DRYING SYSTEMS AND NEW TECHNIQUES FOR PAPERBOARD COATING

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ABSTRACT

Drying systems for coated paperboard applications often seem complex and sometimes contradictory in nature. Just how does one sort out which drying technology to use following a paperboard coating application? A reasonable place to start is to develop a basic understanding of the drying process and the capabilities of the various drying technologies currently available.

Paperboard coatings, while applied in the fluid state, are used in the dried state which means their final properties can be either enhanced or diminished by the drying process. It is well known that a coating operation can experience considerable problems if the drying arrangement is not properly selected.

The drying of paperboard coatings consists of evaporating water from the coating through one of the three drying methods: conduction (steam cans), convection (air drying), or radiation (IR). Having a thorough understanding of the drying process, application requirements, drying hardware and quality problems the drying process can cause, will be beneficial in the selection of the right drying combination. For most applications, the selected drying arrangement will be a combination of several technologies so as to take advantage of the benefits that each system has to offer.

Also discussed is the introduction of some new areas in which flotation technology is being incorporated into production lines to specifically address web handling and drying problems. Topics include the following:

- Web cooling
- Differential air temperatures for curl control
- Air turns for non-contact turning
- High performance dryers
- Combining IR with flotation drying

Key Words: steam can drying, air drying, infrared drying, drying applications, drying calculations, web cooling, curl control, high performance flotation drying, combined gas IR and air flotation.

INTRODUCTION

Coated paperboard manufacturers have been under increasing pressure to improve the coated surface to meet printability and appearance requirements. This is a result of the necessity of today's packaging to serve as a visual aid in the selling process. To meet these requirements, coated paperboard manufacturers have had to undertake a comprehensive review of existing coating facilities and corresponding drying systems.

The drying of coated paperboard involves the removal of all but a small amount of the water in the coating by evaporation and begins immediately upon exit of the coater. Additionally, the process needs to be completed so that the coating quality is not compromised during the drying process. This means that the applied coating needs to be dried in a manner which prevents coating binder migration. To accomplish this requires that the drying process be organized in such a manner that the drying rate be controlled until the coating solids are consolidated.

It is well known that coating quality is directly affected by the structure and composition of the base sheet, the coating formulation, the method of application, the number of applications and the details of the drying process. Additionally it is common knowledge that an improper drying strategy can very quickly ruin a potentially good surface coating even though the coating technology is correct. To avoid this potential problem, it is important to have a clear understanding of the drying process, the drying technology available and how to apply the various drying systems in typical coating applications.

Having a sound understanding of the fundamental requirements of heat and mass transfer will provide a format to understand the principles of drying and the application of the various technologies available. Because evaporation or drying is an endothermic process, heat must be supplied to the drying process through one of the three methods of heat transfer: conduction, convection, or radiation. Proper application of one or more of these methods can result in a dried coating which has the quality attributes required of today's modern packaging.

Today's manufacturers of coated paperboard and paper face an increasing requirement for the production of sophisticated functional products. The move towards higher value added products and the recent trend towards "on-machine" coating operations has in turn brought with it a requirement for advanced drying/cooling configurations and contactless web handling systems.

Advances in these areas have brought forth a myriad of new machine configurations not thought possible with older generation equipment. These possibilities are still emerging and some new layouts have emerged as a direct result of the new technology.

Today's competitive global market requires a re-thinking of traditional operational practices. What we did yesterday may not be applicable for today's requirements. New technology and refinements of existing technology should not be overlooked when considering modifications to existing operations. Many times the new technology being offered can give a marginal operation a competitive edge in the marketplace.

Coated Paperboard

To develop an understanding of the coated paperboard drying process, one needs to have a good physical picture of what it actually is that needs to be dried. Fig. 1 represents a coated paperboard cross-section upon exiting the coater.

