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(54) **SECHEUR A AIR TRAVERSANT HAUTE INTENSITE POUR CONVERSION DE MACHINES A PAPIER CLASSIQUES A PRESSE HUMIDE**

(54) **HIGH-INTENSITY THROUGH-AIR-DRYING FOR CONVERSION OF CONVENTIONAL WET-PRESS PAPER MACHINES**

(57) La présente invention porte sur une méthode pour convertir une machine à papier classique à presse humide feutrée en machine à papier avec sécheur à air traversant, sans qu'on n'ait besoin de déplacer aucune section d'appareils qu'on veut garder dans la machine à air traversant. La présente invention comporte une méthode utilisant l'application d'une pression différentielle dans un cylindre sécheur de diamètre réduit pour obtenir les conditions de séchage nécessaires dans un espace réduit.

(57) The present invention is a method of retrofitting a conventional felted wet-press paper machine to a through-air-drying (TAD) paper machine, without the need to move any of the apparatus sections that will be retained in the TAD machine. The present invention is a method of using an applied pressure differential in a reduced diameter TAD cylinder to achieve necessary drying conditions in a reduced area.

ABSTRACT OF THE DISCLOSURE

The present invention is a method of retrofitting a conventional felted wet-press paper machine to a through-air-drying (TAD) paper machine, without the need to move any of the apparatus sections that will be retained in the TAD machine. The present invention is a method of using an applied pressure differential in a reduced diameter TAD cylinder to achieve necessary drying conditions in a reduced area.

FIELD OF THE INVENTION

The present invention relates to a method of retrofitting a papermaking apparatus having a conventional pressing felt with a through-air-dryer unit without the expenses involved in increasing the length of the papermaking apparatus. The present invention further relates to the use of elevated applied pressure differential to the drying section of a through-air-dryer to efficiently remove moisture using a limited size through-air-drying unit. Finally, the present invention relates to a method of making a web using an applied pressure differential across the web and fabric from greater than about 1 to about 15 inches of Hg.

BACKGROUND

In consumer paper products, such as facial tissue, paper towels, and toilet tissue, the industry has seen a shift away from products made by conventional wet-pressing (CWP) to those made by the more recent through-air-drying (TAD) technology. Conventional felted wet press (CWP) processes are significantly more energy efficient than processes such as through-air-drying (TAD), since they remove excess moisture by mechanically pressing it from the web. Final drying of the web, after pressing, is obtained while the web is on a heated Yankee drying cylinder which is maintained at the proper drying temperature. CWP processes conserve energy because they do not require heating and moving large quantities of air as are required by TAD processes, and also because they remove a greater fraction of the water in the web mechanically, rather than via evaporation.

In contrast to CWP processes, the TAD process uses the passage of heated air through the wet fibrous web after it is formed on a wire and transferred to a permeable carrier to dry the web. The result is no overall compaction of the web during drying. The lack of overall compaction, such as would occur when the web is pressed while on a felt and against the drying cylinder when it is transferred thereto, reduces the opportunity for interfiber bonding to occur, and allows the finished product to have greater bulk and absorbent capacity than can be achieved in a wet press process. Because of the consumer perceived softness of these products, and their greater ability to absorb liquids than webs formed in wet press processes, the products formed by the newer processes enjoy an advantage in consumer acceptance. The present invention takes advantage of this newer TAD technology by retrofitting existing conventional wet press (CWP) paper machines.

CWP systems include three basic sections, a forming section, a pressing section, and a drying section. One conventional CWP system is described with reference to Figure 1; however, variations and alternatives will be understood by the skilled artisan. In a conventional wet press process and apparatus **10**, a furnish is fed from silo **50** through conduits **40, 41** to headbox chambers **20, 20'**. A web **W** is formed on a forming wire **12**, supported by rolls **18, 19**, from a liquid slurry of pulp, water and other chemicals. Materials removed from the web through the forming fabric when wrapped on forming roll **15** are returned to silo **50**, from saveall **22** through conduit **24**. The web is then transferred to a moving felt or fabric **14**, supported by roll **11**. The web is then pressed by suction press roll **16** against the surface of a rotating Yankee dryer cylinder **26** which is heated to cause the paper to substantially dry on the cylinder surface. The moisture within the web as it is laid on the Yankee surface causes the web to transfer to the surface. Liquid adhesive may be applied to the surface of the dryer to provide substantial adherence of the web to the creping surface. The web is then creped from the surface with a creping blade **27**. The creped web is then optionally passed between calender rollers (not shown) and rolled up on reel **28** prior to further converting operations, for example, embossing. The action of the creping blade on the paper is known to cause a portion of the interfiber bonds within the paper to be broken up by the mechanical action of the blade against the web as it is being driven into the blade.

TAD systems, like conventional CWP systems, can include three sections, in this case a forming section, a predrying section and a drying section. Unlike CWP systems, TAD systems can forego a drying section and do complete drying of the web in the predrying section. One example of a through-air-drying paper machine having three sections is set forth in Figure 2. As depicted, this through-air-drying line includes a forming section **40**, a predrying section **42**, and optionally a drying section **44**. The forming section **40** of the through-air-drying machine parallels that of the conventional paper machine. The forming section **40** includes a headbox **46** and a forming wire **48**. The former can be any conventional former such as a twin wire former, a crescent former, a suction breast roll former and the like. The fibrous slurry is fed from the headbox **46** to the forming wire **48** to form a nascent web. The nascent web is transferred from the forming wire **48** to the predrying section **42**. The predrying section includes a drying fabric **50** for supporting the wet web during passage over vacuum dewatering box **51** and during the passage of hot air through the web and the fabric to further dewater and dry the web. This section, as depicted in Figure 2, includes two TAD cylinders **52** for supporting the fabric and web during drying. The web, if sufficiently dry, can be removed directly from the fabric to a take up reel **54**. However, as depicted the web proceeds to an additional drying section **44** that, like the CWP system, includes a Yankee dryer **56**. If a Yankee dryer **56** is used, the web is creped using a creping blade **58** and then rolled up on a take up reel **54**.

A variety of TAD processes and apparatus are described in the patent literature. One example can be found in U.S. Patent No. 3,303,576 to Sisson. In that process a sheet initially at 20% dryness was reduced to a dryness of 50% on a four foot TAD cylinder using a flow of hot air that is maintained using a pressure differential across the web, fabric and cylindrical roll of about 5 to 25 inches of water. This pressure differential was believed sufficient to achieve a reasonable flow of heated air through the cylinder, web and fabric. However, the operating speed was only about 1200 fpm. In this disclosed process, dryness was increased to 80% using a second drying cylinder and hot air.

An alternative TAD configuration is set forth in U.S. patent No. 3,447,247, which discloses a drying system where the drying air is in the form of high speed jets of small diameters for directing heated air onto the sheet. Instead of allowing the air to follow the path of least resistance through the fiber materials, the jets force the heated air through the sheet across its entire surface. This provides more uniform drying of the sheet. Moreover, the speed of the jets may reduce side leaks and lessen the need for seals. This patent discloses air jets with speeds of up to 40 m/sec which are much higher than in conventional through-air dryers; however, the total pressure differential across the cylinder according to this disclosure is still only about 30 inches of water or less, and, in fact is progressively reduced. This total pressure differential comprises that needed across the nozzle to create the jet and that across the web and fabric. The use of concentrated, high-speed air jets can cause disruption of the web making the process unpredictable.

