# United States Patent

**Rodwin**

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[54] **INTEGRATED DRYING PROCESSES AND APPARATUS**


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[51] **Int. Cl.**..........................................................**F26b 5/14**

[58] **Field of Search**........................34/1, 14, 18, 23, 69, 114, 34/115, 155


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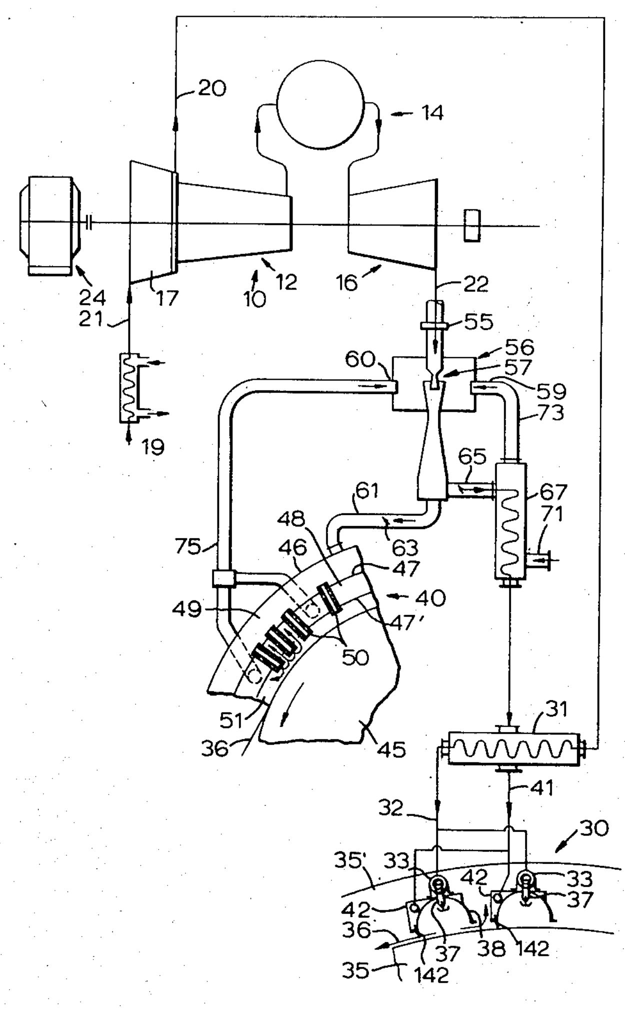
[57] **ABSTRACT**


Paper or other webs are dried in a composite drying cycle having pre-heated air compressed in a gas turbine to provide compressed air as a mechanical input to whistles of a dryer section, with thermal input to a succeeding dryer section provided directly or by heat exchange from the turbine exhaust gases, at least one section using impingement air in drying relation to remove moisture from the web.


