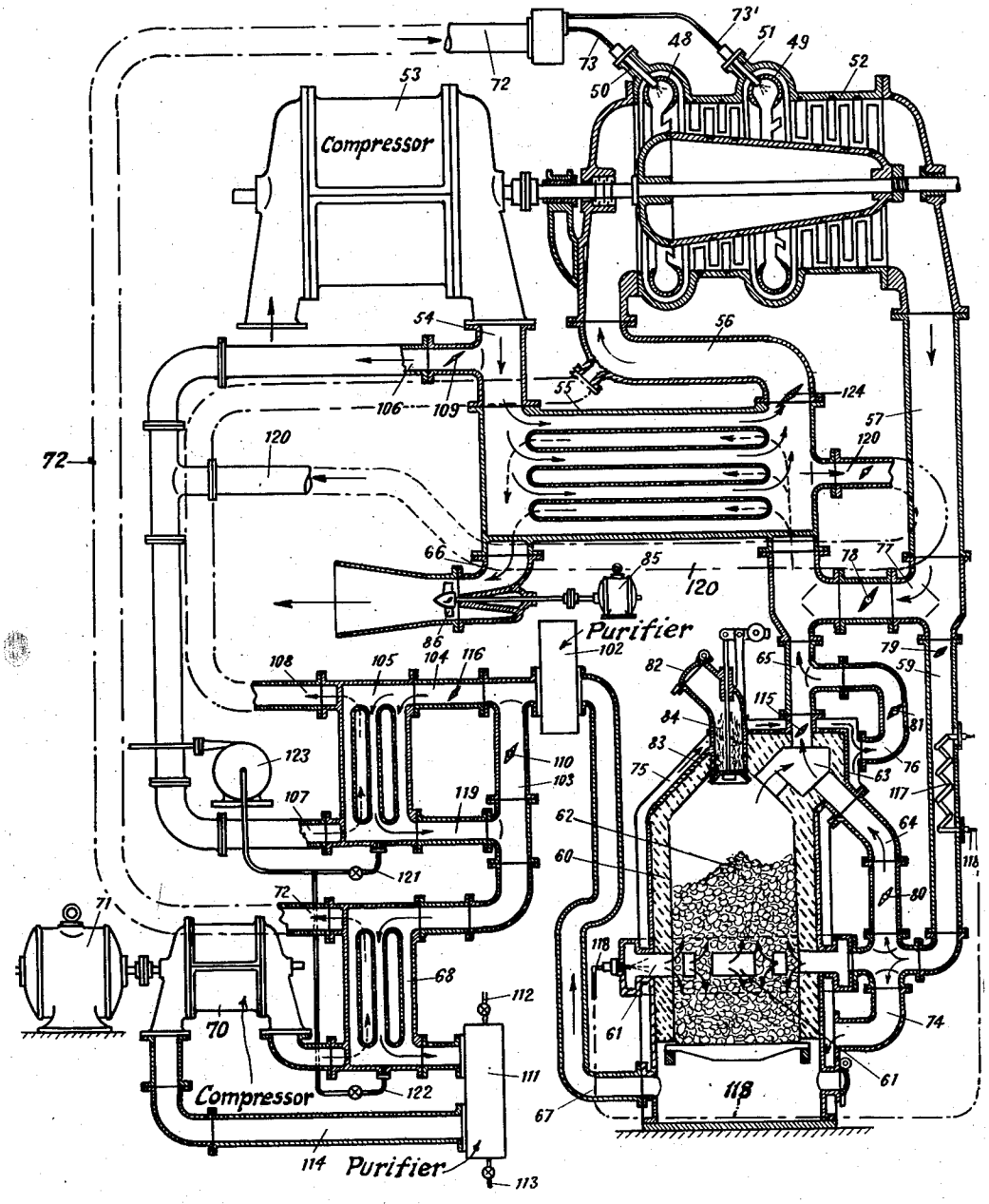
Witnesses:
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Dec. 22, 1942. G. JENDRASSIK 2,305,785

WORKING PROCESS AND MECHANICAL EQUIPMENT FOR GAS TURBINES

Filed May 18, 1938 5 Sheets-Sheet 2



Witnesses:
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Fig. 2.

