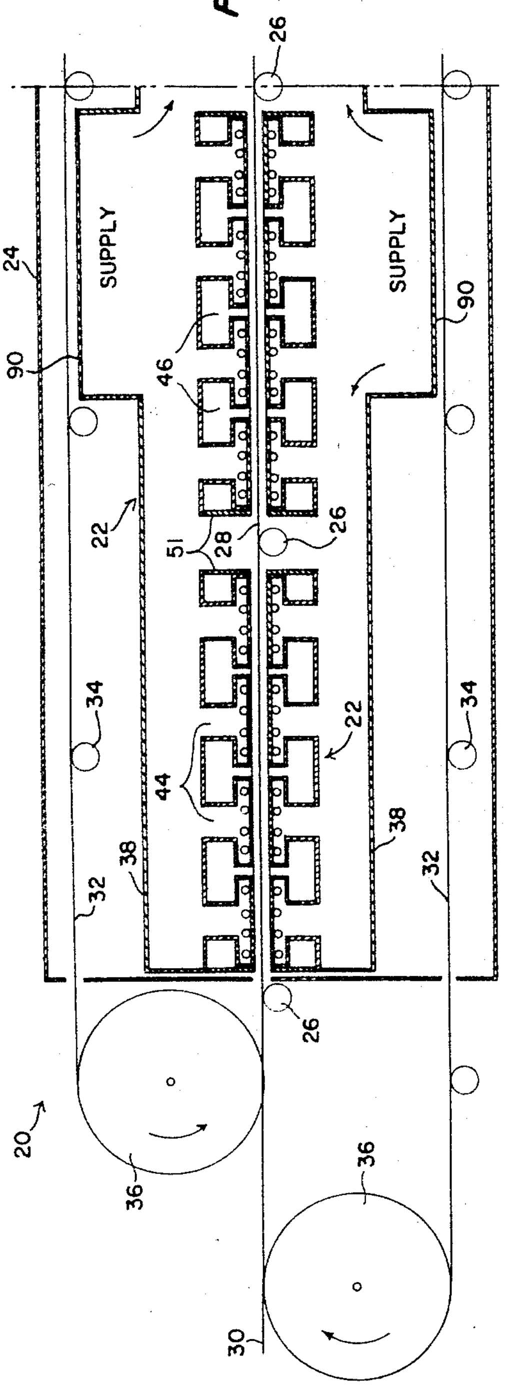
Aug. 12, 1969 H. L. SMITH, JR **3,460,265**