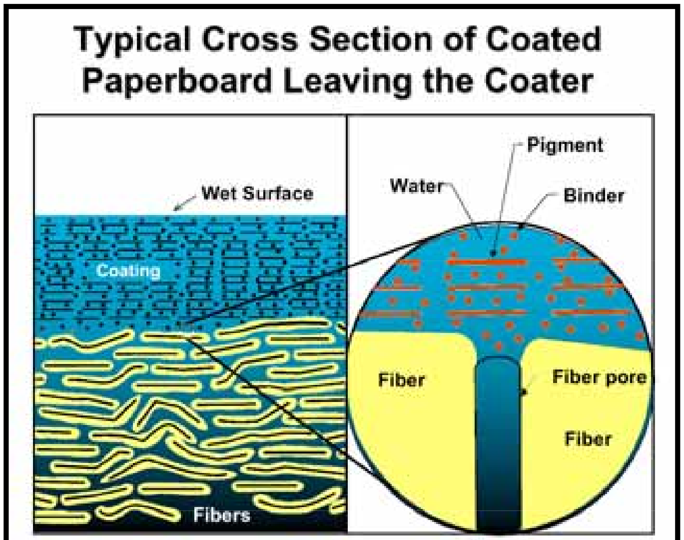

Fig. 1

Notice that the base sheet consists of a stack of individual hollow wood fibers which vary in thickness depending on the tree species and age. The coating is then applied on top of this stack of fibers during the coating process.

The applied coating is a fairly homogeneous mixture of pigments, binder and water as depicted in the representative cross-section. The water is the carrier for the other coating ingredients and is removed during the drying process. The pigments are used to hide or cover-up the fibers in the base sheet. The binder is used as the glue to join everything together and to fasten the other ingredients to the base sheet.

The coating dry weight and applied solids content will determine the applied wet coating thickness. Typically, clay coatings are applied at a solids content of 55-65% which results in wet coating thickness which averages from 5 to 30 microns. The relationship of coating thickness to coating solids is illustrated in Fig. 2 below.

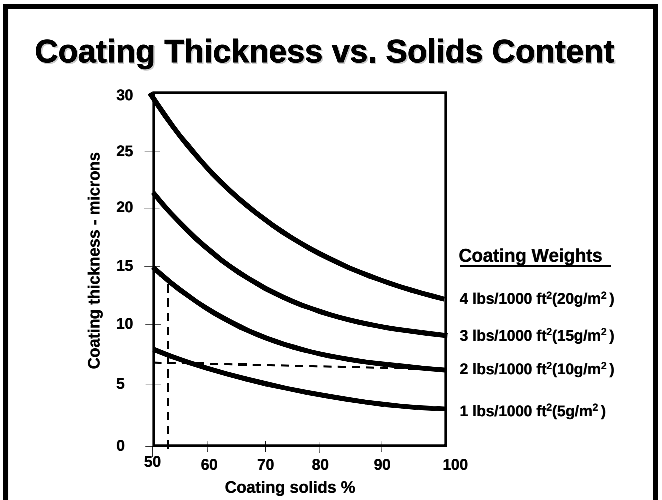

Fig. 2

For example, a wet coating of 2 lbs/1000 ft^2 (10 g/m^2) applied at 55% solids would have a coating thickness of about 14 microns. At 100% solids, the coating thickness is reduced to approximately 6 microns. This arrangement represents a fully packed configuration with no water remaining in the coating.

Dewatering into the Paperboard Base Sheet

While still in the coater the excess water in the coating will begin to migrate into the paperboard by moving into the fiber pore structure and by absorption into the actual fibers. The movement of water into the base sheet is termed dewatering and is the primary mode of water movement prior to the actual drying process. It is important to understand the dewatering process and its effect on the movement and redistribution of coating binder as related to binder migration. During the drying process most of this water will need to be removed to meet the target web dryness.

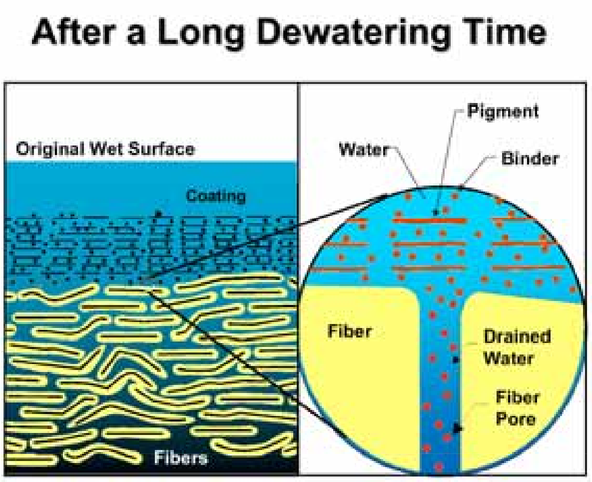

Fig. 3

During the dewatering process moisture from the coating layers near the base sheet will move throughout the porous coating solids matrix from the spaces between the pigment particles. This will cause the liquid areas near the base sheet to be depleted first causing compacting of the coating solids in that area and then moving towards the coating surface. Dewatering will therefore tend to immobilize some of the coating binder and promote coating bonding to the base sheet. Fig. 3 illustrates how dewatering into the base sheet occurs immediately following the coater and prior to drying.