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WORKING PROCESS AND MECHANICAL EQUIPMENT FOR GAS TURBINES

Filed May 18, 1938 5 Sheets-Sheet 3

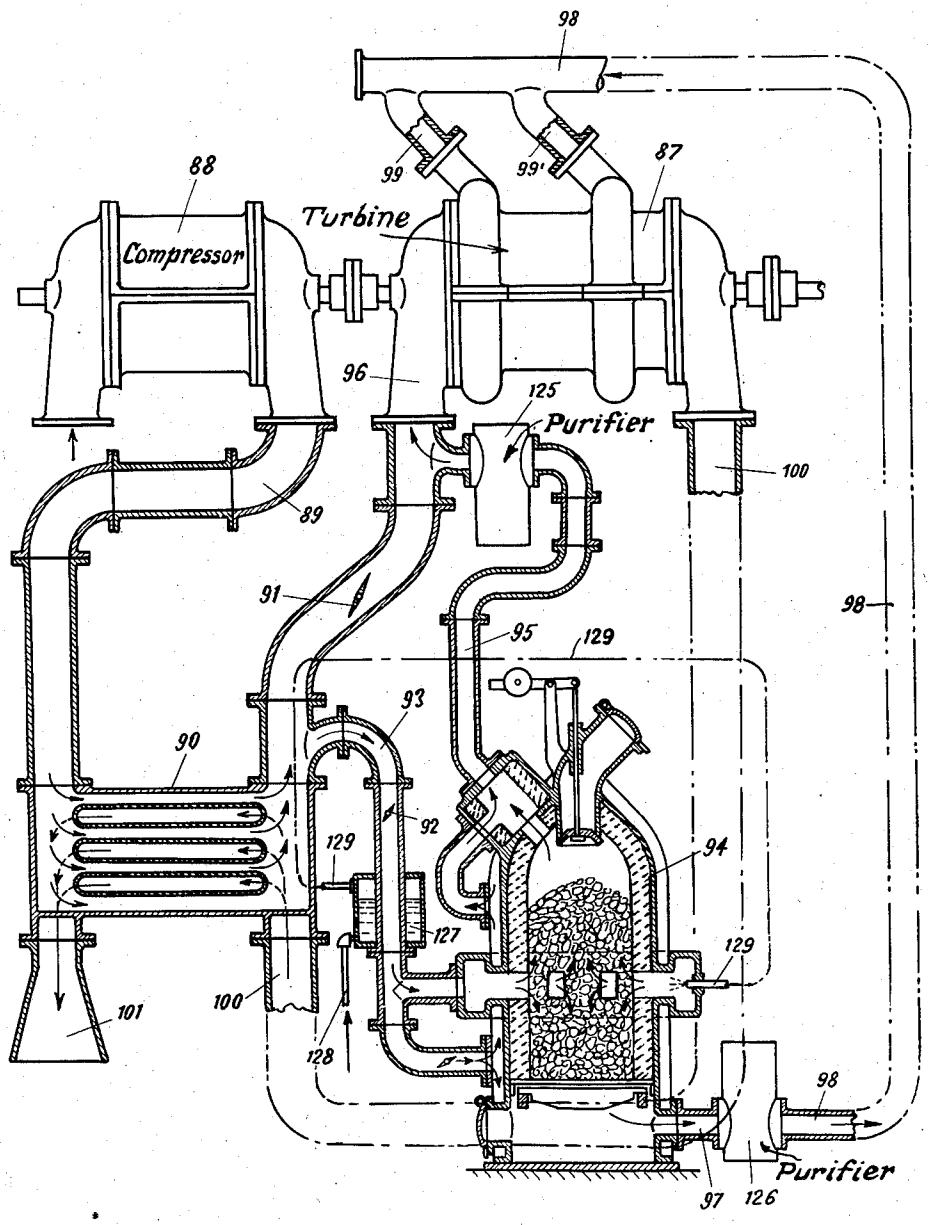


Fig. 3.

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Dec. 22, 1942. G. JENDRASSIK 2,305,785

WORKING PROCESS AND MECHANICAL EQUIPMENT FOR GAS TURBINES

Filed May 18, 1938 5 Sheets-Sheet 4

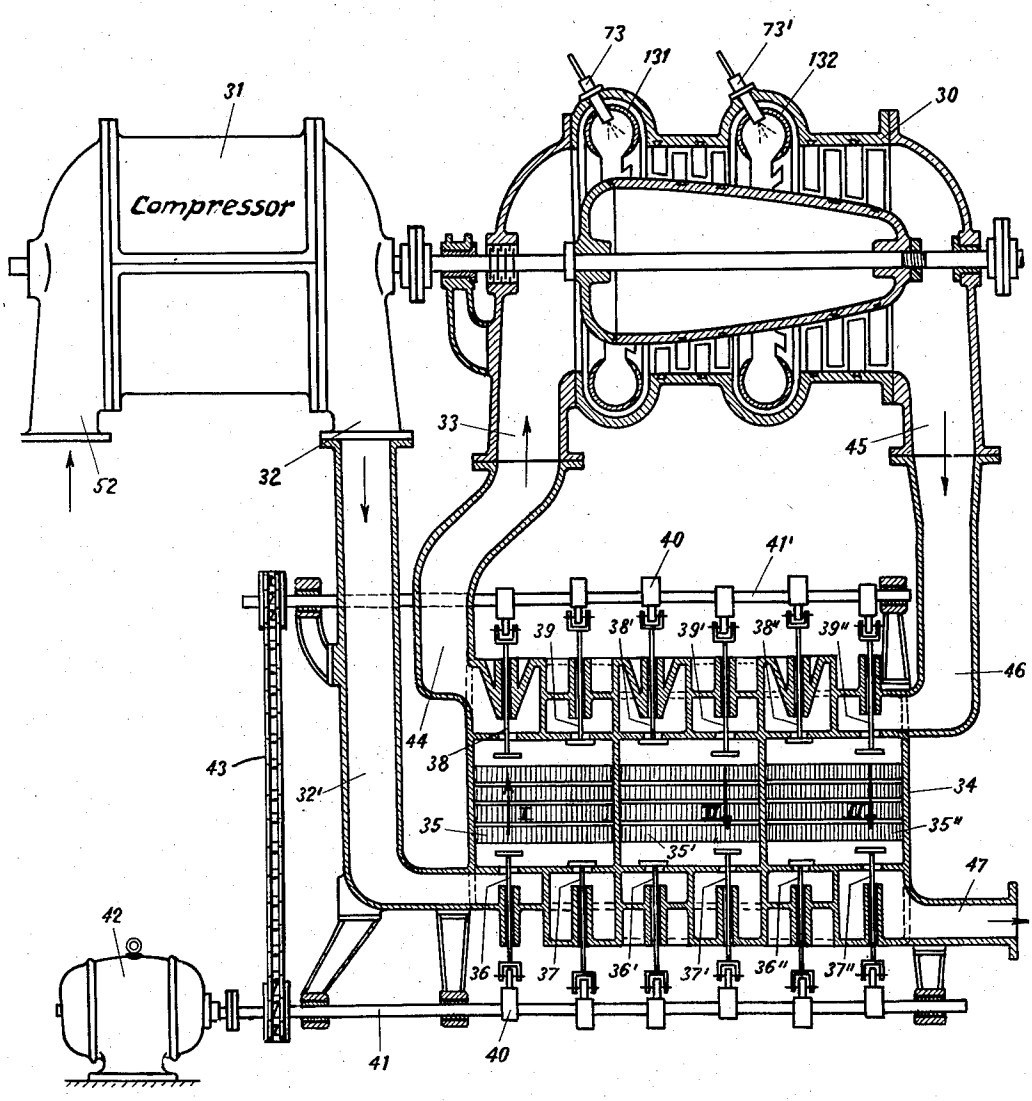


Fig. 4.

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Dec. 22, 1942. G. JENDRASSIK 2,305,785

WORKING PROCESS AND MECHANICAL EQUIPMENT FOR GAS TURBINES

Filed May 18, 1938 5 Sheets-Sheet 5

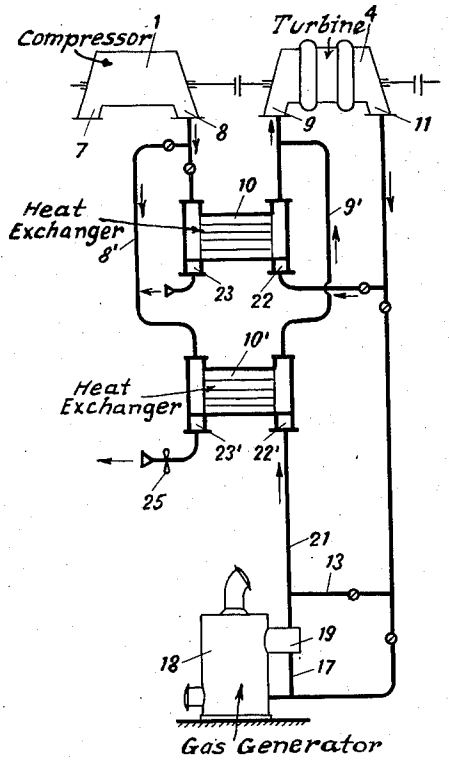


Fig. 5.

