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METHOD AND APPARATUS FOR CIRCULATING AIR

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This invention relates to a method and apparatus for circulating air around articles to be dried or frozen. More particularly, the present invention is concerned with a method and apparatus for enhancing the circulation of air around goods in cold storage spaces for the purpose of accelerating the freezing of such goods. However, although the present invention will be described in connection with the freezing of goods in cold storage spaces, it will be understood that it is intended to be applicable also to the problem of drying goods or to any other process in which efficient circulation of air around articles to be treated is desired.

In cold storage warehouses in which the air temperature ranges between 15° F. and 30° F. below zero, it is desirable, when goods are brought into the warehouse for cold storage, to freeze and lower the temperature of the same as quickly as possible to the ambient air temperature in the warehouse. In addition to other advantages of such quick freezing, the quality of the goods is thereby considerably enhanced.

Inasmuch as the temperature of the ambient air is much lower than freezing, the only problem existing is that of circulating air around the goods so as to effect the desired heat transfer.

Heretofore, such circulation of air has been performed by "tunnel freezing" wherein a plurality of stacks of goods are arranged in a row in a horizontally elongated tunnel and high velocity air is forced through the tunnel.

I have found, however, that the rate of heat transfer from the goods to the air is principally a function of temperature difference between the goods and the air and not a function of the velocity of the air except that a minimum velocity exists for most efficient heat transfer.

Tunnel freezing is therefore not only undesirable and inefficient because of the fact that the goods must be placed in stacks in series thus impeding circulation through successive stacks of goods, but the high velocities required result in a waste of power. Furthermore, the larger the motor required for the fan or blower, the greater is the likelihood of heat loss to the same air which is being relied on to effect the cooling.

In addition to the abovementioned disadvantages, "tunnel freezing" requires the manufacture of a tunnel structure which adds to the expense of the cooling operation and complicates the materials handling problem inasmuch as the goods must usually be inserted on pallets into the tunnel and then removed after they are frozen.

The main object of the present invention is to overcome the disadvantages of present methods and apparatus for circulating air around goods.

Another object of the invention is the provision of an extremely simple method and apparatus for circulating air around goods without expensive equipment and without unnecessary delay in handling the goods.

Still another object of the invention is the provision of a method of circulating air in a cold storage space around goods with a minimum of power and a minimum loss of heat to the air.

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Other objects and advantages will be apparent from the following specification and from the drawings wherein:

Fig. 1 is a schematic side elevational view of a typical installation assembled in accordance with the present invention.

Fig. 2 is a horizontal cross sectional view through the nozzles of Fig. 1 showing the arrangement of the stacks of articles to be frozen.

Fig. 3 is a sectional view through the installation of Fig. 2 as taken along lines 3—3.

Fig. 4 is an end elevational view of an installation showing a somewhat different means for accommodating the air nozzles to stacks of different height.

One embodiment of the invention will be described with reference to the freezing of poultry, but it will be understood that the principles involved are equally applicable to any type of product including vegetables, beef and the like. Furthermore, as above mentioned, the method and apparatus now to be described may be used to circulate air around any type of articles such as lumber for drying the same.

In handling poultry, the same are generally packed in thin wooden boxes having a plurality of cracks in their sidewalls to promote air circulation. These boxes are stacked on pallets so as to permit handling a stack of such boxes on a pallet by means of a fork truck.

In order to enhance air circulation around the poultry, it is preferable to provide racks generally designated 1 between adjacent tiers for promoting circulation in a manner to be described later on in greater detail.

Each rack 1 comprises a plurality of elongated elements or slats 2 which are arranged in coplanar parallel spaced relationship and rigidly secured together by cross pieces 3 (Fig. 2).

In the arrangement shown in the drawings, a tier of boxes or crates 5 are placed on a rack 1 and a conventional pallet 6 is employed to receive four or five vertically stacked tiers of boxes with a rack 1 between each pair of adjacent tiers. The loaded pallets may be stacked two high as indicated in Fig. 1 so that each stack of boxes comprises eight or ten tiers.

The operator of the fork truck then arranges the stacks of boxes in two horizontally extending, parallel rows A, B with a relatively small slot or pocket 7 between said rows. In Fig. 2 each row A, B contains five stacks of boxes but the number is not critical. The ends of the pocket 7 are then closed by one or more stacks of boxes C, E so that movement of air to or from said pocket is possible only vertically through the upper open end of pocket 7 and horizontally through the spaces between the poultry in boxes 5.