METHODS OF DRYING

Original Filed Feb. 14, 1967 5 Sheets-Sheet 1

FIG. 1A



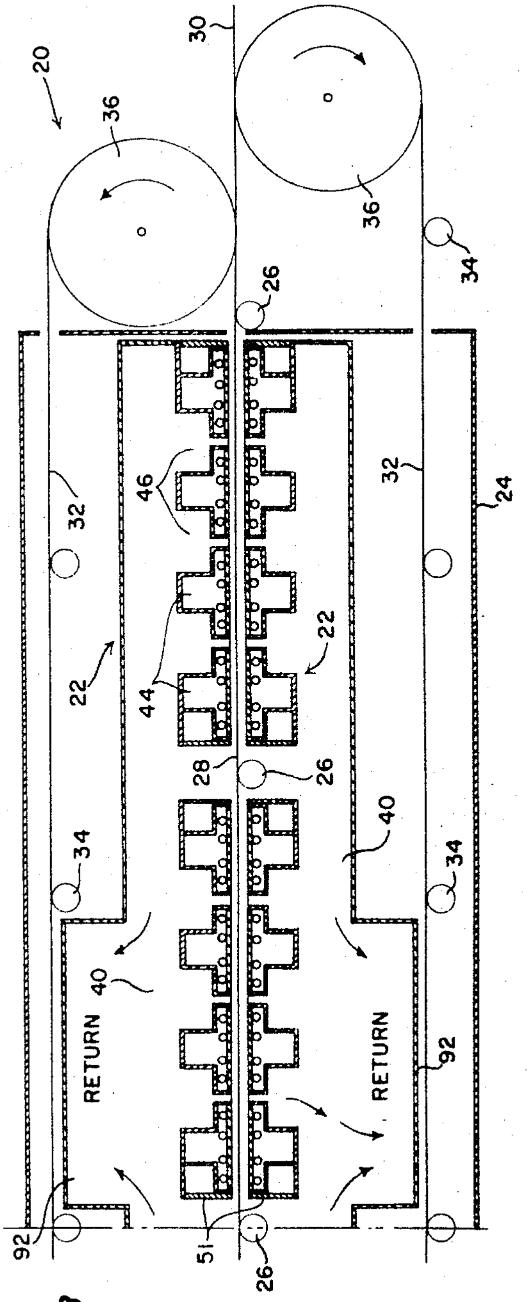


FIG. 1B

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METHODS OF DRYING

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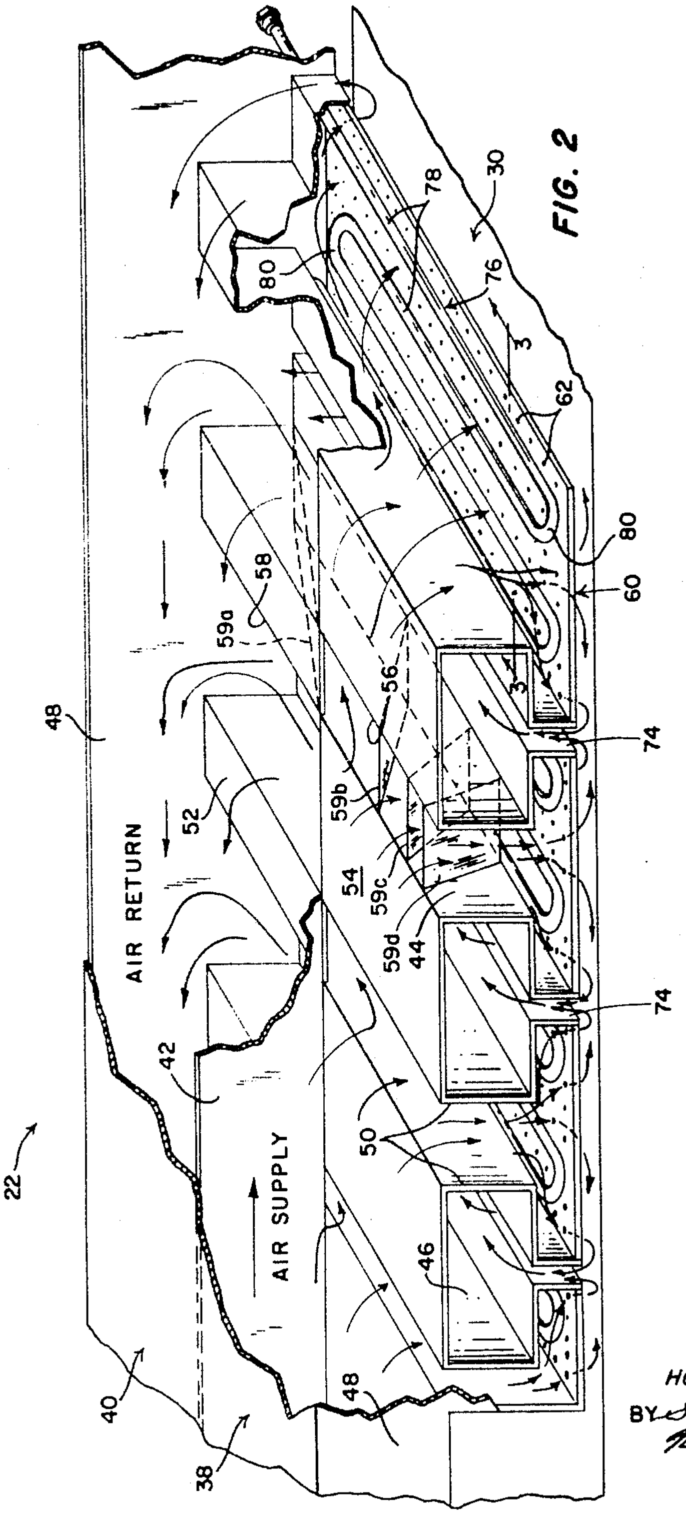

