United States Patent [19]

Comstock

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[54] **ORIFICE PATTERN FOR JET DRYERS**

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[52] **U.S. Cl.** **34/162,** 34/155

[51] **Int. Cl.** **F26b 9/00**

[58] **Field of Search** 34/23, 151, 155, 34/156, 160, 162

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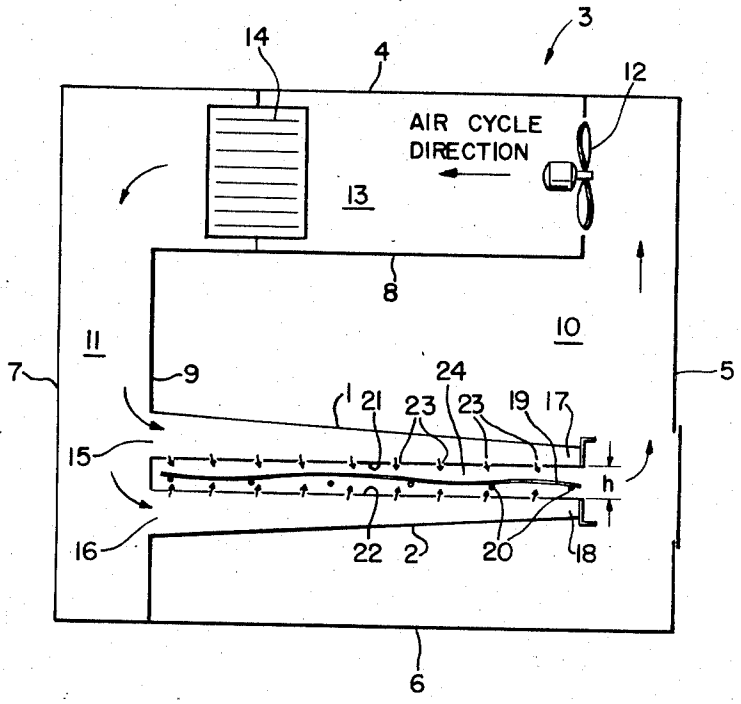
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[57] **ABSTRACT**

An impinging jet air dryer generally utilizes a plurality of opposed jet dryer boxes having a plurality of spaced orifices therein. Suitable formulas are disclosed which offers a method of selecting the optimum orifice pattern for repeating row units which result in a uniform heat transfer over the entire surface of the sheet material as well as maximuzing the overall rate of heat transfer to the sheet material. A means for providing a uniform moisture profile across the sheet material is disclosed which allows more air to be supplied to the sheet material toward the cooler end of the jet dryer boxes. This can be done by varying either orifice spacing or orifice size. The combination of the above-mentioned orifice placement methods gives a jet dryer box which provides the fastest most uniform drying for an impinging jet air dryer.