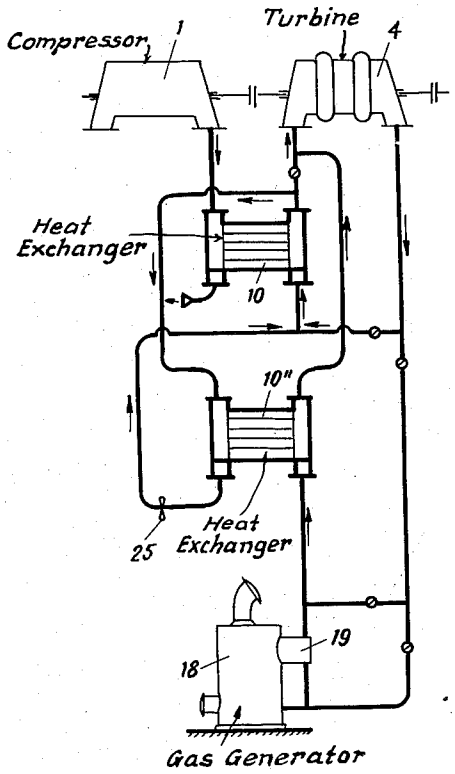


Fig. 6.

Witnesses:

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Patented Dec. 22, 1942 2,305,785

UNITED STATES PATENT OFFICE

2,305,785

WORKING PROCESS AND MECHANICAL EQUIPMENT FOR GAS TURBINES

George Jendrassik, Budapest, Hungary; vested in the Alien Property Custodian

Application May 18, 1938, Serial No. 208,556
In Hungary May 18, 1937

4 Claims. (Cl. 60—41)

According to the known gas turbine proposals it is before the passage of the working medium through the gas turbine, i. e. before the expansion of the working medium has taken place, that the combustion of the fuel in the working medium is effected, in order to enable the heat generated by the combustion of the fuel to be converted into mechanical work with an as high efficiency as possible. This method possesses many drawbacks. The working process and the gas turbine suitable for carrying the said process into effect, which are forming the subject-matter of the present invention, eliminate these drawbacks by an arrangement according to which the combustion of at least a part of the fuel to be burnt in the working medium of the turbine is effected after the said working medium has passed through the turbine. This working process can be employed for multi-stage gas turbines of a type fitted with a heat exchange device composed of metal sheets in which latter the heating of the working medium, which has been compressed prior to such heating, is effected by means of the heat contained in the working medium leaving the turbine in an as efficient degree as possible before the admission of the said working medium into the turbine. If in such turbines fitted with heat exchange device of the said type the fuel is—at least partly—burnt in the working medium after the latter has passed through the turbine, but before the working medium has entered the heat exchange device, it is indeed only the spent gases leaving the turbine that will be heated by the heat produced by the combustion, but the said heat exchange device, which should preferably operate according to the counter-current principle, will enable this heat to be transferred to the working medium of higher pressure entering the turbine, this being done, notably, theoretically, without any particular losses deriving from the new arrangement, in view of the fact that the transmission in its total extent in the heat exchange device of the extra quantity of heat introduced into the working process behind the turbine but in front of the heat exchange device can be assured by designing and dimensioning the heat exchange device in a suitable manner. Accordingly this heat will not be lost, but is able to perform work, without there being any necessity for products of combustion flowing in the turbine.

This process, or in other words, the gas turbine operating in this manner, offers substantial advantages as compared to the processes known up to now, as it renders possible the use of fuels of such a kind also, the gases of combustion, ash etc. of which are exerting a detrimental influence on the parts of the turbine, and further it enables the combustion to be effected in the working medium leaving the turbine i. e. in a working medium of lower pressure—which is usually equal to atmospheric pressure—by means of firing equipments of a simple kind, enabling also fuels of a primitive, inexpensive kind, like low grade coals, etc. to be burnt in an efficient manner.

It is a further advantage of this process, that in cases, where it is desired for the purpose of ensuring higher efficiency or the performance of a higher amount of work, or for other reasons, to produce, if possible, an isothermic expansion or an expansion during the course of which the introduction of heat into the working medium is continued in the turbine itself, it will be permissible, without any substantial loss to effect the combustion of the fuel partly also after the passage of the working medium through the turbine, whereby the carrying into effect of the ideal expansion at a constant temperature will be substantially facilitated. Finally, this process will enable the realization of expansion accompanied by the introduction of heat mentioned above to be carried out also in the cases of such fuels as are not directly suitable for producing such a combustion, or the gases of combustion of which are, owing to their detrimental effects, unsuitable for passing them through the turbine. Notably this is rendered possible by the said working process, owing to the fact that the combustion of such fuels is effected partly after they have passed through the turbine, a part of the fuel being, during such combustion, converted either by means of distillation, or by chemical changes, gasification, cracking etc. into a kind of fuel which can be burnt without any difficulty or drawback either in front of the turbine or during its passage through a part or the whole of the turbine, or between the various stages of the latter.

Among the figures of the annexed drawings, Fig. 1 illustrates, in a diagrammatical manner, the arrangement of the turbine and of the whole equipment serving as an example for carrying the working process into effect, with a furnace arranged behind the turbine and with a heat exchange device operating in a continuous manner. Fig. 2 is a diagrammatical drawing of a further embodiment shown by way of example, suitable for the use of solid fuels and with combustion effected partly behind the turbine. Fig. 3 is a diagrammatical drawing of another em-

bodiment shown by way of example suitable for the use of solid fuels likewise, in which the partial combustion of the fuel in front of the turbine is effected in such a manner that the portions becoming gasified etc. of the said fuel are partly being burnt behind the turbine. Fig. 4 is the diagrammatical cross-section of an embodiment shown by way of example in which a heat exchange device operating in a non-continuous manner is employed. Finally Figs. 5 and 6 are illustrating advantageous variants of the arrangement according to Fig. 1.