**6 Claims, 3 Drawing Figures**



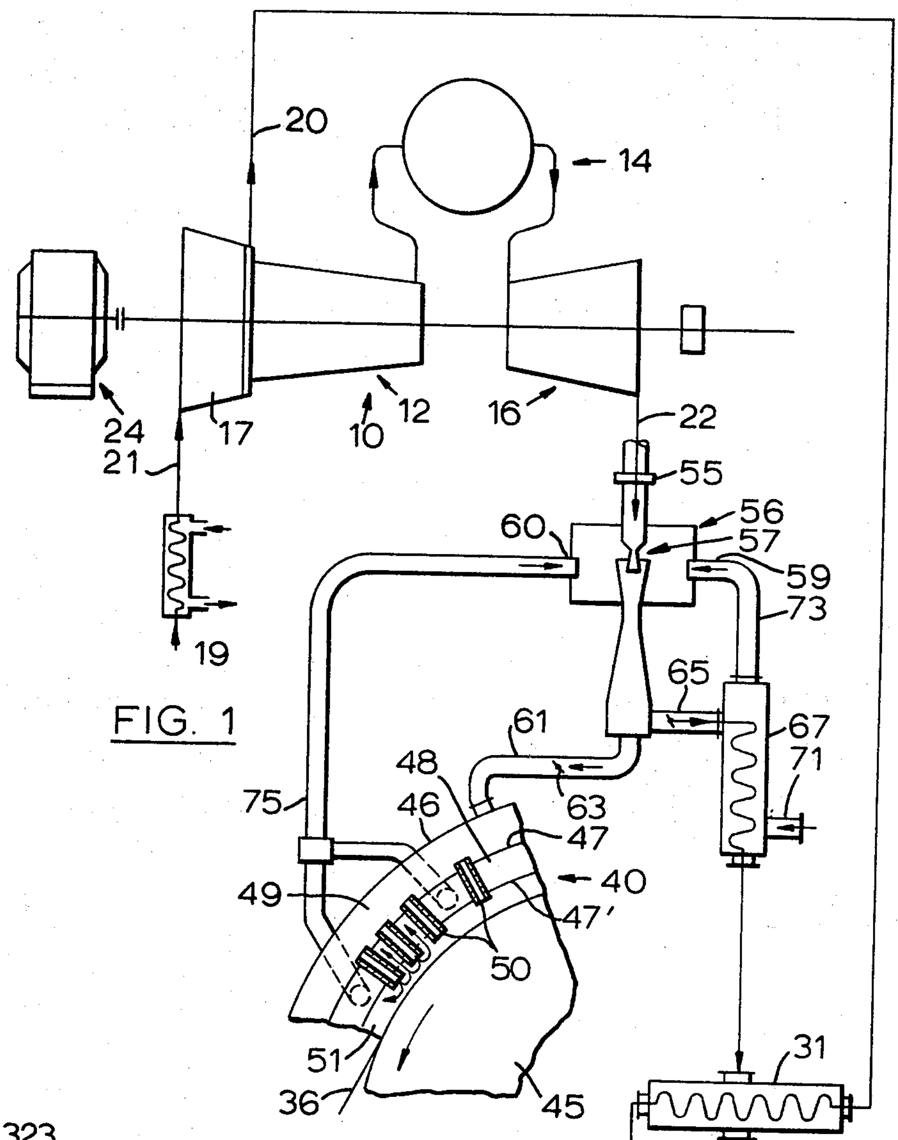
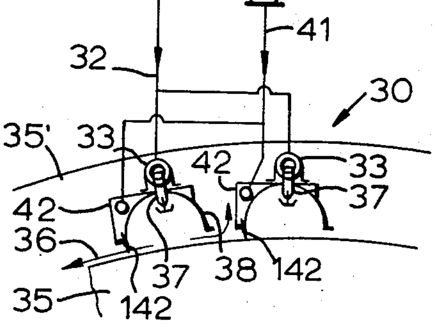