5 Claims, 6 Drawing Figures

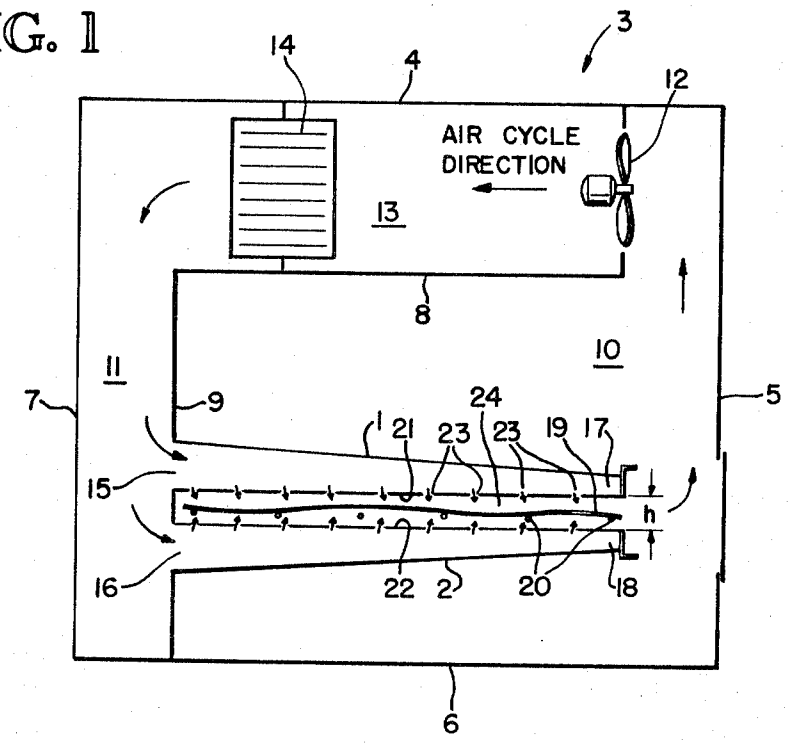


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SHEET 1 OF 2

FIG. 1



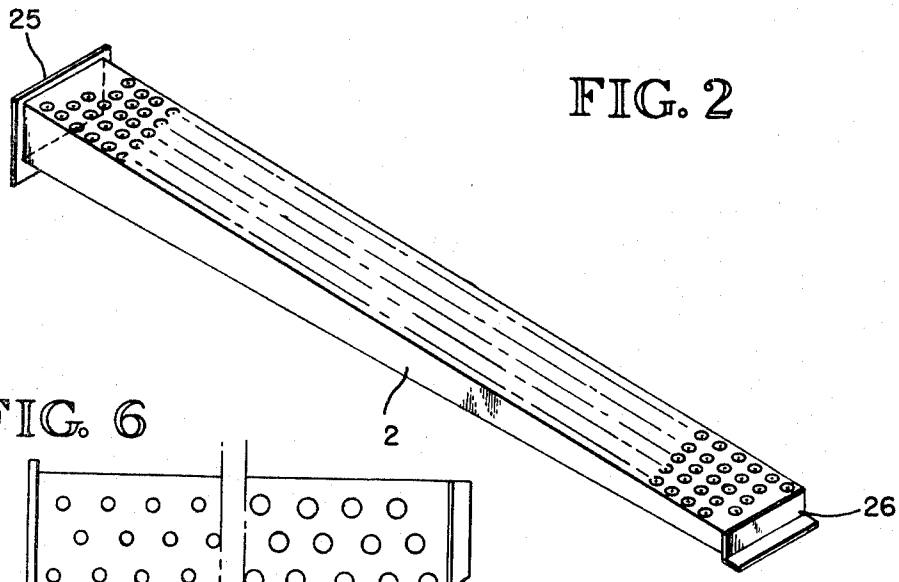
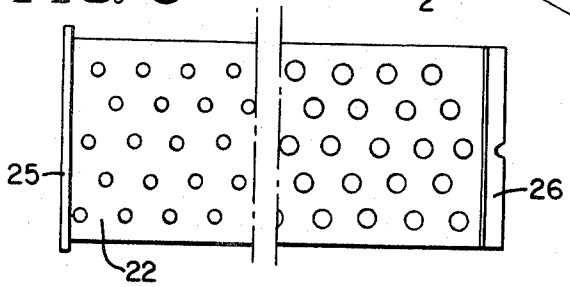