In Fig. 1, the rotor 2 of the rotary compressor 1, shown by way of example as being of the axial throughflow type, is driven by means of the shaft coupling 3 by the rotor 5 of the turbine 4 shown likewise as being of the axial throughflow type, the other shaft end of the said rotor 5 joining on by means of the shaft coupling 6 to the consumer of mechanical energy. The working medium—preferably air—enters the compressor through the inlet opening 7 and leaves it through the discharge opening 8. It is between this discharge opening and the inlet opening 9 of the turbine 4 that the heat exchange device 10 is arranged, which in the case of this example of construction is of continuous operation and of the counter-flow type. To the discharge opening 11 of the turbine there join on, on the one hand the by-pass pipe line 13 capable of being controlled by means of the throttle-valve 12, and on the other hand the pipe line 15 capable of being controlled by means of the throttle-valve 14. The pipe line 15, moreover, possesses a branch 17 capable of being controlled by means of the throttle-valve 16, which branch issues into the space 19 of the furnace 18, suitable, for example, for the combustion of solid fuel. In the example shown, it is below the grate 20 of the furnace equipment 18 that the pipe-line 15 is joining on. Behind the furnace equipment, the by-pass pipe-line 13 and the flue gas duct 21 of the furnace equipment are, after their mutual junction, joining on to the heat exchange device 10, into which the gas enters through its inlet duct 22. The gas leaving the heat exchange device is discharged through the duct 23 into which the fan 25 driven by the electric motor 24 is installed. It is the pit space 27 of the furnace equipment 18 which contains the solid fuel, which is admitted by the charging valve 28 and through the door 29.

The method of operation of this apparatus is the following:

The working medium enters the compressor driven by the turbine through the inlet opening 7 of the compressor 1, and leaves it through the discharge duct 8 at a pressure higher than the admission pressure, e. g. at a pressure amounting to 1.5 to 8 times the admission pressure. Following this, the working medium passes through the heat exchange device 10 designed on the counter-flow principle in which its temperature becomes raised considerably, e. g. to a temperature of 450°–900° C., at the expense of the heat of the spent gases leaving the turbine plant, that is to say the furnace, and following this it enters through the inlet opening 9 into the turbine 4. Here its pressure drops during expansion to approximately the figure of the admission pressure of the compressor, and during such expansion it performs mechanical work. From the turbine the gas discharged at the discharge opening 11 passes through the duct 15 or the by-pass duct 13, respectively, partly into the furnace 18 and partly directly into the duct 21 leading to the heat exchange device. The gas entering the furnace causes combustion to be effected, becomes heated and—if necessary—the combustion is continued in the space 19, use being made for this purpose of the secondary admixture air received through the duct 17. Following this the products of combustion of high temperature, leaving the space 19, are for the purpose of adjusting at will the temperature of the current of gas heating the heat exchange device, becoming mixed with the working medium supplied by the by-pass duct 13, and are through the duct 21 entering the heat exchange device 10, through which latter they are passing preferably in counter-flow relatively to the direction of throughflow of the high-pressure medium entering the turbine, and during this passage they are transmitting their heat to the said high-pressure working medium in an as complete degree as possible. The fan 25 produces a certain depression in the duct 21 and thereby in the furnace 18, so that when attending to the operation of the furnace, one need not fear that the hot gases should rush out and accordingly the handling of the furnace will be attended without any danger. The control members 12, 14, 16, which may for example be throttle valves, are serving for regulating the air quantities for the mentioned various functions.

By means of this example of construction it is possible to carry into effect that variant of the working process according to the invention in which the fuel is burnt in its totality behind the turbine. In the case of this variant a furnace or combustion chamber is inserted into the path of flow of the working medium behind the turbine and in front of the heat exchange device, through which furnace or combustion chamber at least a part of the working medium passes, the control members mentioned in what precedes, as valves etc. being arranged in the path of travel of the working medium for the purpose of regulating the quantity of working medium flowing through the furnace or combustion chamber.

In the case of the arrangement shown on Fig. 2 combustion is taking place not only behind the turbine, but also in the turbine before expansion and during expansion. In the case of this arrangement it is to the discharge duct 54 of the compressor 53 driven by the turbine 52 that the heat exchange device 55 operating in counter-flow is joining on, and after traversing this heat exchange device the compressed gas enters the turbine through the duct 56. From the turbine the gas discharged through the duct 57 passes through the duct 59 into the furnace 60, which latter is in the example of construction shown suitable for the combustion of solid fuels, in such a manner, that the fuel will partly be burnt and partly will become gasified or distilled etc., the said furnace being at the same time also suitable for removing the fuels formed in this manner from the furnace. In the case of the example shown the air entering the furnace 60 through the openings 61 is partly flowing in the upward direction, during which flow the combustion of a part of the fuel with the oxygen contained in the air takes place. The gases entering the space 63 from the pit space 62 of the furnace are completely burnt with the secondary air arriving through the duct 64 and are through the duct 65 passing into the heat exchange device 55, and after having passed through the heat exchange device, they are leaving the latter through its