FIG. 1



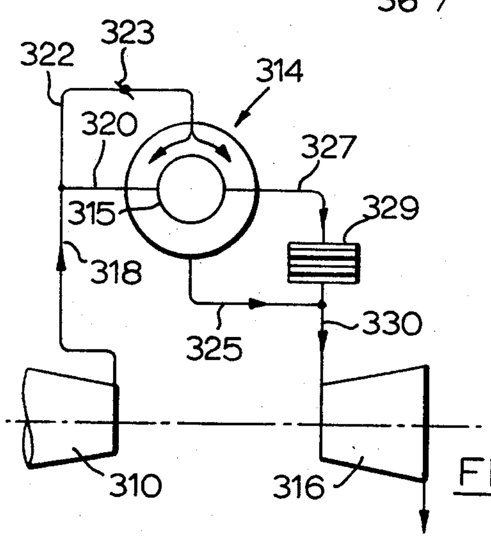



FIG. 3

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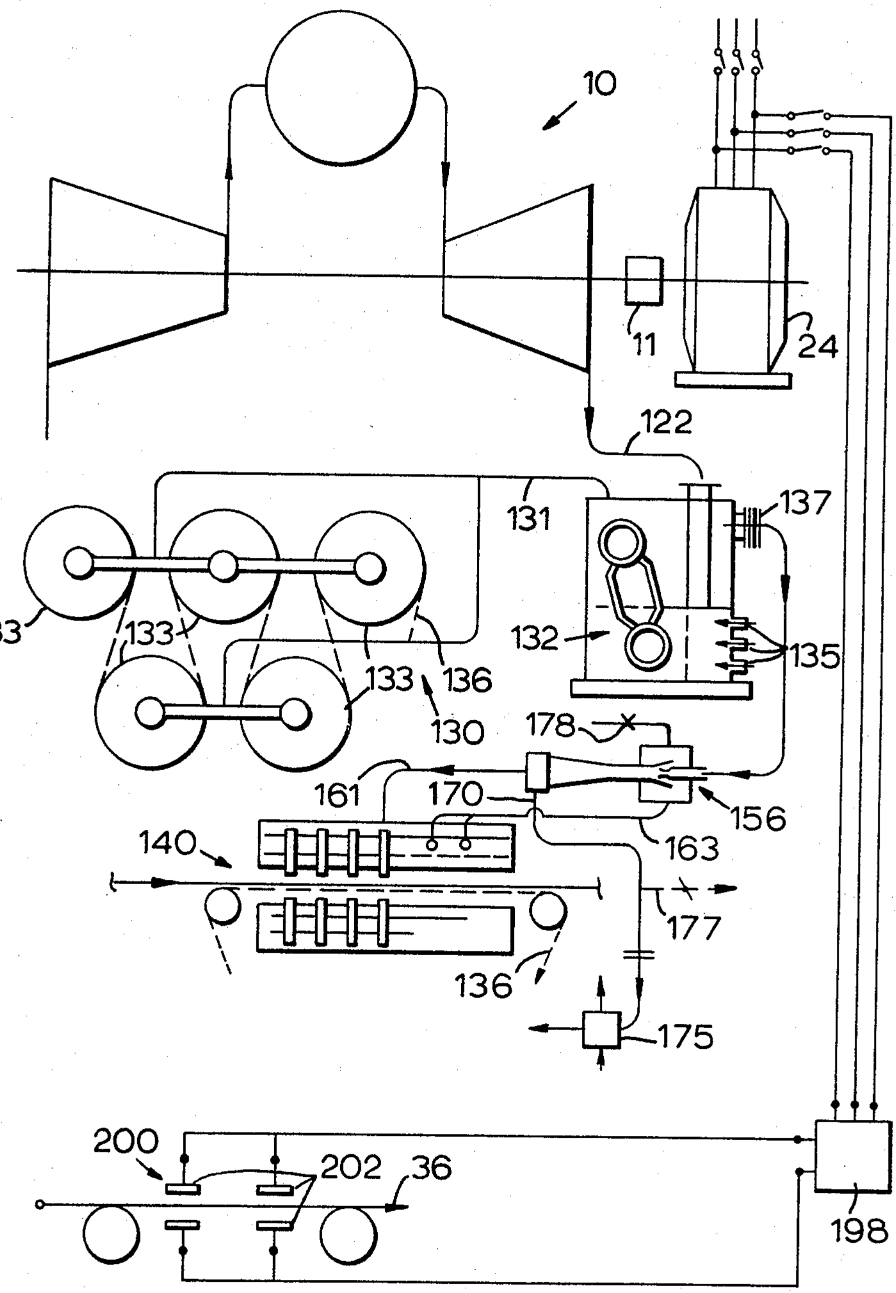


FIG. 2

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## INTEGRATED DRYING PROCESSES AND APPARATUS

This invention is directed to a web drying method using a gas turbine and to apparatus for carrying out the method, in particular for use in the drying of paper.

The use of gas turbines in the drying of paper webs has been previously proposed. Such proposals for utilizing gas turbines have not proved generally practicable, as they have failed to make best use of the performance characteristics of gas turbines, which characteristics while appearing disadvantageous may in fact be used in particular and unobvious ways to achieve high utilization of the total thermal energy input to the gas turbine in the drying of webs such as paper products.

The present invention is directed to the use of a process gas turbine in a drying system in which the function of the turbine is utilized in a novel and effective fashion.

Effective use of a gas turbine for drying purposes is dependent upon the selection of compatible drying systems.

Selection of an appropriate drying system or combination of systems, including the adoption of novel drying processes is dependent on the effective energy utilization afforded by such systems, measured on a basis of thermal units of energy per pound of water removed. Prior test results are available for determination of many such values.

In making comparisons of process energy requirements, it may be found that whereas one novel, mainly non-evaporative process requires 500 BTU's per pound of water removed, another evaporative process might require 2 to 4 times as much energy per pound of water removed. In selecting a process combination for instance of sonic drying and impingement flow drying, the total combined specific energy requirement for these two processes may be provided in the form of compressed air and gas turbine exhaust gas. Sufficient compressed air may thus be obtained from the mechanical output side of a process gas turbine at a much reduced specific energy input, measured in BTU per pound of compressed air, as compared with an electrically driven, separate air compressor. By integrating the compressed air requirements for both the gas turbine and for sonic drying energization in a single machine an advantage in machine size may be obtained. Such an arrangement permits approximately one half of the total drying to be carried out in the dryer section by sonic drying. The balance of the drying may then be effectively performed by a conventional thermal process having the higher specific energy requirement normally associated therewith supplied from the exhaust side of the machine, to achieve high energy utilization. The selection of suitable liquid or gaseous fuels and/or the provision of effective hot gas filtering also is necessary.