Products made by TAD technology have consistently exhibited superior absorbency and handfeel, often at lighter weights than corresponding conventional wet-press products. These TAD products cannot be manufactured using the conventional apparatus found on the existing wet-press paper machines. The excessive cost associated with installing new TAD paper machines makes the introduction of new TAD lines cost prohibitive as a replacement for existing and functioning wet-press paper machines.

Retrofitting existing CWP machines has always been a possibility for achieving the product advantages of TAD paper. Unfortunately, retrofitting has not been available at reasonable costs due to limited space between the forming section and the Yankee dryer cylinder of conventional wet-press machines. The space between the forming section and the Yankee dryer, conventionally used for the press-felt, is generally too small to allow introduction of either a single standard TAD drying cylinder often having a diameter of at least about 16 ft, or of multiple TAD cylinders with diameters of about six to seven feet as would be required to maintain machine productivity.

Sufficient space between the forming section and the Yankee has been necessary to accommodate one or more large diameter TAD cylinders. Conventionally, these cylinders are on the order of 16 feet in diameter for a single cylinder and could be the same or smaller for multiple cylinder installations. The size of conventional TAD cylinders stems from a number of processing characteristics including but not limited to the amount of residence time on the dryer that is needed to dry the web at conventional differential pressures and machine speeds to an appropriate dryness before removing it from the TAD fabric. These TAD dryers are conventionally operated at modest air pressure differentials across the web and supporting fabric, on the order of 0.5 to 0.75 in. Hg, thereby, among other advantages, minimizing the electrical energy needed to drive the hot air through the web. This results in a relatively small cost in the production of the paper product, but TAD energy costs are still above a typical conventional wet press process expressed on the basis of dollars per ton.

The cost associated with moving one or both of the forming section and Yankee dryer section has also heretofore made retrofitting cost prohibitive. The use of one smaller cylinder and conventional pressure differentials (typically < 1 in. Hg) leads to unacceptably low production capacities. Some machines have multiple TAD cylinders of six to seven foot diameters, but these are used at conventional pressure differential and thus, due to the number required, retrofitting such multiple cylinders into an existing machine is cost prohibitive.

As discussed below, the use of high-intensity through-air-drying according to the present invention allows satisfactory drying using a much smaller cylinder, thus, making retrofitting of conventional wet-press machines a viable alternative.

SUMMARY OF THE INVENTION

Further advantages of the invention will be set forth in part in the description which follows and in part will be apparent from the description. The advantages of the invention may be realized and attained by means of the instrumentalities and combinations particularly pointed out in the appended claims.

To achieve the foregoing advantages and in accordance with the purpose of the invention, as embodied and broadly described herein, there is disclosed:

An apparatus for forming a paper web comprising: a forming means for forming a nascent web; a non-compactive dewatering means for removing liquid water from the nascent web where the means does not include passage of air at elevated temperatures through the sheet; an impression fabric for supporting the nascent web during drying; means for creating a pressure differential of from about 1.5 in Hg to about 15 in of Hg between the first side of the impression fabric and the second side of the web on the impression fabric; and means for removing the dried web.

There is further disclosed:

A method of retrofitting a conventional wet press paper line including a forming section, a felted dewatering section and a drying section comprising: removing the felted dewatering section of a paper line and replacing that section with a through-air-drying cylinder sized to use all available space between the forming section and the drying section; where the through-air-drying cylinder has associated with it, means for creating a pressure differential of from at least about 1.5 in. Hg to about 15 in. Hg.

There is still further disclosed:

A method of making a fibrous web comprising: providing fibers in an appropriate liquid dispersion to a forming structure; forming an embryonic web; dewatering the embryonic web to a solids content of at least about 20% by removal of liquid water; passing heated air through the web wherein the pressure differential across the web is between about 1.5 and 15 in of Hg.

Finally, there is disclosed:

A method of making a cellulose web comprising: providing fibers in an appropriate solution to a forming structure to form an embryonic web; dewatering the embryonic web to a solids content of greater than 30% by removal of liquid water from the web; thereafter passing heated air through the web, where the pressure differential across the web during passage of the hot air is between about 1 in. Hg and 15 in. Hg.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a conventional wet press processing apparatus.

Figure 2 illustrates a conventional through-air-drying (TAD) apparatus.

Figure 3 is a graphical representation of the residence time requirement of TAD processes as a function of pressure differential across a TAD fabric and web.

Figure 4 is a graphical representation of the energy cost associated with TAD processes as a function of the pressure differential across the TAD fabric and web.

Figure 5 is a graphical representation of the relationship between residence time requirement of TAD processes and through-air-dryer energy cost.

Figure 6 illustrates a preferred retrofit arrangement for a conventional wet-press paper line using both high vacuum assisted dewatering and high-intensity through-air-drying.

Figure 7 is a graphical representation of the drying rate based upon effectiveness, as a function of air inlet velocity.

DETAILED DESCRIPTION

In a preferred embodiment of the present invention a higher than conventional pressure differential is applied across the paper web during through-air-drying in order to achieve higher than normal drying rates per unit area, so that the required size of the TAD equipment will be reduced to the point that its cost and size facilitate a low-cost rebuild of an existing CWP machine to a TAD process. The improvements according to the present invention are not, however, limited to retrofitting and are expected to be of benefit for new and /or existing TAD paper machines, as well.

Figure 3 illustrates the effect of the pressure differential on the residence time required to dry a web via the through-air-dryer method. This figure illustrates the improvements that can be realized in one preferred embodiment of the present invention where high pressure differential (vacuum) through-air-drying is used to reduce drying time by a factor of at least about two to six.

Figure 4 illustrates the effect on through-air-drying energy cost that can be expected when high vacuum through-air-drying is used.

Figure 5 illustrates the tradeoff between the increased cost for the energy to assist the TAD process through higher pressure differential and the residence time required to dry the web.

The TAD process of the present invention retains essentially the same steps as conventional TAD processes:

1) formation of a nascent web;
2) transferring the nascent web to an impression fabric;
3) vacuum or any other suitable dewatering of the web;
4) through-air-drying of the web;
5) transferring the web to a Yankee dryer (optional);
6) creping the web (optional); and
7) transporting the dry web to a reel.

In the case of retrofitting CWP machines for TAD use, it would be evident to the skilled artisan that art recognized changes can be effected to any of the retained apparatus, particularly for improving process efficiency. In most retrofit instances, the Yankee dryer would be retained.

A nascent web is formed from a fibrous slurry in a liquid dispersion. The fibers can be natural fibers, artificial fibers, or mixtures thereof. The fibers are preferably selected from softwood, hardwood, chemical pulp obtained from softwood and/or hardwood by treatment with sulfate or sulfite moieties, mechanical pulp obtained by mechanical treatment of softwood and/or hardwood, recycle fiber, refined fiber and the like. The slurry can contain appropriate modifying chemicals including but not limited to dry- strength agents, wet-strength agents, softeners, debonders, surfactants, defoamers, scavengers, retention aids, dyes or colorants, release agents, and pH control agents.

The present invention contemplates the use of any known headbox configuration for feeding the fibrous slurry to the forming wire. Accordingly, a single feed nozzle or multiple feed nozzles may be used leading to a homogeneous or stratified product. The forming means may be any art recognized configuration including but not limited to a twin wire former, a crescent former, a suction breast roll former, and the like.