FIG. 2

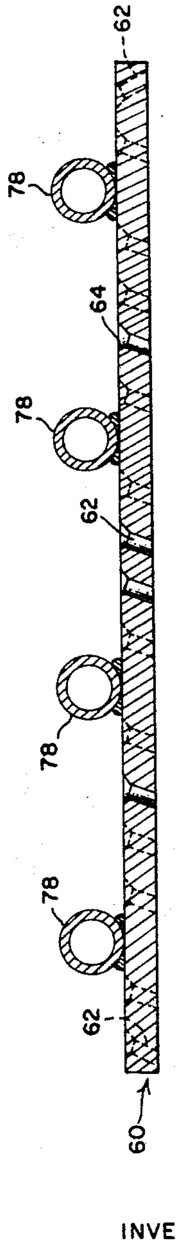

FIG. 3

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METHODS OF DRYING

Original Filed Feb. 14, 1967 5 Sheets-Sheet 3

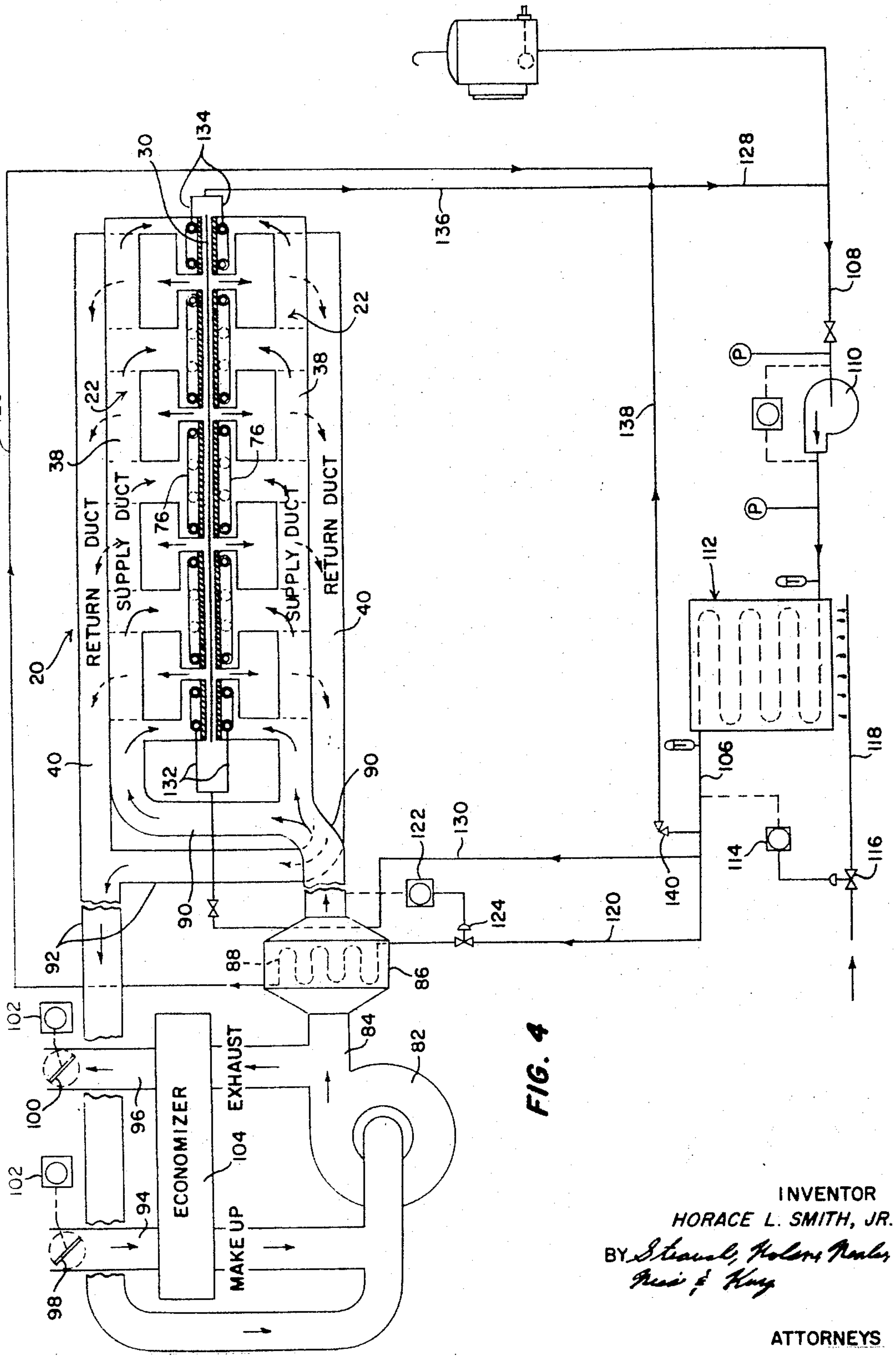

FIG. 4

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METHODS OF DRYING

Original Filed Feb. 14, 1967 5 Sheets-Sheet 4

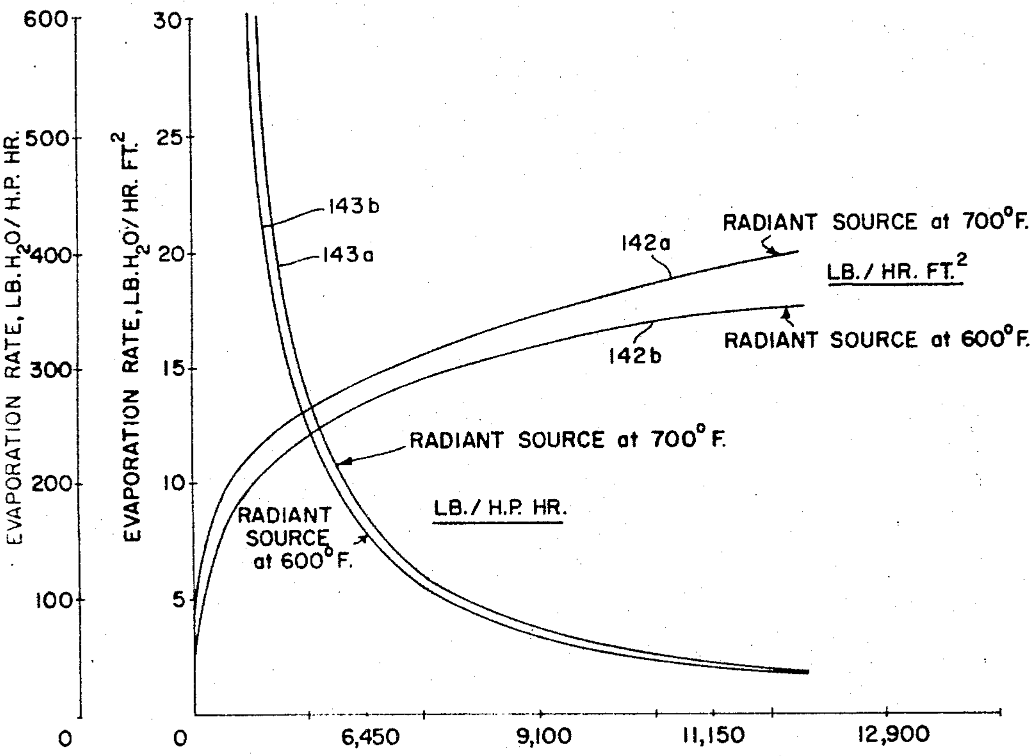

FIG. 5

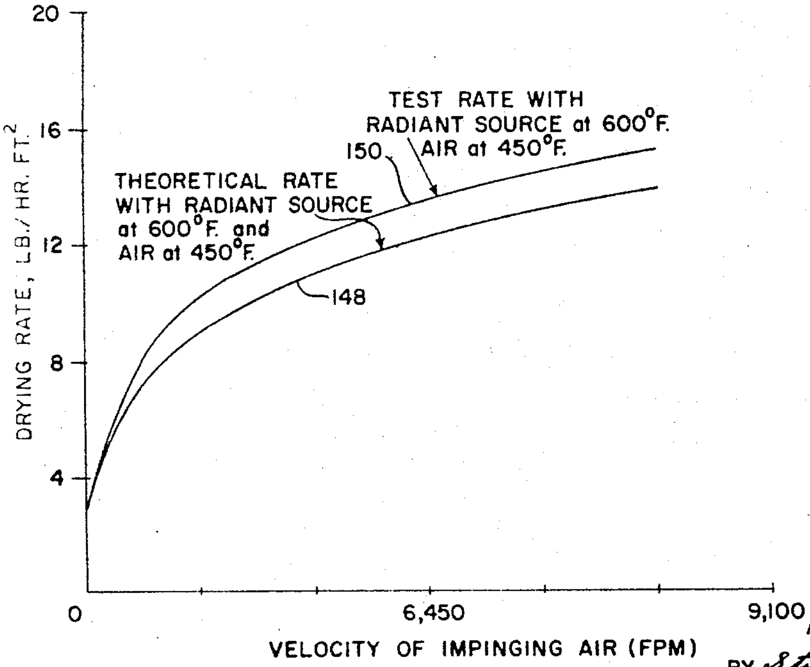

FIG. 7

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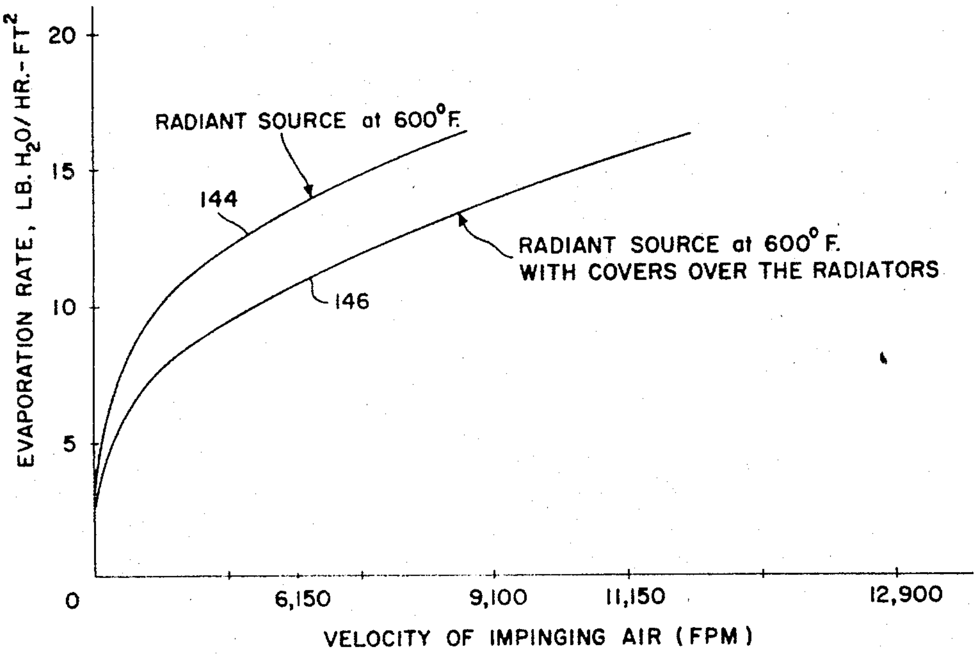

FIG. 6

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United States Patent Office

3,460,265

Patented Aug. 12, 1969

3,460,265

METHODS OF DRYING

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Original application Feb. 14, 1967, Ser. No. 615,966, now Patent No. 3,403,456, dated Oct. 1, 1968. Divided and this application Aug. 23, 1968, Ser. No. 754,928
Int. Cl. F26b *3/04, 3/28, 13/04*
U.S. Cl. 34—1 11 Claims

ABSTRACT OF THE DISCLOSURE

Methods of drying web, sheet, and similarly configured material by the impingement of a fluid medium and, if desired, the combination of radiant heating with fluid impingement.

Cross reference to related application

This application is a division of application No. 615,966 filed Feb. 14, 1967, which is now U.S. Patent No. 3,403,456.

Background and summary of the invention

The present invention relates to drying and, more specifically, to methods of drying material of sheet, web, and similar configurations.

One method of drying materials related to that which I have developed is disclosed in U.S. Patent No. 3,199,213 issued Aug. 10, 1965, to F. H. Milligan et al., for Method of Changing the Moisture Content of Wood. In one aspect, my novel method differs from Milligan's in the use of radiant energy plus fluid impingement instead of impingement alone. I have found that the combination of radiation and fluid impingement produces significant increases in drying rates in comparison to those obtained with impingement alone. In fact the increase is appreciably greater than would be obtained if the effects of impingeemnt and radiant heating were additive. This indicates that a combination of radiation and fluid impingement in accord with the present invention has a synergistic effect on the drying of web and sheet materials, particularly those which are difficult to dry.

In conjunction with the foregoing the increased drying rates provided by the present invention produce a decrease in the time for which the product being dried is retained in the dryer. This permits a reduction in the size of the dryer needed, resulting in a saving in initial equipment costs as well as savings in installation costs and in the costs of a structure for sheltering the drying apparatus. Accordingly, the increase in drying rates provided by the present invention is accomplished by a considerable decrease in initial costs.

Another important difference between the drying process disclosed herein and that disclosed in the Milligan patent is in the impingement of the air or other treating fluid on the material being treated at an angle having a component in a direction opposite to the direction of movement of the material rather than normally as in the Milligan process. The inclination of the flow apertures at an angle to the material being treated and the inclination of the apertures in a direction opposite to that of material movement increase the capability of the fluid for scouring evolved volatiles away from the surface of the material being treated. Accordingly, this flow aperture arrangement also produces increased efficiency.