FIG. 2

FIG. 6



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FIG. 3

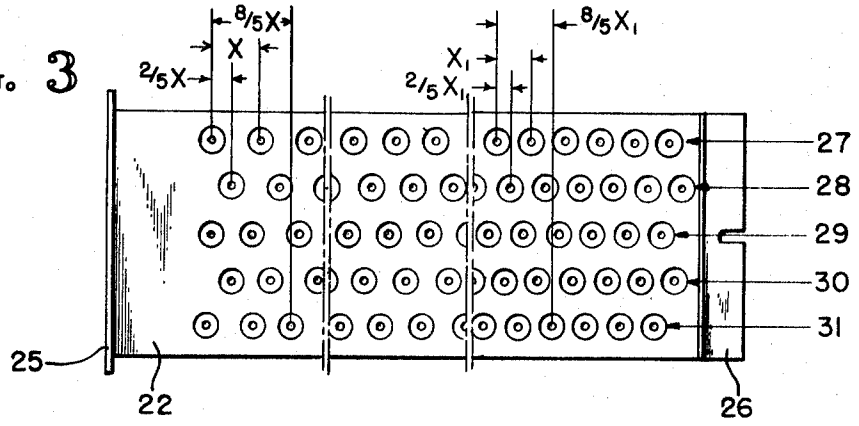


FIG. 4

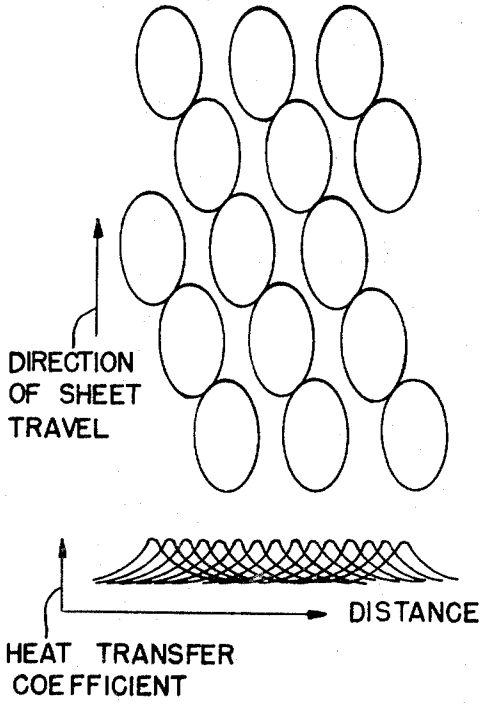
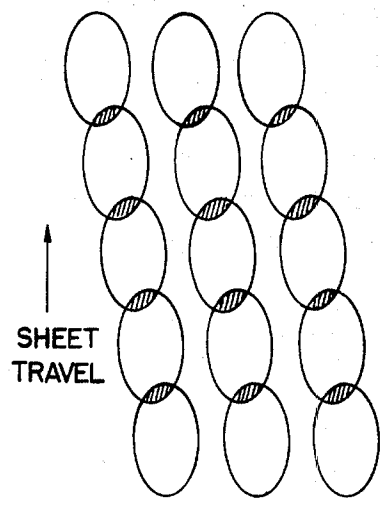


FIG. 5



PRIOR ART

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ORIFICE PATTERN FOR JET DRYERS

BACKGROUND OF THE INVENTION

This invention relates generally to impinging jet air dryers for use in the drying of large sheet material or the like. More particularly, it relates to an orifice configuration for a jet dryer box which serves to direct the impinging air onto the sheet material for optimum drying conditions.

This invention is particularly suited to the drying of wood veneer sheets that travel through an impinging jet air dryer. It has been found through experiment that the size, shape and distribution of the jet orifices in the dryer box have a very large influence on the drying rate achieved for a given energy expenditure. When constructing a more efficient dryer box, it is, of course, the intent to maximize the drying efficiency for a given expenditure of energy.

In the past, it was common practice in the art to provide either a single transverse slot or a single row of holes through which the air passed prior to impinging upon the sheet material to be dried. Some jet dryer boxes in the prior art did utilize a plurality of orifices spaced in a pattern on the box face. Examples of such orifice patterns may be seen by referring to the issued U.S. patents to J. K. Lamb et al. — U.S. Pat. No. 3,254,426 and W. A. Dickens et al. — U.S. Pat. No. 3,097,994. In the patent to Dickens, his FIG. 4 discloses an orifice pattern having nine rows of laterally-spaced orifices as the repeating unit. In each succeeding adjacent row, the corresponding orifice is laterally displaced a distance which is equal to one-ninth of the lateral distance between two adjacent orifices in the first row. It has been found that this orifice pattern does not offer the most efficient drying for sheet material.