Dewatering of the web can take place on the forming fabric, on an impression fabric, and/or on an intermediate carrier fabric. According to the present invention, the dewatering means can be selected from any art recognized system including one or more of: steam preheating of the web, followed by vacuum dewatering; capillary dewatering; and vacuum dewatering augmented with hot, moist air. Capillary dewatering is described in U.S. Patent Nos. 4,556, 450 and 5,274,930, as well as PCT Application No. WO 96/16305, each of which are incorporated herein by reference in their entirety. Vacuum dewatering augmented with hot, moist air is described in PCT Application No. WO 96/29467 to Marchal et al., which is incorporated herein by reference in its entirety. The present invention may use any known non-compactive dewatering technology thus allowing the dewatering system to be selected from the most cost-effective dewatering technologies available at the time. Furthermore, it allows for dewatering to be applied up to any physically reasonable solids level, likely in the 20% to 40% range, prior to starting the TAD step. The preferred solids content after dewatering is at least 20%, more preferably at least 25%, still more preferably at least 30% and in some instances as much as 40% solids may be achieved in the dewatering step.

The nascent web can be transferred from the forming structure to a carrier fabric which may also be a TAD impression fabric. During transfer of the paper web from the forming fabric or a carrier fabric to a TAD fabric, differential speed of the two fabrics (with the forming fabric speed exceeding the TAD fabric speed) can create conditions which impart properties to the web similar to creping. The effect of this differential fabric speed has been referred to as fabric/fabric creping. In a preferred embodiment of the present invention, the fabric/fabric crepe is carried out at 0% to 30%, more preferably 5% to 15%, most preferably 7%-10% speed differential (using the TAD fabric speed as the base).

After dewatering, the web is passed through a predryer means where hot air is passed through both the web and the impression fabric to cause substantial drying of the web. For paper lines already containing a TAD drying section, the present technology can be used to modify the existing TAD lines through the addition of an increased pressure differential across the web and TAD fabric, and thus increase productivity.

TAD systems operate in two basic configurations. When a TAD system is operated in the inside/out mode, hot air is pushed out of the TAD cylinder and through the web and fabric sandwich into a collector. In this mode, the impression fabric tension must be in force balance with the pressure differential across the fabric and web. Thus, the pressure differential and/or cylinder diameter must be limited, due to limitations on allowable fabric tension (fabric strength).

When a TAD system is operated in the outside/in mode, hot air is directed from a supply hood through the web and fabric sandwich into the TAD cylinder. This is the preferred mode for implementing the present invention, due to the fabric support provided by the TAD cylinder, which permits greater pressure differentials to be utilized. In this configuration, the air must be removed from inside the cylinder. The TAD cylinder should be selected considering the maximum allowable air velocity inside the cylinder necessary to ensure sufficiently uniform cross-directional distribution of air flow through the web and thus concomitant drying uniformity. The average air velocity through the web tends to increase with increasing pressure differential across the web/fabric sandwich, for a given web basis weight and furnish.

The predryer section can include a drying cylinder for supporting the fabric and web during the hot air drying. Such a cylinder can be any known configuration including but not limited to honeycomb type TAD cylinders, drilled rolls, and the like. In one preferred embodiment, the drying roll is a perforated drying drum, more preferably a drilled roll including internal seals to reduce air infiltration that never passes through the web. The cylinder may have an open area from about 30 to 97% of the area theoretically available. The cylinder preferably has an open area in the range of 60 to 80% of the area theoretically available. The total pressure differential used with the present invention will have to be adjusted upward at lower percent open area to retain the same drying effect per unit time. This total pressure differential comprises at least the pressure drop across the web, fabric and cylinder shell.

The TAD drying cylinders of the present invention must be capable of withstanding a pressure differential across the web, fabric and cylinder of greater than about 1 in. Hg to about 15 in. of Hg, more preferably about 2 in. Hg to about 10 in. Hg, still more preferably, about 2 in. Hg to about 5 in. Hg. The preferred pressure differential across the web, fabric and cylinder may be affected by the % open area available on the TAD cylinder selected and thus, in one embodiment of the present invention, the pressure differential across the web, fabric and cylinder is preferably between about 2 in. Hg and about 3 in. Hg. In another embodiment of the present invention, the total pressure differential across the web, fabric, and cylinder is preferably between about 4 in. Hg and about 5 in. Hg.

The through-air-drying step, which would likely begin after the sheet has been dewatered to 20% to 40% solids and end when the sheet has reached 50% to 80% solids, if the system includes a Yankee dryer, will be done using an applied pressure differential across the web and fabric in the range of greater than about 1 in. Hg to about 15 in. Hg. Hot air is forced through the sheet at a rate many times that in a conventional TAD dryer which typically employs pressure differential across the web, fabric and cylinder of 0.5 to 0.75 in. Hg.

The differential pressure described above affects the air velocity, which affects the drying rate of the paper. Figure 7 is a graphical representation of the effect of air velocity on the drying rate at inlet temperatures of 200 to 220°C dry bulb and 60°C wet bulb. The graph provides a means for considering the effectiveness or efficiency of the system.

In the ideal case, 100% effectiveness, all of the air leaving the moist web is at the wet bulb temperature of the supply air and is saturated with water vapor. The quantity of saturated air leaving the web, and the quantity of hot unsaturated air entering the web, per unit time and per unit web are, are directly proportional to the air inlet velocity. The drying rate for this ideal situation is again represented by the 100% effectiveness curve of Figure 7.

A variety of variables can affect this ideal condition resulting in an effectiveness somewhere below 100%. These variables include but are not limited to finite air velocity, basis weight, finite residence time, and air channeling. Thus, in practice, the air leaving the web may not be fully-saturated.

The average air inlet velocity used during conventional TAD does not exceed about 4.0 m/sec, and is probably closer to about 2.5 or 3.0 m/sec. With reference to Figure 7, it can be seen that for conventional TAD, the drying rates would be less than 140 lb/hr-ft^2. In practice, most conventional TAD systems operate in the area of 60 lb/hr-ft^2.

The average air velocity through the web for the present invention is preferably greater than about 5 m/s, more preferably from about 5 m/s to about 20 m/s, most preferably from about 7 m/s to about 15 m/s. These air velocities allow the drying rates achieved by the present invention to be about 140 lb/hr-ft^2, more preferably between 140 and 400 lb/hr-ft^2 and most preferably 140 to 250 lb/hr-ft^2.

The inlet temperature for TAD dryers can range from .e.g., 120 to 300°C. In this range of temperature, the required size for a high-pressure-differential dryer will be several times less than for a conventional TAD dryer, for equal production rate and inlet temperature. Average diameters for the TAD dryer are less than about 14 feet, preferably less than about 12 feet, more preferably less than about 10 feet, still more preferably less than about 8 feet, and most preferably between about 5 and 8 feet.

With smaller TAD cylinders, the necessary space and related installed cost will be far less, facilitating low-cost rebuilds of CWP machines to TAD capability. The energy cost associated with operating the hot air circuit at a high pressure differential will see a marginal increase. However, given the potential reduction in installed cost, the marginal increase will not make retrofitting in this manner cost prohibitive. An additional benefit of a rebuild in accordance with the present invention is that greater production rates are possible, for a given TAD cylinder diameter, due to the high-intensity drying.