There is yet another advantage of inclined jets over those oriented normally to the material being dried. Specifically, the latter produce a pattern of pressure distribution in the fluid treating medium which tends to make the web or sheet being dried flutter or drift. This

problem can be at least substantially eliminated by the use of properly inclined flow apertures.

In conjunction with the foregoing, part of the treating fluid is so directed toward the material being treated that it has a velocity component directed toward the inlet to the exhaust structure for removing spent fluid, evolved volatiles, etc.

This is an important practical feature of the present invention since the fluid will assist in effecting a flow of spent fluid, evolved volatiles, etc. into the exhaust structure, increasing the operating efficiency of the apparatus involved.

From the foregoing it will be apparent that the primary object of the present invention resides in the provision of novel improved methods of drying materials with sheet, web, and similar configurations.

Other objects, additional important features, and further advantages of the present invention will become apparent from the appended claims and as the ensuing detailed description and discussion proceeds in conjunction with the accompanying drawing.

Detailed description of the drawing

In the drawing:

FIGURES 1A and 1B together constitute a partially diagrammatic longitudinal section through a dryer adapted to dry web, sheet, and other materials in accord with the principles of the present invention;

FIGURE 2 is a partial and partly broken away isometric projection of a fluid impingement and radiant heating unit employed in the dryer of FIGURE 1;

FIGURE 3 is a section through a flow plate incorporated in the unit of FIGURE 2;

FIGURE 4 is a diagrammatic illustration of a system for supplying fluid to and exhausting it from the impingement and radiant heating units in the dryer of FIGURE 1 and of a system for heating the fluid and the radiant heaters in the foregoing units;

FIGURE 5 is a chart showing the relationship for an exemplary material being dried between the velocity of the fluid supplied to the drying apparatus of FIGURE 1 on one hand and the amount of water evaporated per blower horsepower hour and per square foot of radiant energy emitting surface on the other;

FIGURE 6 is a chart showing the contribution made by radiant energy in drying materials in accord with the principles of the present invention; and

FIGURE 7 is a chart showing the synergistic effect of combined impinging fluid and radiant energy on drying rates.

Description of an exemplary preferred embodiment

Referring now to the drawing, FIGURES 1A and 1B depict a single pass dryer **20** having fluid impingement and radiant heating units **22** for drying the product to be treated in accord with the principles of the present invention. Dryer **20** also includes a casing **24**, a series of parallel, spaced apart, rotatably mounted rolls **26** establishing a path **28** for the product or material being dried, which is in the form of a web **30**, and endless, open mesh belts or felts **32** which confine and prevent warpage of web **30**. Conventional idler rolls **34** and drive rolls **36** are also provided to support and effect movement of belts **32**. Except as discussed below the dryer components are of conventional construction and will not be described further herein.