In designing the optimum orifice configuration for a jet dryer box, there are two separate aspects to be considered. The first pertains to the selection of a geometrical pattern of orifices which maximizes the amount of heat transferred to the sheet material. The second pertains to a means for producing a flat moisture profile across the sheet width as the sheet is dried.

The optimum orifice geometrical arrangement should in turn satisfy two primary requirements: uniform heat transfer over the entire sheet and maximization of the overall rate of heat transfer. Uniformity of heat transfer for a given orifice configuration will depend to a considerable measure on the relative movement between the dryer orifices and the sheet material being dried. If the sheet is stationary, maximum uniformity and maximum overall heat transfer coefficient will be obtained when each orifice is equidistant from its adjacent neighbor. Even though this is the optimum pattern, the heat transfer will be nonuniform because of the characteristic heat transfer pattern around an impinging jet. The heat transfer coefficient is highest directly under the orifice and drops sharply to a minimum between the orifices.

Movement of the sheet relative to the orifices, such as occurs in an impinging jet dryer, results in a more uniform heat transfer over the sheet material. The profile in the direction of the sheet travel is eliminated by being averaged out over a period of time. However, a nonuniformity across the lateral dimension of the sheet material, in the form of a striped pattern, will remain and the degree of nonuniformity will depend directly upon the orifice pattern.

In practice, it is desirable and generally necessary to have an orifice pattern which repeats periodically. A repeating unit may consist of any number of rows of orifices. In the prior art, a five row repeating pattern would lead one skilled in the art to position the orifice in the next adjacent row one-fifth the lateral distance away from a longitudinal line through the first orifice in the first row. This practice results in increased uniformity of heat transfer. The level of uniformity will decrease as the denominator of the lateral displacement fraction becomes larger. In prior art repeating row units it was common practice to space the rows a distance which was approximately equal to the average spacing between the orifices in a single row. This basic teaching is followed with the present invention and results in a compact, inexpensive, highly efficient dryer box when combined with the teachings of the present invention.

Maximizing the overall rate of heat transfer to the sheet material implies minimizing the interference between the impinging jets from adjacent orifices as well as providing the sheet material with uniform exposure to the dryer box orifices. When the sheet material moves longitudinally through the impinging jet dryer, the area of influence of an individual orifice on the sheet material will be elongated in the direction of sheet travel, and can be schematically represented by an ellipse. Maximum interference between adjacent jets and therefore maximum overall rate of heat transfer will occur when the amount of overlap of the ellipses is minimized.

It has been generalized that uniformity in heat transfer will increase directly with the magnitude of the denominator of the fraction by which each orifice of a row is laterally displaced from the orifices of the adjacent rows. In the present invention it has been discovered that the amount of overlap or interference between adjacent jets will be minimized by choosing the lateral displacement fraction nearest one-half.

Factors such as orifice size, total orifice area per unit dryer surface or face surface, and return air system will all have a bearing on the total number of rows in the repeating unit. However, it is desirable to arrange these with at least five rows in the repeating unit in order to obtain near optimum performance from the jet dryer box. By arranging the orifice pattern of a five row unit according to the teaching of the present invention the performance is increased on the order of from 3 to 5% when compared to a prior art pattern. The performance increase may be somewhat higher as the number of rows in the repeating unit is increased.

The second aspect of the present invention relates to a means for adjusting the moisture profile across the sheet material by varying the orifice area along the length of the jet dryer box. In an impinging air dryer where the orifices are distributed on the faces of jet boxes, air flows from the high pressure plenum into the boxes, impinges on the sheet material being dried and then exits by way of the spacing between the opposed jet dryer boxes. The return air will be somewhat cooler than the entering air because of the heat expended in evaporating water and heating the sheet material. The jet dryer boxes are bathed in this cool return air and the net result is that the air traveling inside the dryer boxes is cooled as it travels along the box length. The temperature of the air impinging on the sheet material will therefore be lower with increasing distance from the

entrance of the dryer box. The lower temperature results in slower drying and a nonuniform moisture distribution across the sheet material.