Sonic drying provides mechanical displacement of moisture to the web surface or surfaces, while an air impingement drying process which normally removes moisture primarily by evaporation from the web surface is particularly compatible therewith if applied in sequence, when the respective processes operate in the moisture ranges to which they are best suited.

The provision of sonic drying, as set forth in copending application Ser. No. 46,979 dated June 17, 1970 usually requires the provision of auxiliary heat in addition to the supply of compressed air, to effect the following:

a. An increase in temperature of compressed air supplied to the sonic generators obtained by preheating the compressor inlet, or alternatively and less economically by reheating the compressor air output; and
b. an increase in temperature of secondary air circulated or recirculated in the resonance zone, to control psychrometric conditions such auxiliary heat provision may be obtained from the gas turbine exhaust side directly or by use of heat exchangers.

In considering the effectiveness of an air compressor supplying a sonic drying system, it must be borne in mind that normally undesired losses in efficiency which stem from internal losses in the compressor appear as a beneficial rise in the temperature of output air going to the sound generators. This is true both for gas turbine compressors or compressors driven by mechanical means such as an electric motor, and obviates



the need of providing a compressor intercooler. In the case of a process gas turbine having an integral two spool compressor, beneficial use of this characteristic can be made.

In the case of external mechanical drives to a compressor, such as an electric motor, the mechanical and electrical energy losses of the motor are dissipated from the system, and do not appear as useful heat in the output air, thus favoring the use of the direct power drive of a gas turbine as prime mover, wherein such losses are virtually eliminated.

The adoption of a portion of the total drying process as an evaporative process permits balancing of the total output of the gas turbine to maintain effective heat economy. Thus, the use of the turbine mechanical power output to generate low cost electrical power permits the economic utilization of microwave drying which might otherwise be economically impractical if using commercially generated power were used. This is of value for instance in moisture profiling in the case of coated webs, where the characteristics of microwave heating may be effectively utilized, despite the high cost of electrical power which is normally prohibitive when obtained from conventional sources.

Thus a combined total drying process utilizing a process gas turbine having in one instance a gaseous output for sonic and impingement drying, and in another instance an electrical output as for microwave moisture profiling and combined in each instance with a heat drying process using turbine thermal exhaust for a heat drying process may provide significant cost advantages over a corresponding system utilizing commercial electrical supply and gaseous fluid heating and pressurizing obtained by conventional means.

Reverting to the matter of compressor efficiency, in view of the virtual full energy recovery of compressor losses which appear as useful heat in the sonic drying, the adoption of a compressor design without jacket or other cooling means provides potential capital savings, in the selection of a compressor or its related components.

The utilization of a process type gas turbine in the manner described serves to de-emphasize the significance of the power output efficiency of the respective gas turbine components, so that machine costs can be correspondingly reduced. Also, the pressure and thermal loading of machine components is reduced, with corresponding potential savings.

The present invention thus provides a method of utilizing both the mechanical and thermal output of a gas turbine in web drying, whereby the absence of optimum component efficiency in compression or expansion tends merely to change the balance achieved between useful thermal output and useful mechanical output. In particular, by providing a medium efficiency gas turbine wherein pressure expansion is not fully optimized, the cost of the turbine may be significantly reduced, while utilization of the machine as a hot gas generator is enhanced by the higher exhaust pressure available to move the hot exhaust gases externally of the turbine to the components of the drying apparatus. Of the many different aspects of design affecting machine efficiency and cost, the form of blading and closeness of blading tolerances such as tip clearance are typical of the area in which increase in tolerances and clearances can greatly promote cost reduction at an acceptable loss of power generating efficiency in the environment of the present invention.

While there are many ways of utilizing the mechanically produced energy output of the machine, the two following, which are not in themselves novel, are: (1) the use of compressed gas to actuate sonic vibration devices such as stem jet whistles in the dislocation of moisture from the web, as set forth in my application Ser. No. 46,979, filed June 17, 1970 and (2) the generation of electric power for driving components of the paper mill and/or the dryer section, and/or for providing drying as by dielectric drying or microwave drying of the web.