It is preferable to provide two stacks C, E at each end of pocket 7 rather than one because, in the latter case, an undesirable quick escape of air from pocket 7 may be permitted through the oppositely outwardly directed ends of the rows A and B. In other words, it is desirable to require the air to traverse substantially the entire width of each stack as will be more fully understood later on.

The stacking of the boxes as above described is performed so that the upwardly opening pocket 7 formed by the stacks is directly under, and parallel to an elongated air duct 10 (Fig. 1) which may be supported above said pocket by any convenient means. However, to permit shifting duct 10 vertically, it is preferable to provide hoisting means generally designated 11 for hanging the duct 10 from any convenient overhead members 12.

Each hoisting means may, for example, comprise a pair of upper and lower blocks 13, 14 respectively and a rope 15, the end of which may be secured to any suitable member (not shown) to stationarily secure the duct in any desired position.

One end 15 of the duct 10 is closed and at the opposite end a conventional axial flow fan 16 is provided for forcing air longitudinally into the duct 10. A transition piece 17 may be provided as required between the discharge end of fan 16 and duct 10.

The cross sectional shape of duct 10 is not critical, but a rectangular shape is satisfactory and economical to construct. Along the lower side 18 of said duct are provided a plurality of downwardly directed nozzles 19 which are centrally positioned on the underside 18 of duct 10 and in the central vertical plane of the upwardly opening pocket 7.

In the embodiment shown, nozzles 19 are of the convergent type and, although divergent nozzles may be used, the friction loss at the entrance of divergent nozzles is substantially greater than in convergent nozzles.

In the preferred form of the invention, nozzles 19 are rectangular in cross section, with the width of the discharge opening of the nozzle designated "W" and the length "D." Said nozzles are spaced apart along the length of pocket 7 as indicated in Figs. 1, 2 so as to enhance entrainment of ambient air during the cooling operation as will be fully explained later on.

At this point, the description of the operation may be briefly described as follows: Air from the cold storage space is moved by fan 16 into duct 10 and forced out of nozzles 19 in downwardly directed jets 21 through the open upper end of pocket 7. An elevated pressure is thus created in pocket 7 which forces the air therein horizontally outwardly through the stacks which surround said pocket thus providing the desired circulation of air. In addition the downwardly directed jets of air act as pumps and entrain additional ambient air which is also forced into pocket 7. As indicated by arrows in Fig. 3, the entrained air moves inwardly of the stacks toward pocket 7 and horizontally over the tops of the stacks thus creating a cycloning effect which results in the air which has passed horizontally through the stacks moving upwardly along the outer sides of the stacks and then inwardly to be entrained by the jets.

Before considering in detail the preferred method of accomplishing effective circulation it is important at this point to consider, in general, jet pump effect of air blasts.

When air is discharged from an outlet into free air the air jet created acts as a pump for moving the air surrounding it due to the following effects. First, particles of surrounding air are accelerated by impact with the air particles of the jet. Second, the viscous friction between the air in the periphery of primary jet causes entrainment of the surrounding air. Third, the pressure of the air in the primary jet being reduced because of its velocity, results in a flow of the higher pressure surrounding air inwardly toward the central axis of the jet.

By the application of the momentum theory to air jets it will be apparent that the momentum of the moving air stream resulting from a jet is uniform at all cross sections throughout the length of such stream. In other words, the momentum (i. e. weight multiplied by velocity) is the same at a remote point in the jet as it is adjacent the nozzle outlet. Of course, at the remote point secondary air entrained by the jet is also included in the stream thus increasing the weight at such remote point with a corresponding reduction in velocity.

When an air jet is discharged into an upwardly opening pocket such as pocket 7 which is defined by the vertical sidewalls formed by the stacked articles, the behavior of the air stream is entirely different from that above described and especially in the entrainment effect on surrounding air.

When the expansion of the air jet is not free, but is restricted by sidewalls such as the sidewalls of pocket 7 defined by the stacks of boxes, the amount of entrained or secondary induced air is considerably reduced. In this connection, it is pertinent to note that the total included angle of an air jet discharging into free space will vary

from 10 to 35 degrees. However as confining walls become effective the jet angle will be decreased, until the final air flow will be between parallel boundaries at a point where the jet width equals the spacing between such boundaries.