Accordingly, from the foregoing, one object of the present invention is to maximize the amount of heat transferred to a longitudinally moving sheet in an impinging air dryer.

Another object of the invention is to produce a uniform moisture profile across the sheet width.

These and other objects of the invention will become apparent upon reading the following specification in conjunction with the attached drawing.

SUMMARY OF THE INVENTION

Briefly, this invention is practice in one form by providing a jet dryer box with at least a five row repeating pattern for the jet orifices. The lateral displacement between the succeeding orifices in adjacent rows is determined by mathematical formulas which are effective to provide orifice placement resulting in uniform heat transfer over the width of the sheet material and maximization of the overall rate of heat transfer to the sheet material. In the same jet dryer box in order to provide for a uniform moisture profile across the sheet material the orifice area is progressively increased from the entrance to the outer end of the dryer box thereby supplying more air to the sheet material where the temperature is lower

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a very simple schematic elevation view of an impinging air dryer looking toward the direction of sheet travel through the dryer.

FIG. 2 is an isometric view showing an individual jet dryer box.

FIG. 3 is a top plan view of a jet dryer box showing the orifice placement for a five row repeating pattern according to the present invention.

FIG. 4 is a schematic representation of the heat transfer effect of a section of a five row repeating pattern which is constructed according to the present invention.

FIG. 5 is a similar schematic representation as in FIG. 4 which would likely be constructed according to the prior art.

FIG. 6 is a view similar to FIG. 3 showing the differential orifice size over the width of the dryer box.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring first to FIG. 1 a schematic elevation view depicts the general placement of a pair of opposed jet dryer boxes indicated as 1 and 2, respectively. The overall impinging air dryer is generally indicated at 3 and is comprised of a plurality of dryer sidewalls 4, 5, 6 and 7 inside of which the jet dryer boxes 1,2 are disposed. When drying sheet material, it will be appreciated that the impinging air dryer 3 will extend longitudinally (that is, the distance defined by planes perpendicular to the elevation view of FIG. 1) a sufficient distance to allow the sheet material to travel between a sufficient number of spaced apart pairs of jet dryer boxes so that it is dried to the intended degree. In FIG. 1, of course, only one pair of dryer boxes are depicted.

Operatively communicating with the dryer sidewalls 4, 5, 6, and 7 to form a plurality of plenum chambers are the inner side walls 8 and 9. The volume contained within and defined by the side walls 5, 6 and the inner side walls 8 and 9 is the cool air or output plenum chamber 10. The warm air or input plenum is indicated as 11 and is generally defined by the side wall 7 and the inner side wall 9.

Of course, it will be appreciated by those skilled in the art that in the impinging air dryer 3 the air will be circulating through a warming cycle. A fan 12 or other suitable device is placed between the cool air plenum chamber 10 and the warm air plenum chamber 11 such that as the cooled air leaves the area surrounding the jet dryer boxes it will be drawn generally toward the fan 12. Fan 12 then directs the cool air through a duct chamber 13 to a suitable heating element 14. As the air passes through the heating element 14 it is, of course, heated to the appropriate temperature to perform its heat exchange function with the traveling sheet material. Vents, not shown, are used to purge off a predetermined amount of the cooled moisture laden air in order to keep the wet bulb temperature at the desired level. As the warmed air leaves the heating element 14, it then passes into the input plenum 11 and on into the jet dryer boxes 1,2. The jet dryer boxes 1 and 2, of course, are open to the input plenum 11 at their inner or inlet ends 15, 16, respectively.