As shown in FIGURES 1A and 1B, units **22** are located between adjacent rolls **26** and on both sides of path **28** to dry web **30** by simultaneously applying radiant heat to both sides of the web to evolve volatiles from it. Units **22** also direct air or other treating fluid at high velocity into contact with the sides of the web to assist in evolving the volatiles and to scour away evolved volatiles from adjacent its surfaces. The high velocity fluid thus prevents retardation of the drying process by eliminating the formation of a stagnant layer adjacent the web and, in addition, causes evaporative cooling adjacent the surfaces of the material being treated and thereby prevents it from being overheated. It is preferred that the treating fluid also be heated, preferably to a temperature typically on the order of 250 to 700° F., since a hot, high velocity fluid such as air is a highly effective drying agent.

Referring now to FIGURE 2, each of the novel fluid impingement and radiant heating units **22** incorporated in dryer **20** includes a main duct pair consisting of elongated main supply and return ducts **38** and **40** separated by a dividing wall **42**. The main ducts **38** and **40** extend lengthwise of dryer **20**.

Each of the units **22** also includes a number of generally T-sectioned branch supply and return ducts **44** and **46** extending transversely across the associated main supply and return ducts **38** and **40**. The main and branch ducts are in part integral in that the side walls **48** of the main ducts form the end walls for the branch ducts.

The branch ducts are also defined by co-operating, generally Z-sectioned side wall members **50** disposed in parallel, spaced apart relationship and so arranged that each side wall member is disposed in mirror image relationship to the side wall members **50** on either side of it. This results in an array of adjoining, internested ducts with branch supply and return ducts being alternated. At the ends of the units the open sides of ducts thus formed are closed by wall members **51** (see FIGURES 1A and 1B).

Branch supply and return ducts **44** and **46** also include top walls **52** and **54**. As shown in FIGURE 2, the top walls **52** of the branch supply ducts span only those parts of the ducts adjacent main return duct **40**, and the top walls **54** of branch return ducts **46** similarly span only those portions of the return ducts overlaid by main supply duct **38**. Thus, the branch duct top walls prevent fluid from flowing between the branch supply ducts and main return duct and between the branch return ducts and main supply duct. The elimination of the top wall members from the remaining portions of the branch ducts provides communication between the branch and main supply ducts **44** and **38** through openings **56** which are generally equal in length to the width of the main supply duct and similar openings **58** provide communication between the branch and main return ducts.

Preferably, air vanes or other air distributors are employed in branch supply ducts **44** to provide a generally uniform distribution of the treating fluid over the span of the impingement units and, accordingly, over the span of web **30**. One exemplary (but by no means the only) distribution arrangement which may be employed is illustrated in FIGURE 2. This arrangement, which is capable of equalizing distribution of the treating fluid with only a relatively low pressure drop, includes a set of four vanes **59***a–d* in each branch supply duct (only one set of vanes is shown). Vanes **59***a–d* divide the flow of incoming fluid into segments which have a predetermined relation to the areas over which they are to be distributed and divert the segments of flow to the points at which the fluid is discharged against web **30**. By dimensioning and positioning vanes **59***a–d* in accord with available techniques, a generally uniform distribution of fluid across the span of the supply duct can be provided. Equalization of fluid distribution can be obtained to any degree required, generally speaking, by increasing the number of distributor vanes.

The fluid supply arrangement just described minimizes resistance to fluid flow and produces a discharge of fluid from the branch supply ducts which is substantially uniform over the entire width of web **30** and a similar uniform flow of spent treating fluid and/or evolved volatiles from adjacent the web into the branch return ducts. This results in uniform treatment of web **30** across its entire width and, consequently, the production of a highly uniform treated product.

The minimization of flow resistance in the impingement units by the structure described above also reduces to an appreciable extent the power required to circulate the fluid treating medium through the units **22**. This is, of course, a significant advantage in that it reduces the size of the blower required with a consequent reduction in both initial and operating costs. In fact, the fan horsepower requirements of drying apparatus in accord with the present invention are only 10–20% of those of the wood veneer dryers most widely used at the present time.

Air or other treating fluid is accelerated and directed at high velocity (typically on the order of 2000–15,000 feet per minute) against web **30** by flow plates **60** which form the outer or exposed walls of branch supply ducts **44**. Flow apertures **62** (see FIGURES 2, 3, and 6A) are drilled in a predetermined pattern through each of the flow plates **60** with the inlets **64** to apertures **62** preferably being chamfered as shown in FIGURE 3 to prevent the formation of vena contracta in the apertures.

One of the important features of the present invention resides in drilling flow apertures **62** so that the fluid exiting through them impinges upon web **30** at an angle rather than normally as in the conventional arrangement. In the latter the normal impingement of the treating fluid on the web results in instability, drift, and flutter as the web moves at high speed past the flow plate.

By inclining the flow apertures at an angle to the web a velocity and pressure distribution pattern which will result in minimization of flutter can be produced. Also, the arrangement just described virtually eliminates areas in which the flow velocities are too low to produce the desired scouring effect. Thus there is more uniform treatment of the material in the present invention than in the conventional arrangement described above.

This arrangement is particularly important in dryers of the type shown in FIGURES 1A and 1B in which impingement units are located on both sides of the web since, in this type of arrangement, the instability caused by one flow plate is apt to reinforce that caused by the other, materially aggravating flutter and drift and lack of stability in the web.

Also, as shown in FIGURE 3, the majority of the flow apertures **62** in flow plate **60** are so oriented that the treating fluid discharged from them impinges upon web **30** in a direction opposite to the direction of movement of the web. As a result, the velocity of the web and the velocity component of the treating fluid in a direction parallel to the web are additive. Thus, for a given velocity of fluid flow through apertures **62**, a greater effective velocity can be obtained by the preferred orientation than by using the conventional arrangement.

Also, the flow arrangement just described produces greater turbulence than would be obtained if the treating flued impinged on the web at right angles to the direction of movement of the web. The net result of the foregoing factors is that treating fluid impinging on the web in the manner just discussed has a significantly greater scouring action than could be obtained if the fluid impinged upon the web at right angles or in the direction of web movement.