discharge duct 66. As far as that part of the working medium the flow of which takes place in this manner, is concerned, the method of operation corresponds to the principle of operation illustrated on Fig. 1. The second part of the working medium, on the other hand, is handled in the case of this example of construction in such a manner as to enable a secondary fuel, capable of being led back into the turbine and burnt in the latter, to be obtained by such handling. This second portion of the working medium saturated with the fresh air entering through the ducts 61 is flowing downwards in the furnace, during which flow it gasifies a part of the fuel. The combustible gas or vapour of combustible material produced in this manner, is discharged through the duct 67 provided below the grate. The filter or purifier 102 of this duct serves for removing the impurities contained in the gas. From here, the gas passes through the ducts 103 and 104, respectively, into the counter-flow heat exchange devices 68 and 105, respectively, provided for this branch of flow, and transmits its heat in the heat exchange device 68 to the compressed gas leaving the compressor. The duct 106 branching out from the delivery duct 54 of the compressor joins on to the admission duct 107 of the heat exchange device 105, whilst the duct 108 of the heat exchange device is returning the air arriving through the duct 107, after it has been preheated by means of the gas, directly into the current flowing in the duct 56 towards the turbine. If the regulating member 110 provided in the duct 103 is completely closed, the gas arriving through the duct 67 will in its totality flow through the heat exchange device 105 and will there be cooled down to approximately the end temperature of the compressor, following which it will pass at this temperature through the pipe 119 into the heat exchange device 68 connected in series in the direction of the throughflow of the gas with the heat exchange device 105, in which heat exchange device 68 as well as in the purifying and cooling equipment 111 connected behind the latter it will become cooled down still further and if necessary also purified. The cooling equipment 111 receives its cooling water through the pipe line 112 and the cooling water leaves this cooling equipment through the pipe line 113. After having passed through the cooling equipment the gas passes through the duct 114 into the compressor 70 driven by the electric motor 71, in which compressor its pressure becomes raised to at least the figure of pressure ruling at the point of the working cycle, i. e. of the turbine 52 at which point it is intended to introduce the gas. After leaving the compressor 70 the gas will during its passage through the counter-flow heat exchange device 68 become heated, following which it will through the junctions 73, 73' branching out from the duct 72 get into the combustion spaces provided in front of the turbine and between the various stages of the turbine, respectively. In the constructional example shown, combustion spaces 48, 49 are provided in front of the turbine and behind a section of the turbine, respectively, into which spaces the burners 50 and 51, respectively, for the introduction of fuel are issuing at a number of places. The spaces of combustion are designed in such a manner that a part of the working medium of the turbine flows into them and the fuel introduced into them will become burnt in the said working medium. The combustion may also become propagated into the turbine and it is even possible that it is only after passage through the turbine that it will be entirely completed, whereby it becomes possible to produce expansion accompanied by the introduction of heat in the turbine. The control valves 110 and 116, respectively, are intended for regulating such part of the gas leaving the furnace through the duct 67 as flows through the heat exchange device 105, whereas the quantity of compressed air flowing through the heat exchange device 105 is regulated by means of the control valve 109.

Through the pipe 59 branching off from the pipe 57, and following this through the duct 74 joining on to the said pipe 59, a part of the air enters the jacket 75 of the furnace 60 in order to diminish the losses of heat in the furnace equipment, following which, after traversing the jacket, it is, through the pipe 76 joining on to the jacket, joining on to the current flowing in the duct 65. To the pipe 57 there joins on the by-pass line 77 in which the quantity of working medium getting into the furnace can be regulated in accordance with the load of the engine, etc., by means of control members as valves, slide valves or the like 78, 79 arranged in the path of the working medium of the turbine. The control valve 80 serves for regulating the quantity of secondary air for admixture, whilst the valve 81 serves for regulating the quantity of gas passing through the jacket of the furnace. The fuel is introduced into the furnace chamber through the door 82, the valve 83 and the charging pit 84. A circumstance by which the handling of the furnace is substantially facilitated is that there is no pressure above the atmospheric in the furnace, as a suction effect is produced in the same by the fan 86 driven by means of the electric motor 85 or by any other means.

In order to prevent any excessive heating of the gas passing through the furnace 60 it is advisable to introduce water or steam also into the furnace. This purpose is served by the tube coil 117, which in the arrangement shown by way of example is arranged in the duct of the waste gas but can also be arranged elsewhere. Through this heating coil which can also be constructed as a simple heating container, so that its steam space should join on to the pipe line, water is passing, which evaporating in the said container, and passing through duct 118 becomes admixed to the air entering the furnace. Thus steam will enter the furnace, which steam will become dissociated in the furnace chamber and will diminish the temperature ruling there. One part of the gas formed can be burnt in the space 63 in front of the heat exchange device 55, whilst the combustion of its remaining part leaving through the pipe 67 will be effected in the way described above.

It is also possible to operate the equipment described in such a manner that it is not from junction 106 that compressed air for the inlet duct 107 of the heat exchange device 105 abstracting the heat of the combustible gas leaving the furnace is being taken, but that duct 107 is made to join on to duct 120 by means of shutting off the branch 106. In this case it is the air which has already passed through the heat exchange device 55, and which accordingly has become substantially heated that will enter through the duct 120 into the heat exchange device 105, in consequence whereof the temperature of the compressed gas entering the heat exchange device

68, and accordingly also that of the compressed gas leaving the heat exchange device 68 will be higher. This method of procedure may be advantageous from the point of view of the combustion of the gas, for which purpose the quantity of compressed air passing through the heat exchange device 105 can be adjusted by means of the control member 124. It is, however, also possible to regulate the temperature of the combustible gas leaving the heat device 68 through the pipe 72 by means of the control valves 110 and 116, respectively. The equipment described can also be constructed and operated in such a manner that the duct 65 is completely closed by means of the throttle-valve 115 or in some other manner, so that it is only combustible gaseous fuel that is led out from the furnace 60, so that the equipment will operate as a gas generator. In such a case the progress of the cycle of operations will be such that the combustion will become extended from the turbine through the ducts 57, 77 partly even into the heat exchange device and will be completed in the latter. In this last-named case it will be particularly advantageous to introduce steam into the zone of combustion as shown e. g. by means of the duct 118 for the purpose known in connection with gas generators. Such introduction will be justified in an increased degree in the case of the apparatus described, because also the fresh air entering the same is at a high temperature of about 350–500° centigrade and thus it will be necessary in a higher degree still to prevent any overheating of the furnace. In case liquid, i. e. a liquid combustible substance should become condensed owing to the cooling down of the gas in the heat exchange devices 105 or 68 from the combustible gases leaving the furnace 60 through the duct 67, the removal of such products can be effected through the pipes 121 and 122 by means of the pump 123 which may be of any desired type. The fuel obtained in this manner can be introduced into the combustion chambers 48 and 49 respectively mentioned above by means of suitable apparatus and can be burnt in the same.

The example of construction described serves for carrying into effect such a variant of the working process forming the subject of the invention, in which in a furnace arranged behind the turbine, through which at least a part of the working medium passes, a part of the fuel is burnt, whilst from another part of the fuel combustible gases, i. e. gaseous fuel is produced by means of gasification, distillation, cracking etc., and such gaseous fuel is led in front of the turbine, and possibly between the various stages of the turbine, or possibly into separate combustion chambers where combustion takes place. By returning the gaseous fuels thus formed in the furnace by means of distillation, etc. into the turbine in this manner it is possible to carry an expansion accompanied by the introduction of heat into effect in the latter.