The web can then be transferred to another carrier fabric or may be pressed to the surface of a rotating Yankee dryer cylinder. Liquid adhesive can be sprayed on the surface of the Yankee to adhere the web to the Yankee. The web can then creped from the surface with a creping blade. The web is preferably creped with a crepe ratio of 0% to about 20%, more preferably from about 5% to about 15% and most preferably about 10%. The creped web can be passed between calendering rolls and rolled up prior to further converting operations.

As an alternative to adhering the web to the Yankee and creping it from that surface, the web may in some embodiments be dried to about 95% solids on the impression fabric, removed directly from the impression fabric and rolled up.

The web produced according to the present invention has a basis weight of from 10 to 80 g/m^2, more preferably 10 to 50 g/m^2.

One preferred embodiment of the present invention is set forth in Figure 6. A paper slurry in headbox **70** is fed to a forming wire **72** where a nascent web is formed. The nascent web is transferred to impression fabric **74** and subjected to high-vacuum dewatering. The web passes steam box **76** used to preheat the web; shaping box **78** to conform the web to the fabric and to remove liquid water from the web; and dewatering box **80** used to remove additional liquid water from the web. Some liquid water is removed from the web and some shaping of the web occurs during transfer of the web from the forming fabric.

In this preferred embodiment, the dewatering box **80** maintains a pressure differential across the web of about 10 in. Hg. In this preferred embodiment, the shaping box **78** maintains a pressure differential across the web of about 15 in. Hg. The vacuum for the shaping box **78** is preferably supplied from a liquid ring pump. In still a more preferred embodiment, hot moist air is also supplied to the web at the shaping box **78**. In this embodiment, burners are integrated with the supply boxes **82** opposite the shaping **78** and dewatering **80** boxes. Moist air exhausted from the dewatering vacuum box circuit is recirculated to feed the shaping-box circuit, constituting a counter-current process.

The dewatered web at a solids content of about 35%, then passes to a TAD cylinder **84**. In a preferred embodiment, the cylinder is about 6.5 feet in diameter and is run with a differential pressure of about 4 in. Hg across the cylinder shell, fabric and web. The inlet temperature is about 230°C and the air velocity entering the web is in the range of about 5 to about 20 m/sec. The web is dried to a solids content of about 60% and then transferred from the impression fabric **74** to the Yankee cylinder **86**. The web is dried at a temperature of about 90°C and then creped from the Yankee cylinder at a solids content of about 95%.

Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with the true scope and spirit of the invention being indicated by the following claims.

We claim:

1. An apparatus for producing a paper web comprising:

a forming means for forming a nascent web;

a non-compactive dewatering means for removing liquid water from said nascent web free of passage of air at elevated temperature through said sheet;

means for predrying said nascent web, including an impression fabric for supporting said nascent web during drying and means for creating a pressure differential of from about 1.5 in. Hg to about 15 in. Hg between a first side of said web and a second side of said impression fabric; and

means for removing said dried web from said apparatus.

2. The apparatus according to claim 1, wherein said means for drying comprises a through-air-drying cylinder.

3. The apparatus according to claim 2, wherein said through-air-drying cylinder is less than 14 feet in diameter.

4. The apparatus according to claim 2, wherein said through-air-drying cylinder is less than 12 feet in diameter.

5. The apparatus according to claim 2, wherein the through-air-drying cylinder is less than 10 feet in diameter.

6. The apparatus according to claim 2, wherein the through-air-drying cylinder is less than 8 feet in diameter.

7. The apparatus according to claim 6, wherein the through-air-drying cylinder is between about 5 feet and 8 feet in diameter.

8. The apparatus according to claim 1, further comprising a Yankee drying cylinder between said impression fabric and said means for winding said dried web.

9. The apparatus according to claim 1, wherein the forming means is selected from a crescent former, a twin wire former, and a suction-breast-roll former.

10. The apparatus according to claim 1, wherein said means for creating a pressure differential generates a pressure differential of from about 1.5 in. Hg to about 10 in. Hg.

11. The apparatus according to claim 10, wherein said means for creating a pressure differential generates a pressure differential of from about 2 in. Hg to about 5 in. Hg.

12. A method of retrofitting a conventional wet press paper line including a forming section, a felted dewatering section and a drying section said method comprising:

removing the felted dewatering section of said paper line and replacing said section with at least one through-air-drying cylinder;

wherein said through-air-drying cylinder has associated therewith means for creating a pressure differential of from at least about 1.5 in. Hg to about 15 in. Hg.

13. The method according to claim 12, wherein the through-air-drying cylinder has a diameter of less than about 14 feet.

14. The method according to claim 12, wherein the through-air-drying cylinder has a diameter of less than about 12 feet.

15. The method according to claim 12, wherein the through-air-drying cylinder

has a diameter of less than about 10 feet.

16. The method according to claim 12, wherein the through-air-drying cylinder has a diameter of less than about 8 feet.

17. The method according to claim 16, wherein the through-air-drying cylinder has a diameter of from about 5 feet to about 8 feet.

18. The method according to claim 12, wherein said means for creating a pressure differential creates a pressure differential between about 2 in. Hg and about 5 in. Hg.

19. A method of making a fibrous web comprising:

providing fibers in an appropriate dispersion to a forming structure;

forming a nascent web;

dewatering said embryonic web to a solids content of at least about 20% by removal of liquid water; and

passing heated air through said web wherein the pressure differential across said web is between about 1.5 in. Hg and about 15 in. Hg.

20. The method according to claim 19, wherein said heated air is passed through said web at an average air velocity of greater than about 5 m/s.

21. The method according to claim 20, wherein said average air velocity is from about 5 m/s to about 20 m/s.

22. The method according to claim 21, wherein said average air velocity is from about 7 m/s to about 15 m/s.

23. The method according to claim 19, wherein the web is dried at a rate of 140 lb/hr-ft^2.

24. The method according to claim 23, wherein the web is dried at a rate of from about 140 lb/hr-ft^2 to about 400 lb/hr-ft^2.

25. The method according to claim 24, wherein the web is dried at a rate of from about 140 lb/hr-ft^2 to about 250 lb/hr-ft^2.

26. A method of making a cellulose web comprising:

providing fibers in an appropriate dispersion to a forming structure to form a nascent web;

dewatering said nascent web to a solids content of greater than 30% by removal of liquid water from said web; and

thereafter passing heated air through said web, wherein the pressure differential across said web during passage of the heated air is between about 1 in. Hg and 15 in. Hg.

27. The method according to claim 26, wherein said heated air is passed through said web at an average air velocity of greater than about 5 m/s.

28. The method according to claim 27, wherein said average air velocity is from about 5 m/s to about 20 m/s.

29. The method according to claim 28, wherein said average air velocity is from about 7 m/s to about 15 m/s.

30. The method according to claim 26, wherein the web is dried at a rate of 140 lb/hr-ft^2.

31. The method according to claim 27, wherein the web is dried at a rate of from about 140 $lb/hr\text{-}ft^2$ to about 400 $lb/hr\text{-}ft^2$.

32. The method according to claim 28, wherein the web is dried at a rate of from about 140 $lb/hr\text{-}ft^2$ to about 250 $lb/hr\text{-}ft^2$.