The determination of the final coating structure and associated properties will be a function of how the water moves through the coating solids structure. Influencing this movement is the tendency for the water to move into the base sheet pore/fiber structure offset by the effects of the drying process.

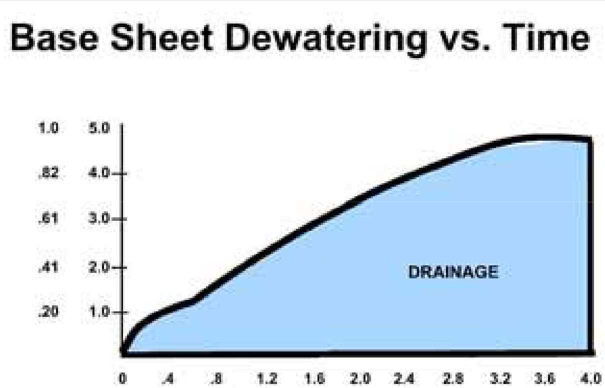

Fig. 4

Dewatering rates will be a function of the composition of the base sheet, the coating, and the corresponding temperature of the composite. Fig. 4 shows a representative plot of the amount of dewatering as a function of time.

Dewatering should not be considered a substitute for drying but rather a shift in the location of some of the water from the coating to the base sheet. The total amount of water to be removed or dried remains the same when everything is viewed as a system.

Drying Paperboard Coatings

One of the first requirements for drying coated paperboard is to dry the newly applied coating without picking off the wet coating by physical contact with a roll surface. Secondly, the drying must be done in such a manner so as that coating quality problems are not developed (binder migration) during the drying process. Surface deposits of binder can influence the printing process by effecting ink receptivity causing print mottle.

The most critical period during the drying process starts when the coating is applied and ends when the coating reaches the gel or immobilization point. Typically this is defined as the point in the drying process where the coating binder movement drops off to a harmless level regardless of the drying rate applied. This occurs when the binder becomes physically trapped between the particles of clay and becomes immobilized or consolidated. Research has shown that coating immobilization is not a discrete event but occurs over a range of average solids contents.

As the coated paperboard sheet travels between the coater and the first dryer and at the same time sheet dewatering is occurring, evaporation from the surface will begin at a slow rate. Due to the absence of an energy source, the coated paperboard sheet will undergo evaporative cooling and will therefore enter the dryer at a lower temperature than when it left the coater.

Prior to the entry of the first dryer, the entire surface of the coated paperboard web is wet and available for evaporation. The drying process will initially remove water from the free liquid on the coating surface and as long as the surface water remains continuous, all the evaporation will occur from that area. Once this surface layer has evaporated, the air/liquid interfaces will move down into the coating pores with surface tension forces drawing water by capillary flow from the spaces between the pigment particles in the coating to replace the water removed by evaporation. As more water is removed consolidation or gelling of the coating solids will occur at the surface of the coating towards the base sheet. As the drying process continues the water from within the coating layer will no longer replenish the surface with the results that dry coating pore will begin to show and the gel point reached. At this point, the coating solids down thorough the coating will be consolidated and the coating binder wherever it may be, will be locked in place. Fig. 5 illustrates this drying process.