Referring again to FIGURE 2, the spent treating fluid, together with its burden of evolved volatiles, flows into branch return ducts **46** through inlet apertures **74**. These extend the length of the branch return ducts and accordingly minimize the resistance to the flow of the treating fluid and evolved volatiles in to the return ducts. Moreover, since the exhaust openings span the material there is virtually no lateral flow of the spent fluid and evolved volatiles. This is important since, as indicated above, lateral flow of the fluid and volatiles can produce variations in drying conditions across the sheet and, accordingly, a nonuniform product.

Referring now to FIG. 2, each of the flow plates **60** (except for those on the ends of impingement units **22**) is located between the inlets **74** to two successive branch ducts; and the rows of flow apertures **62** adjacent each of the branch duct inlets are so oriented that the treating fluid discharged from them is inclined toward the branch duct inlets. This is another important feature of the present invention since the fluid discharging toward the inlet ducts tends to force the spent fluid and evolved volatiles adjacent web **30** through inlets **74** into branch return ducts **46**. As shown in FIGURE 3, these nozzles are preferably inclined at a somewhat greater angle to the surfaces of the flow plates than the remaining apertures to increase the effect just discussed.

While a uniform distribution of the treating fluid across the span of web **30** is normally provided by uniformly spacing flow apertures **62** the length of flow plate **60**, controlled nonuniform distribution of the treating fluid can be provided by an appropriate nonuniform spacing of the flow apertures, where desired.

The flow apertures will typically be drilled through the flow plate at an angle of 15°. The total area of the openings will normally be from 1.25 to 4% of the total area of the plate and may even be a lower percentage of the total plate area.

It will be apparent, from the foregoing, that volatiles may be evolved from web **30** merely by effecting a flow of air or other treating fluid at high velocity and high temperatures through flow plate **60** into contact with the material being dried. However, in the preferred embodiment of the present invention, volatiles are evolved much more rapidly, thereby materially increasing the efficiency of units **22**, by heating flow plates **60** to temperatures above that of the treating fluid so that emission of radiant energy in the infrared portion of the electromagnetic spectrum from the plates will be enhanced. Thus, the material being treated will also be dried by radiant energy as well as impinging fluid.

In the fluid impingement and radiant heating unit **22** illustrated in FIGURE 2, this is readily and simply accomplished by welding or otherwise fixing tubular type heaters **76** in heat conductive relationship to the inner or back sides of the flow plates as shown in FIGURE 3. Each heater **76** consists of a plurality of parallel, spaced apart, straight legs **78** extending longitudinally of the associated flow plate **60**. The legs **78** are connected by end bends **80** alternately located at opposite ends of the associated flow plate.

If they are to be employed as sources of radiant energy, the flow plates will preferably be fabricated of a material which is a good thermal conductor and has a relatively high coefficient of emission yet can be drilled and welded without undue difficulty. One satisfactory material is sheet steel.

To increase the absorptivity of heat from tubular heaters **76** and the emissivity of the flow plates, the surfaces of the latter may be covered with a high emissivity coating. A number of satisfactory coatings are described in my Patent No. 3,262,494 issued July 26, 1966, for Heat Exchangers.

Referring next to FIGURES 1A, 1B, 2, and 4, the treating fluid is supplied to the main supply duct **38** in each unit **22** by a blower **82** connected through a duct **84** to a fluid heater **86**. As it flows through the fluid heater, the treating fluid is heated by a heat exchanger **88**. From heater **86**, the fluid flows through supply trunks **90** into the main supply ducts **38** of units **22** and then into branch supply ducts **44**. Similarly, the spent treating fluid and its burden of evolved volatiles flows from the branch return ducts **46** of the various units **22** through ports **58** into the associated main return ducts **40**, which are displaced from their normal position adjacent supply ducts **38** in FIGURE 4 for explanatory purposes. From these ducts, the spent fluid and its burden flows into a schematically illustrated return trunk identified by reference character **92** in FIGURE 4.

In the present invention, return trunk **92** is preferably connected to the inlet of circulating blower **82** so that the spent treating fluid may be recirculated through the system. This eliminates the loss of sensible heat which would result if the spent fluid were discharged from the system.

In many applications of the present invention, such as in the drying of paper or other cellulosic products, for example, the percentage of moisture or other volatiles in the treating fluid must be closely controlled to produce the desired characteristics in the treated product. To permit such control, return trunk **92** is provided with a make-up duct **94**; and a vent duct **96** branches from the duct **84** between blower **82** and fluid heater **86**. Valves **98** and **100** control the flow through make-up and vent ducts **94** and **96**, respectively. By adjusting valves **98** and **100**, recirculated fluid can be discharged from the system and replaced with fluid having a lower content of volatiles to maintain tthe volatile content at the desired level, Valves **98** and **100** may be adjusted manually or, if desired, may be automatically adjusted by diagrammatically illustrated controllers **102** of any suitable type or by a system of the type described in my Patent No. 3,208,158 issued Sept. 28, 1965 for Dryers.

An economizer **104** of conventional construction may be connected between the vent and make-up ducts to extract sensible heat from the vented fluid and add it to the make-up fluid, if desired. This recovers otherwise wasted heat, increasing the efficiency of the drying system.

Referring still to FIGURE 4, the heat exchanger **88** in fluid heating unit **86** and heaters **76** are all of the type through which a heated fluid heat transfer medium is circulated to elevate them to the desired temperature. The preferred heat transfer mediums are high boiling point organic liquids and eutectic mixtures of inorganic salts, which can be circulated at extremely high temperature in liquid form. Suitable media of this type are discussed in detail in Patent No. 3,262,494.

The advantage of employing liquid heat transfer media is that the radiant treating fluid may be heated to temperatures of several hundred degrees Fahrenheit without the problems appurtenant to the extreme pressures associated with high temperature steam.

The system illustrated in FIGURE 4 for heating and circulating the liquid heat transfer medium includes a storage tank (not shown) from which the liquid can be pumped to the main circulation system. This includes main supply and return conduits **106** and **108** and is a closed loop through which the liquid is circulated by a pump **110**.