Whereas an earlier approach to the problem teaches the use of compressor air as the drying medium for through drying of a web, it is contemplated in the present invention that due to the wide operating pressure range of stem jet whistle sonic generators, pressurized gas from the compressor may be used to drive such type of sound generators, while in addition heat recovery both from compressor air and from turbine exhaust gases may be used in sonic drying and impingement flow drying respectively against web surfaces, or for through drying, and in heat exchange relation with steam generators for the provision of process steam in the paper mill, or for the provision of steam to heat conventional dryer cylinders.

While it is not normally feasible to use turbine exhaust gases in stem jet whistles owing to the susceptibility of the whistles to damage from entrained solids and impurities in the exhaust gases, the provision of mechanical gas filters for the removal of such particles is proposed.

In selecting the use of turbine exhaust gases for direct drying contact with a web, the higher cost involved in the use of suitable non-smutting fuels such as natural gas or the lighter fuel oils such as kerosene will be balanced against the cost of providing mechanical exhaust filtering. Alternatively, the introduction of heat exchangers to provide indirect air heating may be necessary, with corresponding cost increase. Chemical treatment of fuel prior to combustion is contemplated as one means of reducing impurities, to improve combustion products.

Where direct use of exhaust gas in drying impingement flow is required suitable mechanical filtering may be effected using exchangeable sintered ceramic filter cartridges. By performing such hot gas filtering after the combustor, before entry to the expansion turbine, the power loss is minimized, owing to reduced air velocities, while secondary air may be bypassed around the filter, to reduce the losses thereat and to minimize the required filter capacity. This arrangement provides the added advantage that the expansion turbine is thus operated on clean gas, with consequently improved serviceability. The temperature drop across the filter can be readily compensated for by operating the combustor at a higher temperature to provide the desired turbine inlet temperature.

By decreasing the turbine pressure expansion ratio to give an exhaust value such as 3.5 to 5 psig (per square inch, gauge) as compared with a more usual value such as 2 psig, the need for additional high volume low pressure gas pumps or blowers in the dryer section may be dispensed with, at considerable savings, while the apparent loss in mechanical efficiency appears as useful exhaust gas heat for subsequent utilization of the gases for the heat recovery portion of the process or indirect drying.

In commenting further on the proposed embodiments for through flow drying, it is pointed out that the air from the compressor is utilized at a pressure of several atmospheres for through drying of the web. This solution suffers a particular disadvantage in the need to provide web enclosures of great weight and rigidity to withstand the considerable forces involved or of blowing outwardly from the interior of a drier drum, while the avoidance of undue shearing forces acting upon the web is also arduous. In addition air leakage at the hood seals and web edges become unduly significant in relation to process efficiency. It can thus be seen that high pressure systems lack practicality whereas the subject invention is directed to a preferred combination of processes in balanced thermal relation.

By supplying relatively highly pressurized gas to a sound generator of the stem jet whistle type, in addition to the application of mechanical dislocation to the moisture content of the web, the pressure drop resulting from the diffusion of air through the whistle devices reduces over-pressure within the sound hood to nearly atmospheric pressure thereby providing acceptable levels for structure economy and practicality. The need to displace the hood from the web for carrying out the web threading operation is an important consideration in this matter of pressure diffusion and the reduction of hood mass consequent therefrom. The use of a compressor of medium efficiency is contemplated, delivering air at a pressure in the range of 15–40 psig to the whistle sound generators. The use of a heat exchanger or air recirculating means to raise air temperature at the compressor inlet from ambient to a value in the range of 80°–140° F promotes efficient sound generation in the stem jet whistles and provides hotter resonated web impingement air, at exit from the whistles. Whistle inlet temperatures in the range from 280°–400° F. are contemplated, using compression heating, with or without additional heating or hot air blending to achieve the desired air temperature.

Certain embodiments of the present invention are described, reference being had to the accompanying drawings, wherein:

FIG. 1 is a diagrammatic representation of a gas turbine and combined web drying arrangement, showing a first embodiment of the subject invention;

FIG. 2 is a similar representation of a second embodiment; and

FIG. 3, appearing with FIG. 1 shows a hot gas filtering arrangement.