In order to ensure that an expansion accompanied by the introduction of heat should take place in the turbine, which is advantageous for many reasons, it is indeed easily possible to ensure by the suitable construction of the combustion chambers and by employing a suitable method for the introduction of the fuel, that the combustion of the fuel should be continued also during its throughflow through the turbine. In view of the fact, however, that throughflow through the turbine requires only a very short time, about one hundredth of one second, it would cause great difficulty to regulate the combustion in the turbine in such a manner as to ensure that the combustion should already be completed when the gas leaves the turbine. The process forming the subject of the invention, according to which it is possible to continue the combustion also after the passage of the gas from the turbine has been completed, will greatly facilitate the carrying into effect of an expansion accompanied by the introduction of heat.

In the embodiment shown by way of example on Fig. 3 the compressed gas leaving the compressor 88 driven by the turbine 87 through the duct 89 will after having passed through the heat exchange device 90 partly enter in a quantity determined by the control members 91, 92, through the duct 93, into the furnace 94, where the fuel will partly become burnt and partly gasified, distilled, etc. The gas flowing to the furnace will partly, after having become heated up by the effects of the combustion, pass through the duct 95 and the purifier 125 into the inlet duct 96 of the turbine and partly it will with the combustible products prepared from the fuel, pass through the ducts 97, 98 and the purifier 126 to the burners 99, 99'. The expanded gas leaving the turbine will through the duct 100 pass into the inlet opening of the heat exchange device 90 and, following this, it will reach the heat exchange device through the discharge duct 101. In the case of this variant of construction also, it is advisable to introduce steam into the combustion chamber. This purpose is served by the water tank 127 arranged around the duct 93 and fed through the pipe 128, from the steam chamber of which tank the steam generated enters the combustion space of the furnace through the pipe 129.

In the case of this arrangement also, it is possible to construct the furnace equipment in such a manner that it should operate as a gas generator only, whilst the gas produced is, for the purpose of producing an expansion accompanied by the introduction of heat, burnt in the turbine or partly behind the turbine. In this case it is necessary to employ in front of the turbine a furnace through which the working medium is passing, in which furnace the fuel is partly burnt and partly subjected to distillation, etc. whilst the combustible gas or gaseous fuel produced will at least in part become burnt either in front of the turbine or during or after its passage through a part of the stages of the turbine, whereas a further part of the gas, i. e. of the gaseous fuel will only become completely burnt after having passed through the turbine, at the last stage in front of the heat exchange device. The purpose of this arrangement is to enable such an expansion to be carried into effect by means of gaseous fuels obtained by gasification, distillation etc. from such kinds of fuel by means of the direct combustion of which it is not possible to carry the expansion accompanied by introduction of heat into effect in the turbine, particularly if this should be done in such a manner that the combustion be continued behind the turbine also.

In the case of the embodiment shown by way of example on Fig. 4 it is between the turbine 30 and the compressor 31 driven by it, i. e. between the discharge duct 32 of the compressor and the inlet opening 33 of the turbine that the heat exchange device 34 operating periodically, and of the counter-flow type likewise, is inserted. In the embodiment shown by way of example this heat exchange device is composed of three units (35, 35', 35''), each of which is fitted on the cold side with the controlled inlet members

36, 36', 36'', and with the controlled outlet members 37, 37', 37''. The heat exchange device is on the hot side likewise fitted with controlled inlet and outlet members, viz. with the inlet members 39, 39', 39'' and with the outlet members 38, 38', 38''. In the example of construction shown these members (valves) are controlled by the cams 40 mounted on the camshafts 41—41'. The camshafts are driven by the electric motor 42 partly in a direct manner and partly through the transmission gear 43.

In the interior of the various units of the heat exchange device metal plates, preferably arranged in parallel with the direction of the throughflow, are provided, the mutual distance of which is, in view of increasing the heat transmission, made as small as possible (0.1–5 mm., preferably less than 2 mm.), whilst perpendicularly to the direction of the throughflow they are divided by means of air gaps into individual bundles of plates, so as to prevent as far as possible any conduction of heat taking place from one end (the hot end) of the heat exchange device to its other (cold) end. It is instead of metal plates, however, also possible to employ by way of heat-storing material metal wire mesh or some other lining of great surface area consisting of metal or other material, for instance gravel, and incorporating air spaces. The inlet duct 32' communicating with the antechamber of the inlet valves 36, 36', 36'' serves for the introduction of the compressed fresh working medium into the heat exchange device. On the hot end the gas leaves the heat exchange device through the duct 44 communicating with the antechamber of the discharge valves 38, 38', 38''. To the outlet duct 45 of the turbine there joins on the duct 46 through which the hot gas leaving the turbine passes into the antechamber of the inlet valves 39, 39', 39'' of the heat exchange device. The spent and cooled-down gas leaves the heat exchange device through the heat exchange units 35, 35', 35'' and through the duct 47 communicating with the antechamber of the discharge valves 37, 37', 37''. In the example of construction shown the combustion chambers 131, 132, are arranged in front of or between the stages of the turbine, the fuel introduction burners, atomizers etc. 73, or 73' respectively issuing in several plates into these chambers. The method of operation of this apparatus is the following:

The compressor draws in the gas—e. g. air—through its inlet opening 52 and after compression delivers it through the ducts 32, 32' into that section of the periodically operating heat exchange device the inlet valve 36 of which happens to be open at the moment. During this time the discharge valve 38 of the heat exchange unit in question is open likewise, so that the gas will flow through the heat exchange unit in the direction of the arrow I and will enter the turbine through the inlet opening 33. During its passage through the regenerator the compressed gas will become heated. The gas leaving the turbine passes through the ducts 46 and the inlet valve 39 happening to be open at the moment into the working chamber of the regenerator and leaves through the discharge valve 37 open simultaneously with the inlet valve referred to above and through the discharge duct 47. Following this the gas flows in the direction of the arrow II through the heat exchange device and becomes cooled down during such throughflow. The heat exchange units are mutually connected periodically by means of the control valves in such a manner as to ensure that throughflow through them should take place alternately in the direction of arrow I or in that of arrow II in such a manner that whilst in a part of the units the flow takes place in the direction I, the flow in the other group of the units should take place in the direction II.

By constructing the heat exchange device in a suitable manner, it is possible to heat up the compressed gas entering the turbine by means of the heat of the expanded gas leaving the turbine to approximately the temperature of the last-named gas. The compressed gas entering the turbine through the inlet duct 33 will during its passage through the turbine perform work owing to its expansion.