From main return conduit **108** the heat transfer liquid flows into a liquid heating unit **112** where it is heated to the desired temperature. This unit may be of any desired construction and preferably includes a temperature responsive controller **114** which so regulates the flow of fuel to the heating unit through valve **116** and conduit **118** as to maintain the temperature of the heated liquid flowing into main supply conduit **106** substantially constant.

From main supply conduit **106**, part of the heated liquid flows through branch supply conduit **120** to the heat exchanger **88** in fluid heater **86**. The volume of flow through conduit **120** is controlled by temperature responsive controller **122**, which is connected to a valve **124** in conduit **120** and has a sensor (not shown) in supply trunk **90**. Controller **122** regulates valve **124** so as to maintain the temperature of the treating fluid flowing into the supply trunk substantially constant. From fluid heating unit **86**, the heat transfer liquid flows through return conduits **126** and **128** back into main return conduit **108**.

The remainder of the heat transfer liquid flowing through main supply conduit **106** is diverted through supply conduits **130** and **132** to the heaters **76** in fluid impingement and radiant heating units **22** of dryer **20**. From heaters **76** the heat transfer liquid flows through conduits **134** and **136** and the forementioned return conduits **128** and **108** back to heating unit **112**.

The heat transfer liquid circulation system also includes a bypass conduit **138** connected between supply conduit **106** and return conduit **128**. A pressure relief valve **140** in bypass conduit **138** insures continued flow under abnormal conditions such as conduit blockage and therefore prevents such abnormal conditions from causing damage to the system.

Further details and the advantages of the foregoing heating and circulating system are described in U.S. Patent No. 3,236,292 issued Feb. 22, 1966, for Dryers and copending application No. 537,132 filed Mar. 24, 1966, for Apparatus and System (now U.S. Patent No. 3,395,487), which are incorporated herein by reference.

As mentioned briefly above, the dryers of the present invention represent an advance in the art in that they are capable of efficiently drying materials which have heretofore been recognized as difficult to dry. Among these are wood veneers which can be dried only with difficulty because of their thickness and because of the tenaciousness with which moisture is retained in the wood fibers. However even wood veneers can be readily and uniformly dried by the combination of radiant heat and high velocity impinging air provided by the dryers of the present invention. For example, pine veneers as thick as 3⁄16" have been successfully dried in accord with the present invention in approximately 6¼ minutes. In constrast, in present commercially used dryers, as much as 25–30 minutes may be required to satisfactorily dry 3⁄16" veneers.

The foregoing is not to be taken as meaning that no benefits are realized by employing the principles of the present invention in the drying of materials which are more readily handled by conventional techniques. On the contrary, the following exemplary tabulations shows that significant increases in drying rates and corresponding decreases in retention time can also be obtained in employing the principles of the present invention to dry materials which, in comparison to wood veneers, are less difficult to dry.

Drying rates for kraft carton linerboard

Industry average: [1]
  Water evaporated=2.3 lb./hr./sq. ft. of dryer surface
Best reported performance: [1]
  Water evaporated=3.8 lb./hr./sq. ft. of dryer surface
Present invention:
  Water evaporated=13.2 lb./hr./sq. ft. of dryer surface

Drying rates for pulp, unbleached kraft

Industry average: [2]
  Water evaporated=1.2 lb./hr./sq. ft. of dryer surface
Best reported performance: [2]
  Water evaporated=2.1 lb./hr./sq. ft. of dryer surface
Present invention:
  Water evaporated=8 lb./hr./sq. ft. of dryer surface

For drying wood veneers and similar materials radiator temperatures of 300–700° F. are preferably employed to provide radiant energy peaking in the range of about 6.9 to 4.5 microns. The impinging air will typically be heated to temperatures of 400–700° F.

For other materials different radiator and air temperatures may prove more satisfactory. Also, the final moisture to which the product is to be dried will influence the temperature of the air. For example, if cellulosic materials such as cotton linters are to be dried to moisture contents such as 5%, which is very low, air temperatures may have to be reduced to as low as 345° F. to prevent heat damage to the product. On the other hand, for a residual moisture content of 25%, air heated to temperatures as high as 525° F. may be used without danger of overheating. The most appropriate air temperature in a given set of circumstances can be readily ascertained by test drying samples of the material involved. In any event radiator temperatures will normally be in the range of 400–700° F. or higher, and air temperatures will normally be in the range of 250–700° F.

Air having a low moisture content (less than 0.4 pound of water pound of dry air) or "dry" air is preferably employed in the practice of the present invention. Contrary to what might be expected from the numerous statements in the literature regarding the increase in drying capacity and thermal efficiency that can be obtained by increasing the moisture content of air, it has been found that increases in drying rates are not obtained by increasing the moisture content of the drying air in the practice of the present invention.

Furthermore, it has been found that air having a high moisture content will damage the product being dried even while the product still has a high moisture content. In fact, in one actual test in which the air had a relatively high moisture content but a moderate 400° F. temperature, heat damage occurred at a point where the moisture content of the sample was still 200% by weight of the dry weight of the sample. In contrast, material can be dried to moisture contents as low as 5%–10% without damage in dryers embodying the present invention if dry or relatively dry air and the moderate temperature mentioned above are utilized.

Typically, the impingement velocity of the drying air employed in accord with the present invention will be on the order of 2,000–15,000 feet per minute as mentioned above. Even higher velocities may be beneficially employed in certain applications, however, to increase the scouring and evaporative cooling effect. The only significant limitations on this velocity are the ability of the material being treated to withstand the impact of the fluid and the expense of providing and operating equipment capable of delivering fluid at extremely high velocities.

In conjunction with the foregoing, curves **142*a*** and **142*b*** of FIGURE 5 illustrate that drying rates do increase significantly with increases in impingement velocities. However curves **143*a*** and **143*b*** of the same figure show that the increase in impingement velocity is also accompanied by a marked decrease in the pounds of water evaporated per horsepower hour required to circulate the high velocity air as impingement velocities reach high levels. This of course means that, as the air velocity is increased, there is a corresponding increase in operating costs. For any given application, therefore, a compromise must be made between drying rates and the cost of drying the product involved.