33. An apparatus for producing a paper web comprising:

a forming means for forming a nascent web;

a non-compactive dewatering means for removing liquid water from said nascent web wherein said dewatering includes passage of hot moist air through said web and a pressure differential across said web of from 1 in. Hg to 15 in Hg;

means for predrying said nascent web, including an impression fabric for supporting said nascent web during drying and means for creating a pressure differential of from about 1.5 in. Hg to about 15 in. Hg between a first side of said web and a second side of said impression fabric; and

means for removing said dried web from said apparatus.

34. A method of making a fibrous web comprising:

providing fibers in an appropriate dispersion to a forming structure;

forming a nascent web;

dewatering said embryonic web to a solids content of at least about 20% by removal of liquid water; and

passing heated air through said web wherein the pressure differential across said web induces an average air velocity of greater than about 5 m/s.

35. The method according to claim 34, wherein said average air velocity is from

about 5 m/s to about 20 m/s.

36. The method according to claim 35, wherein said average air velocity is from about 7 m/s to about 15 m/s.

37. The method according to claim 34, wherein the web is dried at a rate of 140 $lb/hr\text{-}ft^2$.

38. The method according to claim 37, wherein the web is dried at a rate of from about 140 $lb/hr\text{-}ft^2$ to about 400 $lb/hr\text{-}ft^2$.

39. The method according to claim 38, wherein the web is dried at a rate of from about 140 $lb/hr\text{-}ft^2$ to about 250 $lb/hr\text{-}ft^2$.

FIG. 1

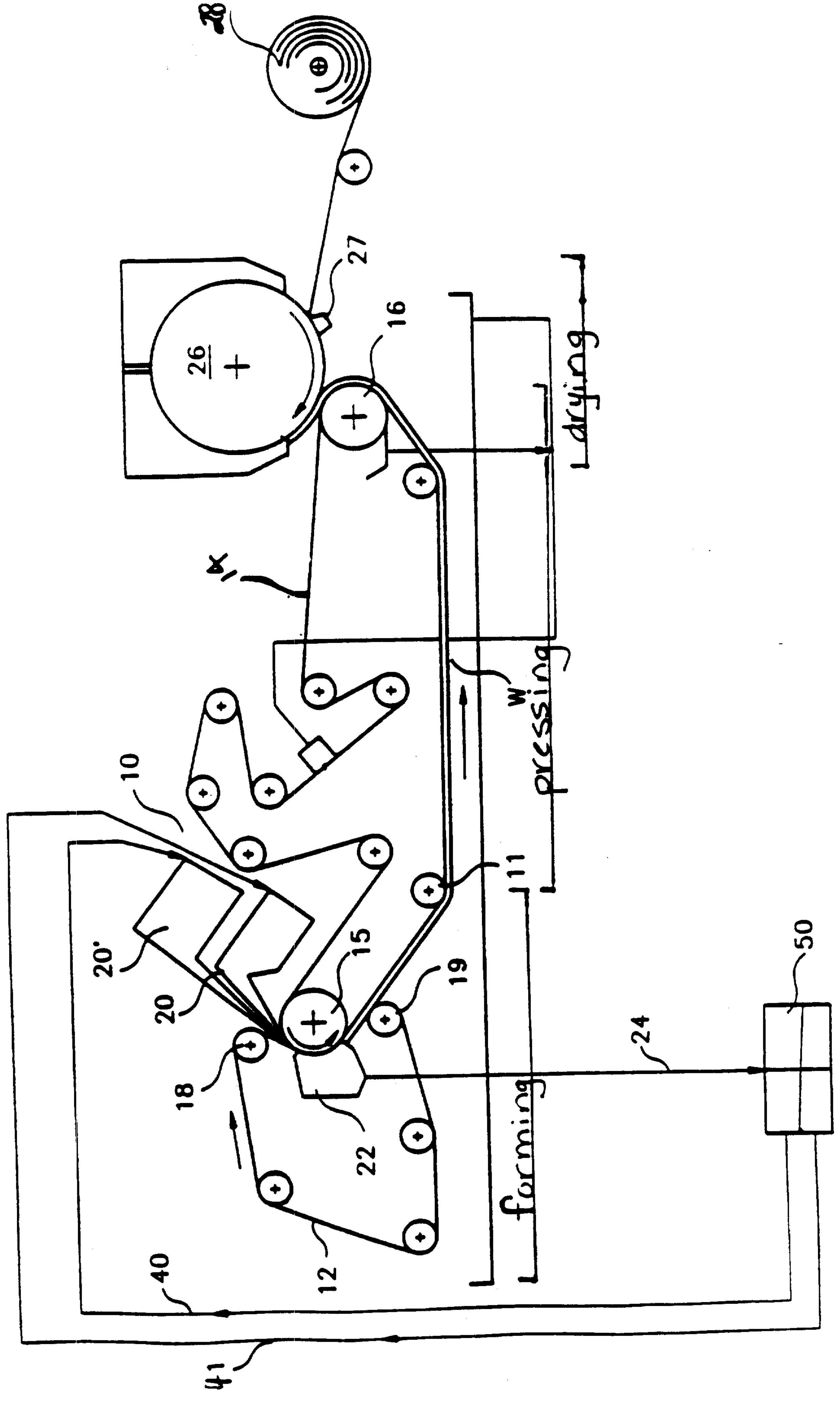
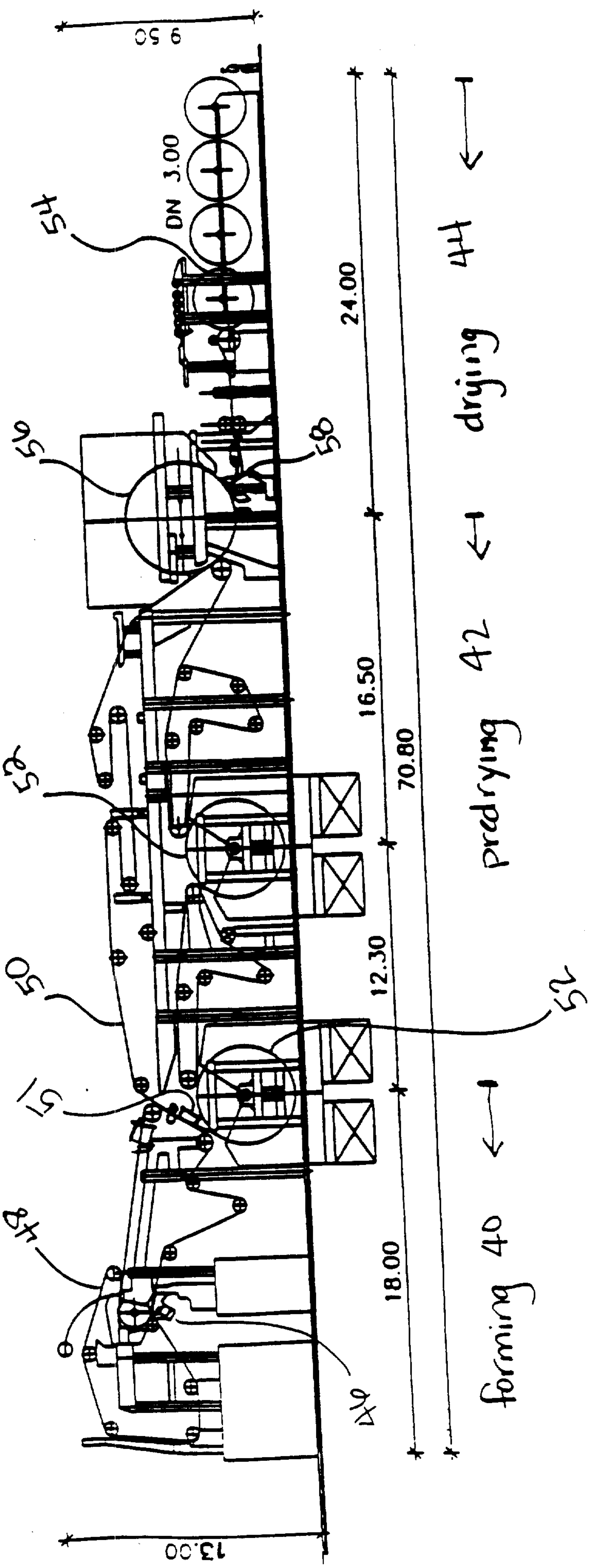