Referring first to FIG. 1, the gas turbine installation **10** consists of a compressor section **12**, and gas turbine section **16** mechanically coupled together, and a combustor **14**. An electrical generator **24** or motor-generator is also driven by the turbine **16**, being coupled as by a clutch to the machine and serving the dual function if desired of starter motor or power generator.

The external energy output connections of the gas turbine **10** are represented by an air bleed **20** from a first section **17** of the compressor **12**, and exhaust gas output **22** from the turbine section **16**.

In the FIG. 1 embodiment mechanical energy in the form of compressed air from compressor section **17** passes by way of conduit **20** to sonic drying section **30**, illustrated as being a drum type sonic dryer as disclosed in co-pending application Ser. No. 86,571, Nov. 3, 1970. Thermal energy from the turbine exhaust **22** passes to an impingement type dryer section **40** of a type well known in the art.

Referring initially to the air supply **20**, the provision of preheater **19** to the compressor inlet **21** is used to raise the temperature of whistle supply air. The compressed air supply **20** connects with reheater **31** of the sonic dryer section **30**, the air then passing by way of conduit **32** to the air supply headers **33**. A plurality of headers **33**, of which two are illustrated, extend transversely of drum **35** on which the drying web **36** is supported. A plurality of sonic generators **37**, such as stem jet whistles are spaced along each header **33**, to receive heated compressed clean air therefrom.

Each header **33** is illustrated as serving a trough-like reflector **38** extending for the width of the drum **35**. Secondary low pressure web impingement gas from the reheater **31** passes by way of conduit **41** to impingement air manifolds **42** mounted adjacent the respective reflector troughs **38**, being co-extensive therewith across the web width. From the manifolds **42**, a jet or curtain of air from the inclined slot nozzles indicated diagramatically at **142** sweeps the surface of the moving web in moisture scouring relation, the gas mixture input to the reheater **31** being obtained indirectly from the turbine exhaust **22**, described in detail below. It will be seen that the curtain jet **142** produces gas motion within the reflectors **38**, with gas exhausting from the oncoming edge of the respective reflector in the direction opposite to web motion, thus enhancing boundary clearing at the surface of the web.

The impingement dryer section **40** comprises a drying cylinder or roll **45** illustrated as a non-perforated roll over which the web **36** passes. The use of a perforated roll to provide through drying is also contemplated, as is well known in the art.

The impingement dryer **40** has a cap **46**, a circumferential partition **47** spaced therefrom to define a hot air manifold **49**; an inner, perforate partition **47'** defining with the partition **47** an exhaust manifold **48**, and nozzle tubes **50** extending between the manifold **49** and the annular space **51** extending between the manifold **49** and to adjacent the drum surface, in the impingement dryer zone through which web **36** passes.

Hot gas mixture from the exhaust 22 of turbine section 16 passes by way of replaceable filters 55 to series of gas injectors 56 of the well known type, each having a nozzle and venturi section 57. Hot exhaust gas induces fluid input to the injectors 56, by way of entries 59, 60, representing fresh air intake and process return respectively, the flow thereof being controlled by dampers (not shown) to form a mixture which blends with the exhaust gas to lower the air temperature and promote suitable psychrometric drying conditions. A portion of the blended mixture passes by way of conduit 61 to the dryer high pressure manifold 49, the pressure thereof being controlled by throttling damper 63 in the conduit 61. A further portion of the blended exhaust passes from the injector 56 by way of conduit 65 to heat exchanger 67, and thence to reheater 31 of the sonic dryer 30. The blended exhaust from conduit 65 is cooled in exchanger 67 and further cooled in reheater 31, passing thence by way of conduit 41 to the sonic dryer, as impingement air of suitable psychometric quality.

The heat exchanger 67 receives fresh air by way of inlet 71, which is drawn therethrough by the suction of the injector 56, to which the exchanger 67 connects by way of conduit 73.

Moist exhaust air from the exhaust manifold 48 of dryer 40 passes by way of conduit 75 to the inlet 60 of the injector 56.

The moist exhaust of the sonic dryer 30, which flows along the web in a direction opposite to web travel is removed from the respective cap space 35', possibly for heat recovery in another portion of the total dryer installation.