The jet dryer boxes 1 and 2 extend outwardly from the inner side wall 9 and terminate at their respective outer or closed ends 17 and 18. Although a pair of opposed jet dryer boxes 1,2 are depicted, it will be appreciated that the present invention is concerned with the construction of a single jet dryer box and if only one side of a traveling sheet was to be dried, or if was desired that all drying should proceed from one side of the sheet, only a single line of jet dryer boxes would be positioned in the impinging air dryer 3. Since a pair of jet dryer boxes are utilized in the normal drying of wood veneer, it will be appreciated that a means must be provided for carrying the sheet of veneer, depicted at 19, through the volume between the jet dryer boxes 1, 2. In the embodiment of FIG. 1 a plurality of laterally spaced, longitudinally extending movable cables 20 provide the appropriate veneer movement and support. The cables 20 are equally spaced laterally and are approximately equidistant from each jet dryer box. With this configuration, it will be appreciated that the veneer sheet 19 will travel through the center of the volume between the jet dryer boxes 1 and 2 and will be subjected to warm impinging air on both sides.

The respective faces 21 and 22 of the jet dryer boxes 1 and 2 are provided with a plurality of spaced apart holes or orifices indicated collectively as 23 in FIG. 1. The jet dryer boxes 1 and 2 are separated by a vertical height indicated as h in FIG. 1, creating a space 24 extending the length of the dryer and through which the veneer 19 passes. Of course, it will be understood that as the warm air enters the jet dryer boxes 1, 2 it will flow through the plurality of orifices under an appropriate static pressure.

Referring now to FIG. 2, a specific example of appropriate dimensions will be given for utilization of the jet dryer boxes in a particular wood veneer impinging air dryer. The dimensions given should be taken by way of example only and are not intended to limit the instant invention. The particular dimensions to be cited are sized so that the air dryer 3 will accommodate sheets of wood veneer on the order of eight feet wide in the lateral direction. That is, the veneer sheet 19 as de-

picted in FIG. 1 is on the order of 8 feet wide. The length dimension for the jet dryer box, that is, from the outer end to the inner end will be on the order of 9½ feet. In the embodiment depicted in FIG. 2, a five row repeating pattern is shown and the width of the dryer box face in this instance will be on the order of one foot. The vertical height of the dryer box will be on the order of 2½ inches at the outer end and seven and a half inches at the inner end where the jet dryer boxes open into the input plenum **11**. The dimension *h* between the faces **21** and **22** will be on the order of 3 inches with the veneer sheet **19** therefore being on the order of 1½ inches from each dryer box face.

In order to mount the jet dryer boxes **1** and **2** on the inner side wall **9** a suitable mounting bracket **25** is attached to the inner ends of the jet dryer boxes. Likewise, a suitable supporting bracket **26** is provided at the outer ends of the jet dryer boxes in order to support the dryer box faces in their proper relationships to one another and to the traveling veneer sheet **19**.

Turning now to the additional Figures of the drawing, the critical spacing for the plurality of orifices **23** will be described. The plan view of a dryer box face having a five row repeating orifice pattern is depicted in FIG. **3**. The length of the dryer box is broken at several places for clarity in the drawing.

It has been found through the reasoning as mentioned in the "Background of the Invention", that the following mathematical formulas will yield the optimum lateral displacement fraction (LDF) of a repeating row unit where *n* is the number of rows in the repeating pattern and is greater than 2.

1. LDF = $(n \pm 1/2)/n$ . . . . for n = odd integer
2. LDF = $(n \pm 2/2)/n$ . . . . for n = even integer and > 2

In FIG. **3**, the first row of orifices is designated as **27**, the second row as **28**, the third row as **29**, the fourth row as **30**, and the fifth and final row in the repeating pattern as **31**. The center line of each orifice in the first row **27** is generally on a laterally extending single line running the length of the dryer box face. Likewise, for the second, third, fourth and fifth rows of orifices. The sizing for the diameter of each individual orifice is determined to an extent by practical considerations such as plugging by debris and ease of cleaning and by the distance from orifice outlet to the veneer sheet. Spacing of rows and holes laterally in a single row depends on hole size and the orifice area for a given area of a dryer box face. For example, in the above-noted dimensions an average orifice area would be on the order of 0.02 – 0.022 ft^2/ft^2 of dryer box face and the orifice diameter would be about 0.5 in.