28
27
26
16
drying
pressing
W
10
111
20'
20
15
19
18
22
24
50
forming
12
40
41

FIG. 2



9 50
DN 3.00
54
56
58
52
50
51
52
48
46
24.00
16.50
70.80
12.30
18.00
13.00
forming 40
predrying 42
drying 44

FIG. 3

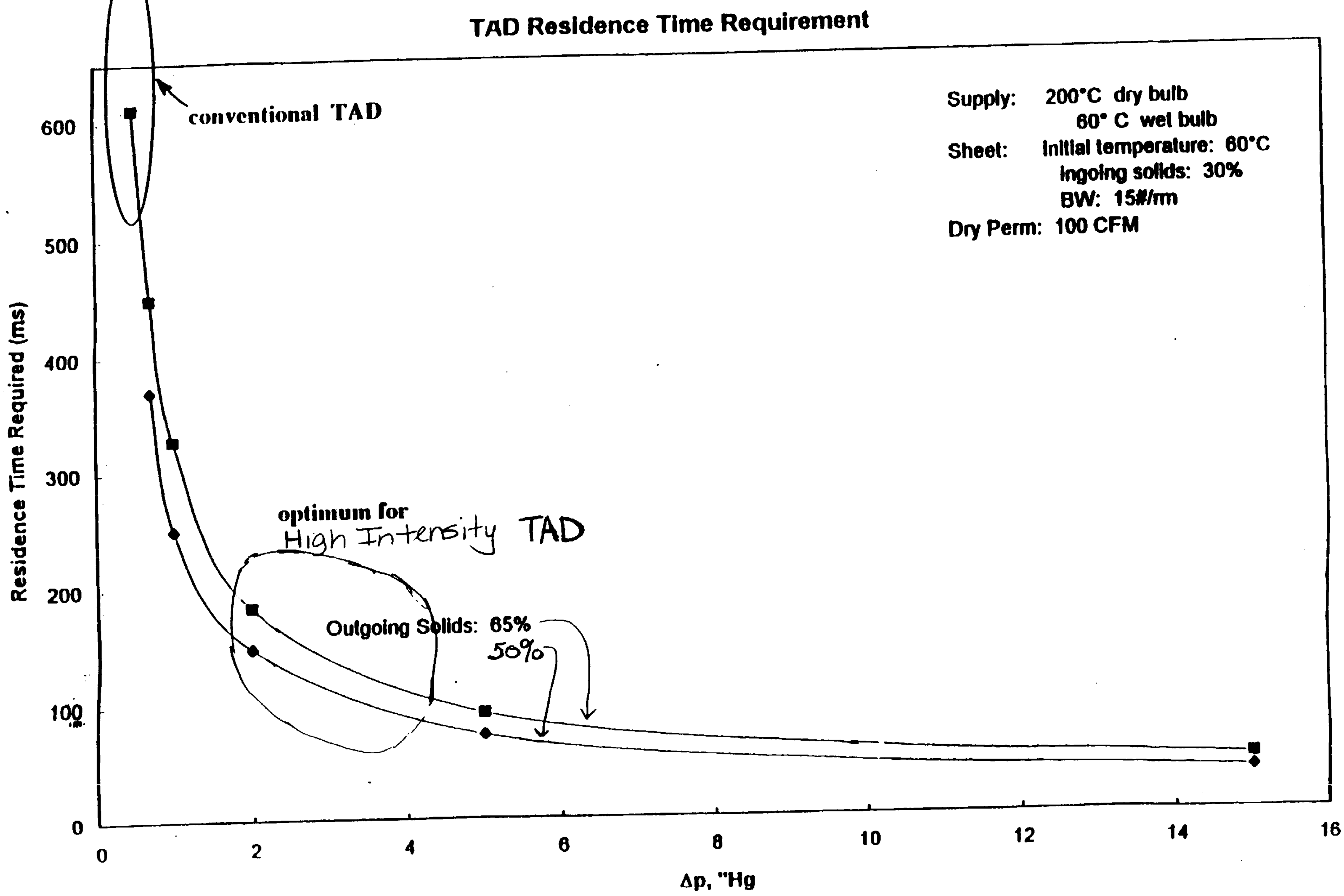
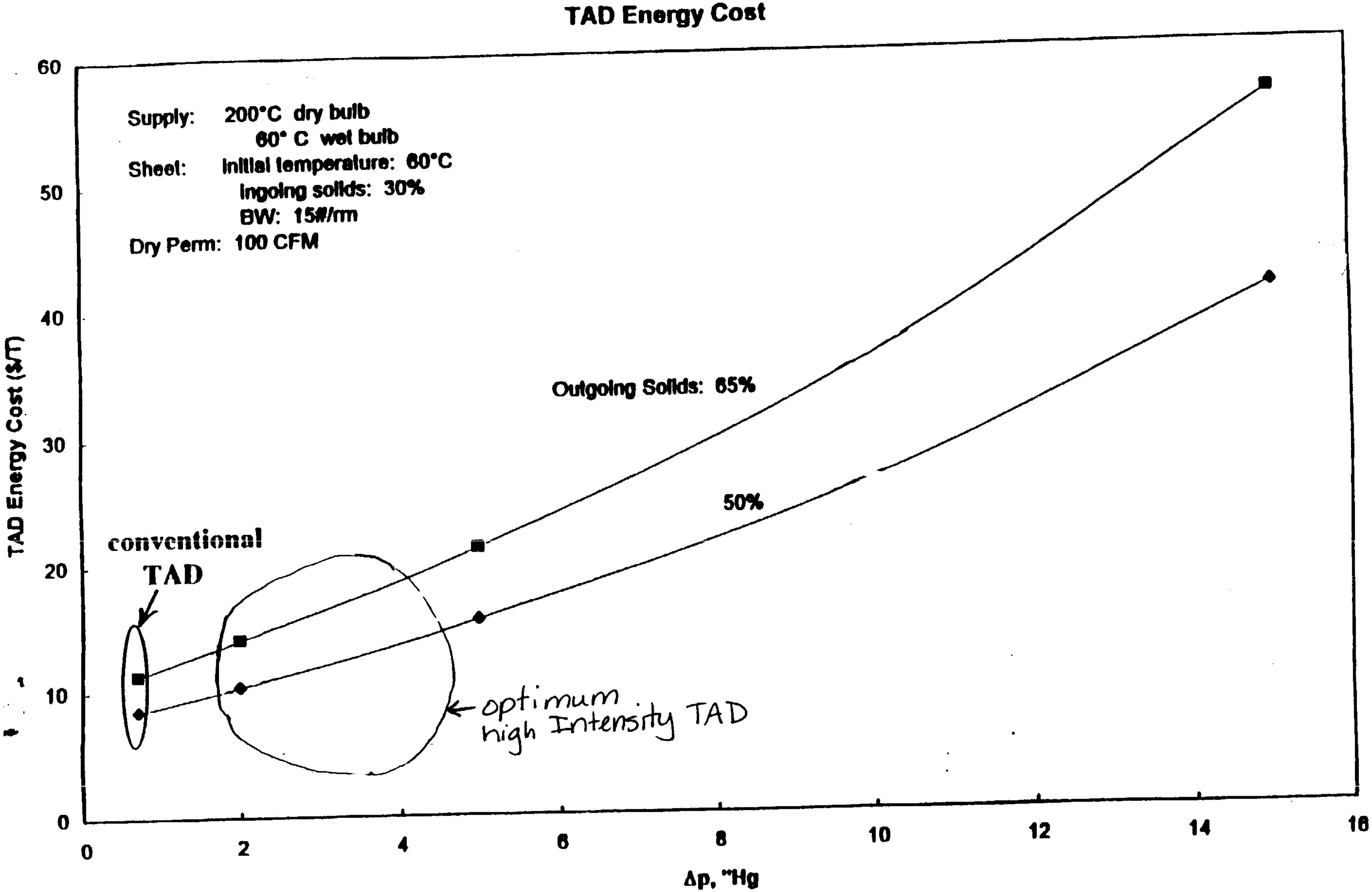