The test conditions for producing the results charted in FIGURE 5 were as follows:

Material dried	⅛" thick green pine veneer.
Radiant energy source	600° F. (4.9μ), 700° F. (4.5μ).
Air temperature	450° F.
Specific humidity of air	0.4 pound of water per pound of dry air.
Air velocity	0→10,000+ f.p.m.
Drying time	1½–3 minutes.
Initial moisture content	110% by weight of the dry wood.
Final moisture content	5% by weight of the dry wood.

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[1] The source of these figures is TAPPI Data Sheet 155D.
[2] The source of these figures is TAPPI Data Sheet 155A.

As mentioned previously, the drying rates produced by the combination of radiant heat and high volecity drying air are substantially higher than those obtainable by using high velocity air alone. To demonstrate this a cellulosic material was dried with a combination of dry air at a temperature of 450° F. and radiant energy from a source at a temperature of 600° F. The test results are shown by curve **144** in FIGURE 6.

The test was then repeated under the same conditions except with the radiation emitting flow plates covered to substantially block the transmission of radiant heat from them to the material being dried. The results of the second series of tests are shown by curve **146** in FIGURE 6.

A comparison of the two curves shows the substantial contribution made by radiant energy when employing it in combination with high velocity air in accord with the present invention.

In conjunction with the foregoing, the driving rates produced by the combination of radiant heat and high velocity impingement air preferably utilized in the dryers of the present invention are, surpisingly, significantly greater than would be expected from adding the theorectical drying rates of radiant heat alone and high velocity air alone. This is apparent from FIGURE 7 in which curve **148** shows the calculated drying rates for a 600° F. radiant source and 450° F. air over a velocity range of 0 to approximately 8000 f.p.m. This was computed by measuring the drying rate with both the air and the radiant source at a temperature of 450° F. and then adding the increment of radiation derived from subtracting the radiation corresponding to a 450° F. temperature from that associated with a 600° F. temperature. Curve **150** shows the results actually obtained. Over substantially the entire velocity range the actual drying rates are considerably higher than the calculated rates.

For example, at an impingement velocity of approximately 4000 f.p.m., the actual drying rate is about 9% greater than the theoretical rate predicted by adding the calculated drying effects of the radiant energy and the impingement air. Accordingly, the combined use of radiant heat and fluid impingement in accord with the present invention is highly advantageous, especially where maximum rates are desired or the product is difficult to dry.

Many modifications may of course be made in the exemplary embodiment of the invention described above without exceeding its scope.

Probably the most important of these is the drying of the material being treated from one side rather than both sides as in the embodiment of FIGURES 1A and 1B. Unexpectedly, it has been found that drying rates obtained by drying from one side are up to 70% as high as those attained by drying material from both sides. Accordingly, it may in many if not most applications be more economical to dry materials from one side only.

Furthermore, the foregoing modification permits significant reductions to be made in the complexity of the drying apparatus, considerably reducing the capital investment required for a plant of given capacity.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed and desired to be secured by Letters Patent is:

1. A method for drying relatively thin sheet and weblike products in a combination radiation and convection type dryer comprising the steps of moving the product to be dried through said dryer; directing radiant energy having wave lengths peaking in the range of from about 4.5 to about 6.9 microns against the product being dried as it moves through the dryer to evolve moisture therefrom; and simultaneously directing against said product at a velocity of at least about 2000 feet per minute a substantially uniformly distributed flow of a fluid heated to a temperature in the range of 250–700° F. to assist in evolving moisture from the product being dried and to scour away from the surface of said product the moisture evolved therefrom.

2. A method for drying relatively thin sheet and weblike products in a combination radiation and convection type dryer comprising the steps of moving the product to be dried through said dryer; directing radiant energy having wave lengths peaking in the range of from about 4.5 to about 6.9 microns against the product being dried as it moves through the dryer to evolve moisture therefrom; and simultaneously directing against said product at an acute angle thereto, and in a direction opposite to the direction of movement of the product a substantially uniformly distributed flow of a fluid heated to a temperature in the range of 250–700° F. to assist in evolving moisture from the product being dried and to scour away from the surface of said product the moisture evolved therefrom.

3. A method for drying relatively thin sheet and weblike products in a combination radiation and convection type dryer comprising the steps of moving the product to be dried through said dryer; directing radiant energy having wave lengths peaking in the range of from about 4.5 to about 6.9 microns against the product being dried as it moves through the dryer to evolve moisture therefrom; and simultaneously directing against said product at an acute angle thereto, in a direction opposite to the direction of movement of the product, and at a velocity of at least about 2000 feet per minute a substantially uniformly distributed flow of a heated fluid to assist in evolving moisture from the product being dried and to scour away from the surface of said product the moisture evolved therefrom.

4. A method for drying relatively thin sheet and weblike products in a combination radiation and convection type dryer comprising the steps of moving the product to be dried through said dryer; directing radiant energy having wave lengths peaking in the range of from about 4.5 to about 6.9 microns against the product being dried as it moves through the dryer to evolve moisture therefrom; and simultaneously directing against said product at an acute angle thereto, in a direction opposite to the direction of movement of the product, and at a velocity of at least about 2000 feet per minute a substantially uniformly distributed flow of a fluid heated to a temperature in the range of 250–700° F. to assist in evolving moisture from the product being dried and to scour away from the surface of said product the moisture evolved therefrom.

5. The method of claim **4**, wherein the fluid directed against the product has a moisture content of not greater than about 0.4 pound of water per pound of dry fluid.

6. The method of claim **4**, wherein said radiant energy and said heated fluid are directed against both sides of the product being dried as it moves through the dryer.

7. The method of claim **4**, wherein the distribution of the heated fluid across the product being dried is substantially uniform.

8. The method of claim **4**, together with the step of directing fluid heated as aforesaid against said product at an angle thereto and in the direction of movement of the product to direct spent fluid and evolved volatiles into exhaust ducts extending across the path of the product through the dryer.

9. The method of claim **4**, wherein said heated fluid is directed against said product in a series of jets and the total area of said jets is in the range of about 1.25 to about 4 percent of the area encompassing said jets.

10. The method of claim 4, together with the step of recirculating fluid exhausted from adjacent said product as it moves through the dryer to conserve the sensible heat therein.

11. The method of claim 4, wherein said heated fluid is directed against said product as it moves through the dryer at a rate sufficient to prevent overheating of the product by the radiant energy directed thereagainst.

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