By means of the combustion chamber 131, i. e. of the atomizers or burners 73 it is possible to introduce fuel into the gas before the latter enters the turbine, that is to say to introduce heat into the gas before its expansion, or in case of the suitable control of the combustion also during the expansion. After the gas has flown through a part of the turbine, the introduction of further quantities of fuel, i. e. of heat can be effected by means of the atomizers or burners 73' arranged in the combustion space 132. In any case however the adjustment of the combustion will be such that when the gas leaves the turbine, the combustion should not be completed yet, but should also extend into the antechamber of the valves 39. Naturally, however, there is also nothing to prevent the heat exchange device of periodical operation employed in the last example to be also employed according to the arrangements described in the previous examples.

It is very essential in connection with the types of apparatus described that the heat exchange device, no matter whether it is of periodical or of continuous operation, should operate in a perfect manner with a low amount of loss, as it is only in this case that it will be possible to transfer the heat introduced behind the turbine to a fresh supply of working medium of higher pressure without appreciable loss in efficiency. For this purpose the heat exchange device of the counter-flow type and operating in a continuous manner described in connection with the former examples is particularly suitable, provided that the mutual distance of the plates separating the working spaces of the heat transmitting and of the heat receiving media from each other is small (less than 5 mm.). Should in accordance with the last-named example a heat exchange device operating periodically be employed, it is, on the one hand for the reason mentioned, and on the other hand in order to enable the so-called charging losses arising at the changing-over of the heat exchange units to be reduced to a minimum, important, likewise, that the mutual distance of the plates should be very small, notably, as mentioned, less than 5 mm. likewise. In order to minimize the quantity of heat flowing from the hot end of the heat exchange device towards its cold end, it is preferable to fit such a heat exchange device with at least five air gaps, perpendicular to the direction of the flow.

In the case of all the variants of process and apparatus described in what precedes it is an important and characteristic feature that at the moment when the combustion starts it is only with a part of the working fluid flowing through the apparatus that the fuel is brought into contact. This appears in the case of the arrange-

ments according to Figures 1 to 3, from the fact of a part of the working fluid being passed through a duct by-passing the furnace equipment, whilst in the case of the arrangement according to Fig. 4, it appears from the circumstance that the fuel is introduced into the combustion chambers 131, 132, into which there enters at the same time, for the purpose of maintaining the combustion, also a part of the working fluid flowing in the working space of the turbine, whereas the remaining part of the working fluid flows along in front of the junction openings of these combustion chambers. This separated or detached portion of the working fluid joins on to the remaining part of the working fluid after having left the furnace equipment or the combustion chamber, thus becoming mixed with this last-named portion. This will enable the high temperature ruling in the combustion chamber to be reduced, thereby reducing also the danger of any damage being suffered by those parts of the apparatus which are sensitive towards high temperatures as e. g. the plates of the heat exchanger or the blades of the turbine, and thus offering the possibility of constructing these constructional parts of normal constructional materials also which are not particularly heat-resisting and are therefore not expensive. Moreover, however, the fact of effecting the combustion of the fuel in such a manner possesses special importance also for the reason because in case of the employment of solid fuel the quantity of fuel to be burnt for the purpose of the introduction of heat can in case of the variation of the load be controlled by merely controlling the quantity of air passed through the quantity of fuel accumulated in the furnace, so that in accordance with varying loads, varying quantities of air have to be passed through the furnace equipment; in view of the fact that the quantity of air the compressor of the equipment is able to supply is defined from other considerations, this can only be achieved if, in the manner described above, only a part of the total current of working fluid is passed through the furnace equipment, whereas the other part of the current of working fluid should be guided so as to by-pass the furnace equipment and should be admixed to the products of combustion leaving the furnace equipment. In order to enable the output to be controlled, it is, of course, necessary that it should be possible to control the quantity of air led into the furnace equipment and that led through the duct by-passing the furnace equipment, respectively, such control being effected preferably by means of control members, e. g. throttling valves mounted into the corresponding duct branches.

The arrangements described can be employed in any desired combinations and also in variants differing from the types of design described above by way of example only. Thus for instance it is possible (similarly to the heat exchange devices shown in Fig. 2) to employ in the main gas flow circuit also a plurality of heat exchange devices connected in parallel or in series, through which possibly not even the whole quantity of gas or air passes. This last-named arrangement may be advantageous for instance in connection with the transfer of the heat of the gases of high temperature obtained in the furnace on the fresh compressed working medium before mixing the gas of high temperature with gas of lower temperature.

Such a connection in parallel, or in series, respectively, of two heat exchange devices situated in the main gas flow circuit, is illustrated in an arrangement, shown by way of example, for each of these two alternatives by Figs. 5 and 6, respectively, which are developed from Fig. 1 and accordingly the symbols used for their common constituent parts are identical with those employed on this last-named figure. According to Fig. 5, the gas to be heated leaving the compressor 1 as well as the expanded gas to be cooled down leaving the turbine 4 are led, divided as to their quantities, through the heat exchange devices 10 and 10', respectively, notably through the heat exchange device 10 by means of the admission ducts arranged as shown on Fig. 1 and through the heat exchange device 10' by means of the pipe lines 8' and 9' branched off from the outlet opening 8 of the compressor and from the admission junction 9 of the turbine, respectively. The expanded gas leaving the heat exchange device 10 after having surrendered its contents of heat, is passing through the opening 23 directly into the atmosphere, whereas the heat exchange device 10' is, as far as the path of flow of the expanded gas is concerned, connected with the gas generator 18 in a manner similar to the arrangement of the heat exchange device 10 of Fig. 1, and accordingly the suction fan 25 is mounted into its outlet opening 23'. As against this arrangement of the heat exchange devices in parallel connection, Fig. 6 shows arrangement of heat exchange devices in series connection. In this arrangement a part of the quantity of compressed gas flowing through the heat exchange device 10 is led through the heat exchange device 10'' also, following which it is united with the quantity of gas following through the heat exchange device 10 exclusively and is led to the inlet opening of the turbine, whereas as regards the quantity of gas leaving the turbine 4, one part of the same is led through the heat exchange device 10 only, whilst the remaining part is, after flowing partly through the gas generator 18 in accordance with the arrangement of Fig. 1, first led through the heat exchange device 10'' and following this—joining on to the quantity of expanded gas flowing to the heat exchange device 10 only—is led through this latter heat exchange device also. The fan 25 producing the depression required for the generation of gas is in this case also mounted into the discharge duct of the heat exchange device 10'' directly connected with the gas generator 18.