In general, owing to the more gentle drying action and high throughput of sonic dryers in removing moisture from very wet webs, and the different characteristic of the impingement dryer 40 which better suits operating on dryer webs, it is contemplated that the web 36 passes first through the sonic dryer section 30 and then through the impingement dryer. The provision of steam heat to the drum 45 is not dealt with specifically herein, but one steam raising arrangement using turbine exhaust heat as detailed below may be used alternatively to normal practice. While the compressor 16 is shown having subsequent low pressure and high pressure sections, the use of two separate compressor sections driven by the common shaft is contemplated, for improved flow control of the power turbine compressor, and more flexible utilization in dryer application.

Turning to the second embodiment of the present invention, as illustrated in FIG. 2, the gas turbine 10 is illustrated as being optionally coupled by way of clutch 11 to the generator 24. The pre-heater 19 which is not shown may be used, or an air mixing arrangement may be provided instead utilizing recirculated hot air, to provide seasonal temperature compensation.

In the FIG. 2 embodiment a conventional steam drum dryer section 130 is shown, to which steam is supplied to the drums 133 by way of header 131 from boiler 132. The boiler 132 is shown as being fossil fueled, by way of burners 135, and receives turbine exhaust gas by way of conduit 122 to support combustion and impart heat from the hot incoming gas. Owing to the excess air available in the turbine exhaust such after burning may be practically achieved to generate steam. The boiler exhaust, illustrated as leaving by way of filter 137 passes to series of injectors 156, the output 161 of which supplies impingement dryer 140 for two sided impingement web drying. Flow connections to the top side only of the dryer 140 are shown, the bottom connections being omitted for purposes of clarification. The exhaust outlet 163 from the dryer 140 is partially recycled as blending gas by return to the injector 156. A damper controlled air feed 178 permits the admission of controlled quantities of air to the injector 156. A portion of the injector output is directed by way of conduit 170 to a hood economizer 175, to preheat incoming fresh hood air. The further use of a spray injector to provide hot process water while further cooling this exhaust gas is contemplated.

The exhaust gas branch line 177 having a control throttle therein is proposed to provide motive fluid for an impingement flow process, such as dryer 45 shown in FIG. 1. In this instance, owing to air circulation being carried out without assistance from the injector 156 to remove the moist air passing out of a dryer section (not shown), the operating pressure in the conduit or line 177 is sustained sufficiently above atmosphere that necessary circulation may be maintained.

A particular characteristic of the subject invention is the maintenance of gas turbine exhaust pressure at a sufficient value that provision of auxiliary blowers for moving drying air is substantially eliminated, the apparent loss of efficiency represented by this higher exhaust pressure and the corresponding higher temperature, is recovered in operating and capital costs, while the drying processes may be based on the higher gas temperatures thus made available, thereby recovering the apparent loss of potential thermal energy resulting from the reduced expansion ratio of the turbine section.

In addition to the foregoing utilization, electrical energy from the generator 24 is passed to microwave generators 198, of which only one is shown, to energize a web dryer 200 having opposed microwave transmitters 202. Such additional drying utilization enhances the flexibility and balanced drying made possible using a gas turbine and combined processes, while providing web drying capability particularly suitable for wet streak control, particularly in the case of coated webs but which is usually too costly on a conventional energy cost basis to prove economic. Owing to the high utilization of system internal losses, such that compressor and turbine inefficiencies appears to a large extent as useful process heat, and owing to effective utilization of lower expansion ratio turbine components to provide effective air pumping throughout the drier section, a high total thermal fuel utilization may be achieved in the process.

Referring to FIG. 3, an arrangement for direct filtration of hot cycle gas is illustrated.

In the illustrated embodiment the combustor 314, located intermediate the compressor 310 and expansion turbine 316 is provided with an output filter 329 having a plurality of replaceable plates, which may be of cartridge form.

The combustor 314 receives compressed air by conduit 318, the primary air passing by conduit 320 to the flame tube 315. Bypass air by way of conduit 322 passes control throttle 323 and flows in heat exchange relation about the flame tube 315. A portion of the bypass air may enter the flame tube 315 in known fashion as secondary combustion air, and to cool the flame tube walls.

Hot combustion products pass by way of conduit 327 to the filter 329, and an exit therefrom mixes with heated bypass air from conduit 325, and thence enters the expansion turbine 316 by way of conduit 330.

By appropriate design of the filter or filters 329, which may comprise a plurality of individual filters in parallel or standby relation, servicing of the filter may be effected to provide continuous filter capability. Sintered ceramic filters of sufficient area cross section and porosity are selected to effect the desired degree of combustion product filtration and to ensure acceptable pressure drop valves between the compressor 310 and expansion turbine 316.