TAD Residence Time Requirement
Residence Time Required (ms)
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
Δp, "Hg
conventional TAD
Supply: 200°C dry bulb
60° C wet bulb
Sheet: Initial temperature: 60°C
ingoing solids: 30%
BW: 15#/rm
Dry Perm: 100 CFM
optimum for
High Intensity TAD
Outgoing Solids: 65%
50%

FIG. 4


TAD Energy Cost
Supply: 200°C dry bulb
60° C wet bulb
Sheet: Initial temperature: 60°C
Ingoing solids: 30%
BW: 15#/rm
Dry Perm: 100 CFM
Outgoing Solids: 65%
50%
conventional
TAD
optimum
high Intensity TAD
TAD Energy Cost ($/T)
Δp, "Hg
0
10
20
30
40
50
60
0
2
4
6
8
10
12
14
16

TAD Residence Time (size) - Energy Cost Tradeoff

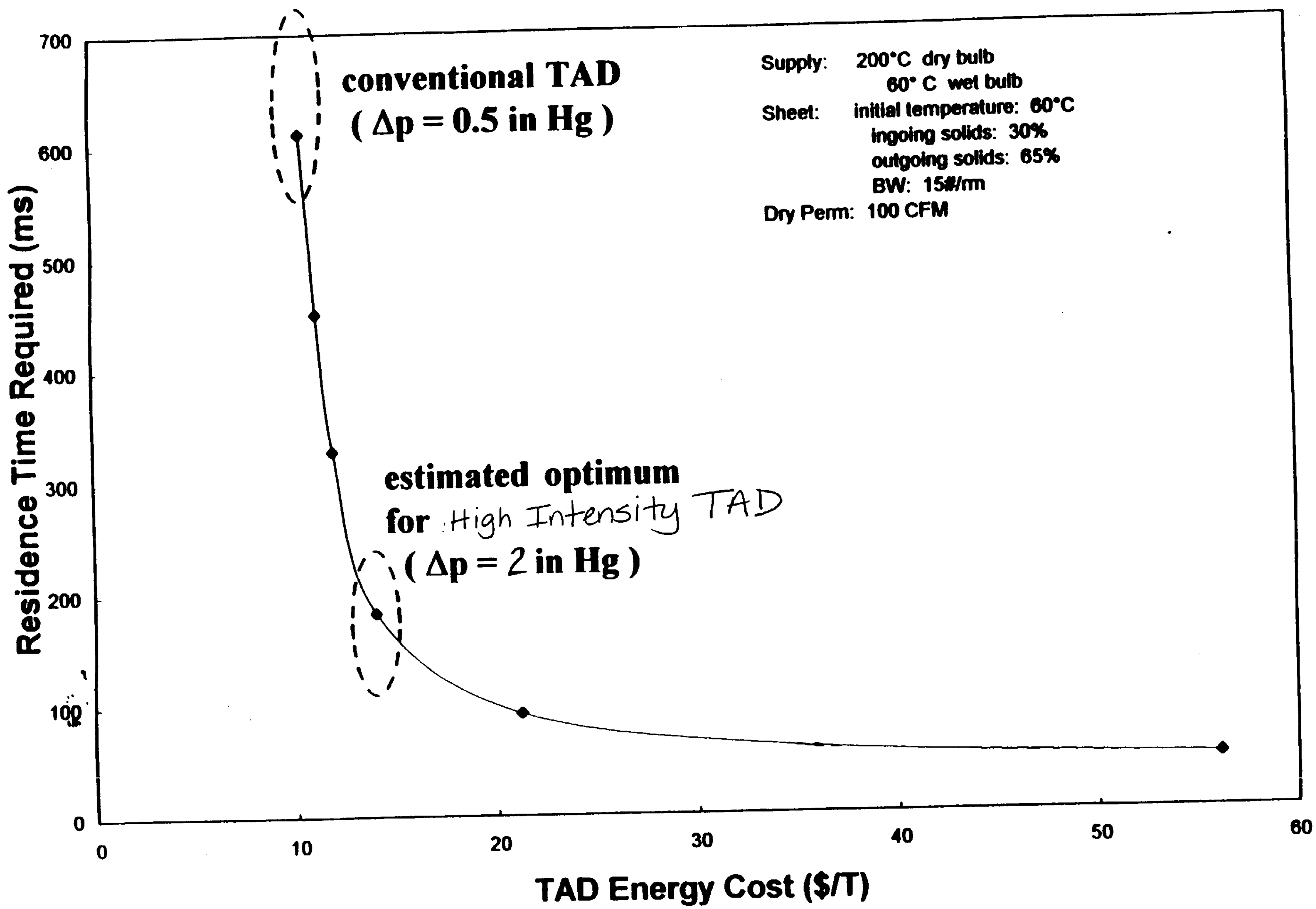
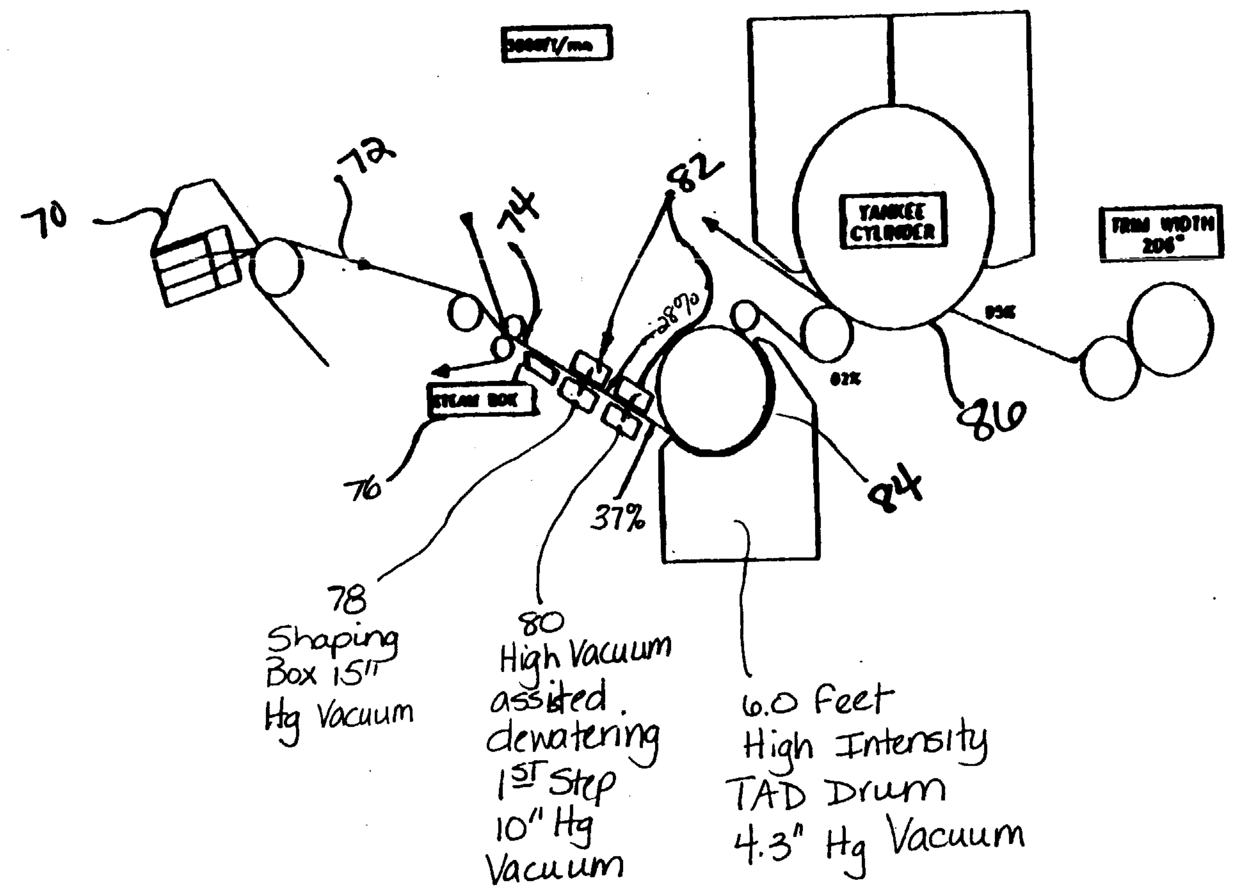
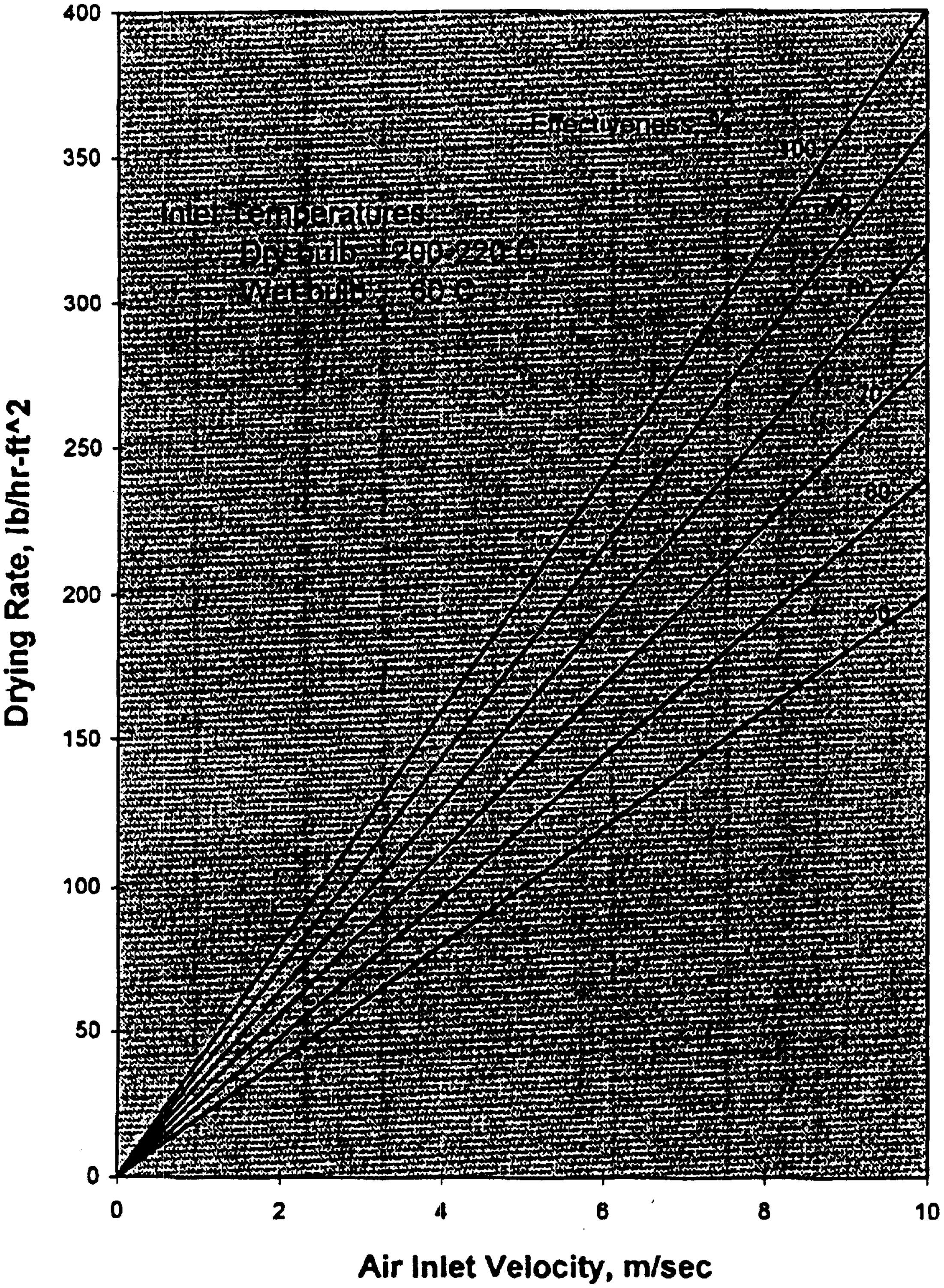


FIG. 6



70
72
74
76
STEAM BOX
78
Shaping Box 15" Hg Vacuum
80
High Vacuum assisted dewatering 1ST Step 10" Hg Vacuum
37%
28%
82
84
6.0 Feet High Intensity TAD Drum 4.3" Hg Vacuum
YANKEE CYLINDER
86
TRIM WIDTH 206"

Figure 7



Effectiveness, %
100
90
80
70
60
50
Inlet Temperatures
Dry bulb 200-220 C
Wet bulb 60 C
Drying Rate, lb/hr-ft^2
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
Air Inlet Velocity, m/sec