In determining the lateral displacement fraction (LDF) by the two above formulas, it is noted that the formulas will yield the optimum lateral displacements for the orifices of the next succeeding rows in the repeating pattern. Using these formulas with the above-noted limitations, a table showing the optimum lateral displacement fraction for successive numbers of rows in a repeating row unit is given for values of from 5 up to 11:

n	LDF
5	2/5 or 3/5
6	2/6 = 1/3 or 2/3
7	3/7 or 4/7
8	3/8 or 5/8
9	4/9 or 5/9
10	4/10 = 2/5 or 3/5
11	5/11 or 6/11

As noted in the "Background of the Invention", it has been found that for optimum performance of the jet dryer box, at least five rows of orifices should be utilized in the repeating unit. It is seen from the above formulas that when *n* is a number from 2 to 4 the optimum row displacement would be what the prior art would likely yield. That is, a displacement fraction where the denominator is equal to the number of rows and the numerator is **1**. When a five row repeating pattern is employed the optimum lateral displacement fraction is found to be two-fifths or three-fifths and not one-fifth. Thus the plurality of orifices in the second row 28 will be positioned laterally a distance from longitudinal lines through the orifices of the first row 27 which is two-fifths of the distance between adjacent orifices (indicated as X on FIG. **3**) in the first row 27. Likewise for each succeeding row.

While the embodiment in FIG 3 indicates that the two-fifths displacement fraction would be to the right of the axial line in row 28 it should be noted that it could be to the left. Vertical lines (for clarity) extend upwardly from the centers of selected orifices in each succeeding row which have been positioned according to an LDF of two-fifths by the above formulas. Thus the total lateral displacement in a five row repeating unit between the first orifice in the first row and the corresponding first orifice in the last row will be eight-fifths of the lateral distance X between the first and second adjacent orifices in the first row. This will be seen by referring to the left side of FIG. **3** where X is a uniform distance. At both ends of the orifice pattern additional orifices will be appropriately placed such that the overall pattern within face **22** is of a generally rectangular shape.

Referring now to FIGS. **4** and **5** the areas of influence of an orifice are depicted relative to the orifice pattern. In FIG. **4** the elipses or areas of influence of an individual orifice, which is the resulting area for a moving sheet, are placed by positioning the plurality of orifices **23** according to the above stated formula where the number of rows is five and the LDF is two-fifths. The direction of travel of the sheet material is indicated by the single directional arrow. The graph at the bottom of FIG. **4** is a plot of the coefficient of heat transfer against the lateral position along the sheet material. It is noted that the tops of the individual curves, each of which represent an individual orifice, establish a generally flat line indicating a substantially constant coefficient of heat transfer over the lateral distance of the sheet material. This, of course, is reflected in the drying characteristics of the sheet material **19** which is moving between the pair of jet dryer boxes **1** and **2**. It is noted that none of the areas of influence intersect with another thereby indicating a maximization of the overall rate of heat transfer to the sheet material. It will thus be appreciated that in the example given for a five row repeating pattern both uniform heat transfer over the entire sheet and maximization of the overall rate of heat transfer is provided by the above stated formulas.

While the orifice pattern areas of influence of FIG. **5** yields substantially uniform heat transfer over the entire sheet it is noted that the elipses intersect with one another thereby making heat transfer less efficient. The spacing of the orifices as would be present in FIG. **5** is with a lateral displacement fraction of one-fifth which would be that established by the prior art.