It should be understood in this connection that the arrangement shown in the drawings is completely ineffectual for the desired purpose if the position of the nozzle and the velocity of the jet is such that the air stream returns through the upper open end of the pocket without building up a pressure such as is required to force the air horizontally outwardly of the pocket 7. This undesirable result obtains especially when the velocity is very high, causing the stream to be reversed, and to discharge through the upper end as an overwash.

By the present invention, the jets of air are related, in a manner to be described, so that a practical and efficient pressure pocket of air is established centrally of the stacks of goods thus causing the air to accept the horizontal path through the goods rather than to reverse its flow as described above.

With reference to the drawings, "W" and "D" designate the width and length respectively of each nozzle outlet. "T" and "L" designate respectively the width and length of the pressure pocket 7 and "H" represents the distance between the upper open side of pressure pocket and the discharge opening of the nozzle 19.

I have found that desirable circulation of air results when the distance "H" is equal to from two to thirty times the square root of the total area of the nozzle outlets per lineal unit of length of the pressure pocket 7.

Expressed as a formula, with all dimensions in feet,

$$H = (2 \text{ to } 30) \sqrt{\frac{\sum DW}{L}}$$

For any length of pressure pocket this formula may be further simplified by removing "L" from the radical. The simplified formula is:

$$H = X(\sum DW)^{1/2}$$

Where X is a dimensionless quantity having a value from 0.45 to 6.70.

As a specific installation which proved to give optimum results, a duct discharging 10,400 C. F. M. of air was provided with four nozzles, as shown in the drawings, each of which had a width of discharge opening (W) equal to 4" and a length (D) of 2'-0". Stacks of boxed poultry about nine feet high were provided so as to form a pressure pocket having a width (T) equal to 1'-2" and a length (L) equal to 20'-0". The distance "H" was established as 3'-11".

In this specific arrangement it will be seen that:

$$H = 2.4(\sum DW)^{1/2}$$

but the factor 2.4 may, as pointed out above, be reduced as low as .45 and increased to as much as 6.7 although it was found that by the above formula the best circulation took place.

In the above specific example the entrainment ratio was 1.53. That is, 10,400 C. F. M. was discharged from nozzles 19 and 15,900 C. F. M. was entrained in the air at points above the top of the stacks giving a total circulation of air of 26,300 C. F. M. through the poultry. From this it will be seen that the circulation of air in the warehouse may be substantially localized and in addition, the cyclone action due to the entrainment of ambient air results in circulation of air, not only horizontally through the stacks of boxes, but also downwardly along the inner sides of the stacks, upwardly along the outer sides and inwardly along the tops of the stacks.

With respect to the width (T) of the pressure pocket 7, I have found that the same should range from 1.5 to 30 times the width of the nozzle outlet. Expressed as a formula,

$$T = (1.5 \text{ to } 30) W$$

In the specific set up above described, the preferred relationship is,

$$T=3.5 W$$

The length (D) of the nozzle discharge openings may be considerably varied inasmuch as more or less nozzles may be employed. As a limiting condition the length (D) may be made equal to the length of the pressure pocket, in which case there would be, of course, only one nozzle. When a greater number of nozzles are employed, the length (D) of each may even be made less than the width (W) if desired provided, of course, the total amount of jet air provided is sufficient to provide the desired circulation.

To achieve effective entrainment of the ambient air in the air jets, it is preferable that more than one nozzle be employed so that the movement of entrained air toward the central axes of the jets is in a direction longitudinally of the length of pocket 7 as well as transversely. Although the present invention contemplates the use of a unitary jet about equal in length to "L," a plurality of jets is desirable for the above reason.

The cross section area (LT) of the pressure pocket 7 is, of course, larger than the total area of the nozzle outlets. A feasible figure in this respect may be derived from the following formula:

$$LT=(4 \text{ to } 20) (\Sigma DW)$$

For the particular installation outlined above optimum results were obtained when

$$LT=8.75 (\Sigma DW)$$

From the particular quantities of air specified above, it will be seen that the jet velocity may be less than 4000 feet per minute which is relatively low. Thus the horsepower required to operate fan 16 is less than that which is normally required in "tunnel freezing" methods. This savings in power is not only desirable in itself, but the likelihood of heat loss to the ambient air from the fan motor is correspondingly reduced.

The use of racks 1 for spacing apart adjacent tiers of goods is extremely important and it will be understood that such racks provide horizontal passageways extending generally laterally outwardly from the pressure pocket 7 thus insuring circulation across the tops and bottoms of all the boxes.