By such a grouping of the heat exchange devices it is possible to ensure that only one of them, notably the one which stands in direct connection with the gas generator 18 (the heat exchange device 10' or 10'', respectively) is exposed in a greater degree to the deposit of soot from the products of combustion and in consequence hereof it is advisable to provide for a suitable possibility of cleaning of this last-named heat exchange device. (The heat exchange device 10 according to Fig. 5 is not exposed to the effects of products of combustion at all.) In the arrangement according to Fig. 6 the heat exchange device 10 is at a low temperature, whilst the heat exchange device 10'' is at a high temperature; through the latter a smaller quantity of gas is passing owing to the arrangement illustrated, than through the heat exchange device 10 and the temperature drop also is smaller in it than in the heat exchange device 10. As against this, in the arrangement according to

Fig. 5 the relative magnitude of the quantities of gas flowing through the heat exchange devices 10 and 10' depends on the adjustment of the open cross-section of the passage valves inserted into the gas ducts, and the lowest temperature of the two heat exchange devices will be identical, whilst their highest temperature is of smaller magnitude in the heat exchange device 10 and of larger magnitude in the heat exchange device 10'.

Naturally it is also possible to employ compressors of a design modified in some respects. Thus for instance it is, owing to its high efficiency, particularly advantageous to employ a compressor, per se known, in which the effects of friction on the flow-guiding wall surfaces of the stator or of the rotor are eliminated by returning the spent boundary layer adhering to the wall surface into zones of lower pressure. Such a compressor is shown on Fig. 1 in which in the stator 2 the spent boundary layer is in consequence of the prevailing pressure difference between the openings of each of the return ducts 133, 134 in the stator, removed and led back through the said ducts in front of stages of lower pressure, where it enters again into the working space and owing to the pressure drop available again acquires a suitable velocity. It is in a similar manner that the removal of the boundary layer is effected, by means of similar return ducts shown on the drawings, in the rotor also.

I claim:

1. A process for generating mechanical power by means of an arrangement containing a rotary compressor, a multi-stage gas turbine and a heat exchange device composed of metal sheets, consisting in introducing heat into the gaseous working medium of the process for the conversion into mechanical work by means of a part of the fuel to be burnt being completely burnt in the working medium after its having expanded in the turbine, in bringing initially only a preferably adjustable part of the working medium into contact with the fuel for effecting this combustion, in mixing such part of the working medium, after at least a part of the fuel being brought into contact therewith has been burnt therein, to the remaining part of the working medium so as to form a common flow, in leading the flow of working medium containing practically all the heat imparted to it in the course of the said complete combustion, into the heat exchange device, and in transmitting the available part of the said quantity of heat in the said heat exchange device to the previously compressed fresh working medium before its entering the turbine, another part of the fuel being burnt in the working medium before the completion of its expansion in the turbine.

2. A process for generating mechanical power by means of an arrangement containing a rotary compressor, a multi-stage gas turbine and a heat exchange device composed of metal sheets, consisting in introducing heat into the gaseous working medium of the process for the conversion into mechanical work by means of a part of the fuel to be burnt being completely burnt in the working medium after its having expanded in the turbine, in bringing initially only a preferably adjustable part of the working medium into contact with the fuel for effecting this combustion, in mixing such part of the working medium, after at least a part of the fuel being brought into contact therewith has been burnt therein, to the remaining part of the working medium so as to form a common flow, in leading the flow of working medium containing practically all the heat imparted to it in the course of the said complete combustion, into the heat exchange device, and in transmitting the available part of the said quantity of heat in the said heat exchange device to the previously compressed fresh working medium before its entering the turbine, another part of the fuel being, in connection with the combustion of its first part, converted into fluid (secondary) fuel and burnt in the working medium before the completion of its expansion in the turbine.

3. In combination, a multi-stage gas turbine, a rotary compressor supplying compressed working medium for the gas turbine, a heat exchange device composed of metal sheets and connected, on the one hand, between the said compressor and the turbine and, on the other hand, into the exhaust pipe line of the turbine, a firing or combustion apparatus, suitable for the complete combustion of one part, and, by means of incomplete combustion, for the conversion into fluid fuel of another part of the fuel contained in it, being inserted into the exhaust pipe line of the said turbine between the outlet opening of the turbine and the heat exchange device, combustion chambers for the combustion of the fluidified (secondary) fuel joining on to the flow path of the working medium between the high-pressure outlet opening of the said heat exchange device and the exhaust opening of the turbine, separate ducts for leading the burnt gases of the said combustion apparatus through the said heat exchange device into the atmosphere and the secondary fuel, respectively, to the said combustion chambers, means as pumps or compressors for increasing the pressure of the secondary fuel inserted into the corresponding ducts, a duct branch in the said exhaust pipe line by-passing the said firing apparatus, and distributing organs as valves in the exhaust pipe branches leading to the said heat exchange device and by-passing it, respectively, being adjustable in such a manner that at least a portion of the expanded working medium should flow through the said firing apparatus, whilst another portion thereof should be mixed, by means of the said by-pass duct, to the burnt gases entering the heat exchange device.

4. In combination, a multi-stage gas turbine, a rotary compressor supplying compressed working medium for the gas turbine, a heat exchange device composed of metal sheets and connected, on the one hand, between the said compressor and the turbine and, on the other hand, into the exhaust pipe line of the turbine, a suction fan in the outlet duct of the heat exchange device serving for the removal of the expanded working medium therefrom, a firing or combustion apparatus, suitable for the complete combustion of one part, and, by means of incomplete combustion, for the conversion into fluid fuel of another part of the fuel contained in it, being inserted into the exhaust pipe line of the said turbine between the outlet opening of the turbine and the heat exchange device, combustion chambers for the combustion of the fluidified (secondary) fuel joining on to the flow path of the working medium between the high-pressure outlet opening of the said heat exchange device and the exhaust opening of the turbine, separate ducts for leading the burnt gases of the said combustion apparatus through the said heat exchange device into the atmosphere and the secondary

fuel, respectively, to the said combustion chambers, means as pumps or compressors for increasing the pressure of the secondary fuel inserted into the corresponding ducts, a duct branch in the said exhaust pipe line by-passing the said firing apparatus, and distributing organs as valves in the exhaust pipe branches leading to the said heat exchange device and by-passing it, respectively, being adjustable in such a manner that at least a portion of the expanded working medium should flow through the said firing apparatus, whilst another portion thereof should be mixed, by means of the said by-pass duct, to the burnt gases entering the heat exchange device.

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