As previously mentioned, the second aspect of the instant invention relates to the means for establishing a uniform moisture profile across the sheet material as it is dried. The method for correcting a nonuniform moisture profile is to supply more air where the temperature is lower and less where it is higher in sufficient amounts to just offset the temperature differential. It has been found through experiment for a dryer box with the aforementioned dimensions, which uniformly has an average orifice area of 0.021 ft^2/ft^2 of dryer box face, that this is accomplished by increasing orifice area 0.0035 ft^2/ft^2 near the low temperature outer ends and decreasing it a like amount at the high temperature inner ends with an approximately uniform change along the length of the dryer box face. It will be appreciated by one skilled in the art that this can be done by varying either orifice spacing (FIG. 3) or orifice size (FIG. 6), spacing being the preferred method because of ease of fabrication. By varying the spacing it is meant that the lateral distance between adjacent orifices in the same row may be varied according to the procedure outlined above. The lateral spacing of the lateral displacement fraction remains as that determined by the above-noted formulas. It should be noted that after the total orifice square footage for given dimensions of a dryer box face is determined the above-described method will then result in approximately 1.4 times the orifice area at the inner end of the dryer box to be positioned at the cooler outer end of the dryer box face.

An example of dimensioning, where lateral spacing between orifices in the same row is varied, will now be given. Referring to FIG. 3 it will be seen that the lateral distance between orifices at the inner end of the dryer box face as previously mentioned will be X which is on the order of 2.75 in. Thus the dimensioned LDF for the first orifice in the second row **28** will be 2/5×2.75 or 1.10 in. The remaining orifices are positioned accordingly. At the outer end of a dryer box the lateral displacement of orifices in the same row will be greater than X and is indicated on FIG. 3 as X_1. Following the example X_1 will be on the order of 2.00 in. when utilizing all of the previously given dimensioning and thus the dimensioned LDF will be 0.80 in. toward the outer end. It will be appreciated by one skilled in the art that the variation in orifice spacing to yield the 1.4 area differential will be fabricated in groupings where the X, X_1, X_n, etc. are constant over a given length of dryer box face.

It will be appreciated that the above procedure when combined with the aforementioned described method of selecting the optimum orifice pattern gives the basis for designing a jet dryer box structure for obtaining the fastest most uniform drying for an impinging air dryer.

While a detailed example of the principal embodiment has been described, it is understood that many changes and modifications may be made in the above-described jet dryer box without departing from the spirit of the invention. All such modifications are intended to be included within the scope of the appended claims.

What is claimed is:

1. In a dryer box unit for drying moving sheet materials by impinging streams of warm air, the dryer box comprising an elongated duct having a closed end and an open end in communication with a source of air under a positive static pressure, one surface of the duct being a face defining a plane lying substantially parallel to and facing the sheet material being dried, said surface having a pattern of at least five rows of orifices directed toward the sheet material and extending parallel to the long dimension of the duct, said orifices in any given row being spaced from each other, and said rows being spaced from each other with respect to a perpendicular line through a given row a distance that is the average spacing between orifices in a given row, the improvement comprising: laterally displacing the orifices of one row from those of its adjacent rows by a spacing determined by the formula LDF times the spacing between the corresponding adjacent orifices in any given row; where,

$LDF = n \pm 1/2 \,/n$ when n is an odd integer, and

$LDF = n \pm 2/2 \,/n$ when n is an even integer, and where LDF is the lateral displacement fraction and n is the number of rows in the pattern.

2. The dryer box unit of claim **1** in which the orifice area per square unit of face is increased from the inlet end of the box to the closed end in order to maintain a uniform delivery of energy across the width of the sheet.

3. The dryer box unit of claim **2** in which the orifice area per square unit is increased by providing orifices of larger cross sectional area.

4. The dryer box unit of claim **2** in which the length of the spacing between the orifices of a given row is decreased from the inlet end to the closed end in order to provide a larger number of orifices per square unit of face area toward the closed end.

5. The dryer box unit of claim **2** in which the total orifice area toward the closed end is on the order of 1.4 times the total orifice area toward the inlet end.

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