An important advantage of the present invention resides in the fact that the duct 10 and particularly the nozzles 19 provide a reference for the fork truck operator by which the stacks may be properly positioned for cooling. In addition, no additional structure except duct 10, need be built to carry out the desired air circulation.

As pointed out above, the stacks are readily positioned so as to require the air to traverse the length of a rack or pallet in all directions, thus subjecting the air flow to the same resistance at all points and insuring uniform circulation.

The present invention contemplates the use of nozzles of various cross sectional shapes including circular and square, although a rectangular cross section as above described is preferred. The lower side 18 of duct 10 may even be provided with one or more slots thus obviating the nozzles. However when nozzles are not used, the air jets tend to drift longitudinally of the duct.

By the lifting means 11, the duct 10 may be suspended at any desired distance from the warehouse floor so that the desired distance "H" is readily arrived at. In addition, the duct 10 may be vertically shifted to suit stacks of different height.

A different method of achieving the last mentioned result is shown in Fig. 4 wherein elongated flexible generally tubular extensions 25 are suspended from nozzles 19 so that the lower ends of said extensions are at the desired height "H" above the top of the stacked goods. Extension 25 may be made of canvas or the like and operates in

somewhat the same manner as a wind sock. In instances where it is not possible to lower the duct 10, the use of extension 25 provides a desirable flexibility.

I claim:

1. Apparatus for circulating air around stacked articles in a cold storage space comprising: an elongated air duct closed at one end and provided at its other end with a fan for forcing air into said duct, means for supporting said duct horizontal and spaced above the floor of said space to permit stacking such articles on said floor in vertically extending stacks to form an upwardly opening horizontally elongated pocket with the vertical sidewalls of said pocket defined by such articles, a plurality of nozzles along the underside of said duct for directing the air in jets from said duct vertically downwardly into said pocket through the upper open end of the latter, said nozzles being elongated longitudinally of said duct and being spaced apart along the length of said duct to permit entrainment of ambient air by said jets from all sides of the latter, elongated tubular extensions secured at one of their corresponding ends to said nozzles and adapted to be suspended from the latter for discharging air downwardly from their opposite ends, said extensions being flexible whereby their lengths may be adjusted to space said opposite ends different distances from the floor to accommodate stacks of different heights.

2. Apparatus for providing circulation of air around articles comprising, in combination: a plurality of spaced tiers of articles in vertical stacks arranged to provide a central upwardly opening pocket with said stacks defining continuous sidewalls and endwalls for said pocket, a plurality of air nozzles adapted to be positioned above said articles when the latter are stacked to form a central upwardly opening horizontally elongated pocket of generally rectangular cross-section, said nozzles being positioned above the open upper end of said pocket with their discharge openings directed downwardly and positioned centrally of the central longitudinal vertical plane of said pocket, the cross sectional area of said pocket being equal to from four to twenty times the total area of said discharge openings of said nozzles and the latter being spaced above said open end a distance in feet equal to from 0.5 to 6.7 times the square root of the combined areas in square feet of said discharge openings.

3. The method of effecting circulation of air around vertically stacked articles comprising the steps of: arranging said articles in spaced tiers to provide a central upwardly opening pocket having continuous vertical sidewalls extending therearound and defined by said articles, discharging air vertically axially downwardly in jets through the open upper side of said pocket whereby said air builds up in pressure in said pocket and is urged generally horizontally outwardly of said pocket through the spaces between said articles, the vertical distance between the origin of said jets and the upper open end of said pocket being represented by the formula

$$H=X (\Sigma DW)^{1/2}$$

wherein H equals said distance, D and W equal the length and width respectively of said jets at said points and X is a dimensionless quantity having a value from 0.45 and 6.70.

4. The method of effecting circulation of air around vertically stacked articles comprising the steps of: arranging said articles in spaced tiers to provide a central upwardly opening pocket having continuous vertical sidewalls extending therearound and defined by said articles, discharging air vertically axially downwardly in jets through the open upper side of said pocket whereby said air builds up in pressure in said pocket and is urged generally horizontally outwardly of said pocket through the spaces between said articles, the vertical distance between the origin of said jets and the upper open end of said pocket being represented by the formula

$$H=X (\Sigma DW)^{1/2}$$

wherein H equals said distance, D and W equal the length and width respectively of said jets at said points and X is a dimensionless quantity having a value of about 2.

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