The provision of pretreatment of the fuel chemically is contemplated to reduce the formation of combustion impurities. Similarly the use of automatic temperature responsive controls for the bypass throttle 323 is proposed.

It will be appreciated by those skilled in the art that the arrangements are illustrative only, in that the electrical energy may be utilized in dielectric heaters and/or for powering component drives, while the benefits of the invention may be arrived at using different air circulation and heat interchange arrangements.

What is illustrated is the ease and flexibility with which the mechanical output and the thermal output of the gas turbine may be combined in web drying.

It will be understood that steam generated or heated by exchange with the exhaust gas may be used as process steam for purposes other than in dryer roll heating.

Referring again to the FIG. 2 embodiment, it will be understood that substitution of a suction roll for the dryer cylinder, together with a suitable extraction pump exhausting the interior of the roll to provide an appropriate pressure drop of a few inches of mercury across the web thickness will provide effective through drying.

Considering the economics of providing a relatively inefficient gas turbine exhausting at slightly higher than usual pressure, in addition to cost savings for the turbine, the resulting increase in exhaust gas temperature and pressure reduces or eliminates the need for auxiliary gas pumping equipment and also reduces the size of heat exchangers necessary for steam generation from the exhaust gases. The overall utilization of energy of up to 70–80 percent of the fuel energy input is contemplated, while the acceptability of lower power conversion efficiency in the gas turbine reduces the machine maintenance requirements.

In the case of the extraction of gaseous media as for instance the partial evacuation of a suction roll for web through drying, the use of pressurized turbine fluid in combination with injectors of the type illustrated, connected with the roll interior, is contemplated for webs of high permeability.

In cases where paper quality precludes the direct impingement of exhaust gases on the web surface, either the use of heat exchangers or effective exhaust gas filtration is proposed.

In addition to the economic cost benefits in providing mechanical, electrical and heat energy at low cost, the subject invention is particularly meritorious in the flexibility of low cost high speed drying made possible, including particular capability in web streak control, by suitable combination of drying methods.

In addition to utilizing electrical energy generated by the gas turbine for dielectric heating, the use of microwave energy utilizing a lossy media to generate heat in the web is contemplated.

It will be understood that the attainable overall process efficiency depends upon full utilization of energy available from the two aspects of machine output. By selecting lower expansion turbine efficiency, say in the order of 18 percent for the previously disclosed reasons, then mechanical energy output available to the combined drying process is so limited, for use in the disclosed modes. Owing to the characteristic performance of sonic drying when so energized this still permits approximately one half of the drying to be accomplished, at relatively low energy requirements. The thermal load portion of the drying process can then absorb the corresponding thermal power of say 70 percent of total energy input, based on an assumed 12 percent for duct and other non-recoverable losses of the system.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. Web drying apparatus comprising a gas turbine machine, pre-heater means to raise the temperature of air entering a compressor portion of the machine, air bleed means to extract uncombusted air from the compressor, sonic actuated web drying means receiving the extracted air for energization in moisture dislocating operation relative to a travelling web, and gaseous impingement web drying means, means to pass exhaust gas from a turbine portion of the machine to the impingement drying means, and heat interchange means for controlling the psychrometric condition of gaseous fluid impinging on a said web.

2. Apparatus as claimed in claim 1 including gaseous induction means to induce flow of web conditioning gaseous fluid.

3. Apparatus as claimed in claim 1 including electrical generating means powered by said turbine machine, and web drying apparatus energized thereby.

4. Apparatus as claimed in claim 1 including hot gas filter means to filter post-combustion gases prior to utilization thereof in a said drying means.

5. Apparatus as claimed in claim 1 including hot gas filter means interposed between a combustor portion of said machine and said turbine to remove impurities of a predetermined size range from said hot gas before admission of the gas to the turbine.

6. The method of utilizing a gas turbine machine, having a compressor section, a combustor section and a turbine section, in the drying of an air permeable web comprising the steps heating air prior to entry into the compressor section; raising the temperature and pressure of the air within the section; passing a portion of thus heated air from the compressor section to sound generating means arranged in web drying relation adjacent the path of a moving web, to generate a sonic field of sufficient intensity to dislocate moisture within the web; passing hot exhaust gas from the turbine section in impinging relation against the web, and controlling the psychrometric state of a gaseous fluid before passage thereof in impinging relation on said web.

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