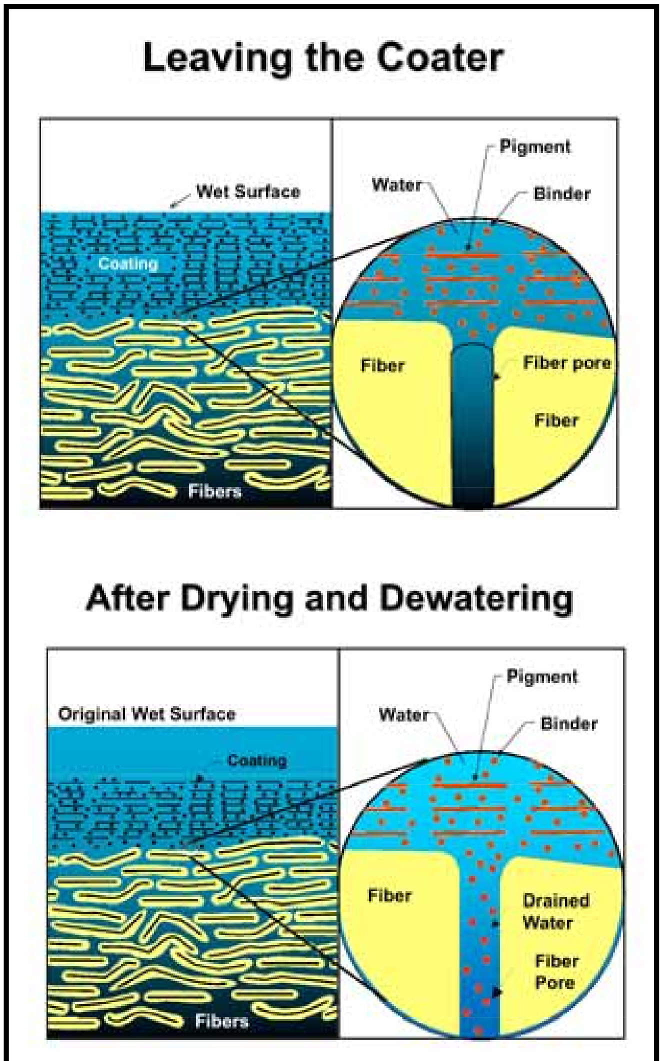

Fig. 5

The drying process is opposite to the dewatering process since it moves binder towards the coating surface, where as dewatering moves binder towards the paperboard base sheet. Manipulating the drying process will allow the organized movement of moisture to the coating surface in a way that insures coating quality.

Optimizing coating quality requires a delicate drying balance. This requires that drying rates, coating application temperature, base sheet temperatures and distance to the drying system all must be managed to ensure the optimum sheet quality. Drying the coating too aggressively can lead to potentially harmful binder migration. Drying too slowly can lead to potentially harmful dewatering with corresponding fiber swelling. Therefore, it is important that care be taken to apply each type of drying properly and in the proper sequence at the necessary intensity.

Drying Fundamentals

Commonly used paperboard drying systems all function by thermally removing the excess water from the coating applied to the web. Another way of looking at this is to say that drying occurs when the coated web is subjected simultaneously to heat and mass transfer. The speed at which heat and mass transfer can be applied and maintained can be characterized as the drying rate of the drying process. This process is illustrated in Fig. 6.

Simultaneous Transfer of Heat and Mass During the Drying Process

Heat Transfer = f (Ta - Tc)
Where: Ta = Temperature air
Tc = Temperature coating and web mass

Evaporation Rate (Mass Transfer) = f (Pc - Pa)
Where: Pc = Partial pressure of solvents at coating slurry surface
Pa = Partial pressure of solvents in turbulent air stream

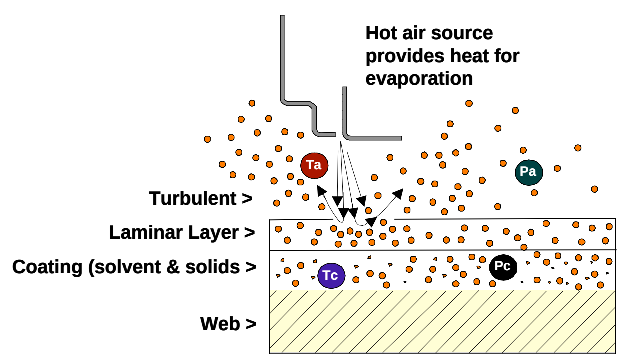

Fig. 6

Heat transfer is defined as energy in transition due to a temperature difference. During the drying process the driving force for heat transfer is the temperature difference between the coated paperboard and the drying system.

The three basic mechanisms of heat transfer can be identified as follows:

- *conduction*: transmission of heat between molecules through a stationary solid, liquid or gas. Steam cylinders in direct contact with the sheet would be an example of this method of heat transfer.

- *convection*: the process of heat transfer between a surface and a liquid or gas in motion. Impingement air from an air dryer would be an example.

- *radiation:* the transfer of heat in the form of electromagnetic waves. IR drying would be an example.

At operating temperatures below 750°F (400°C), both conduction and convection are the major modes of heat transfer while at higher temperatures radiation serves this role.

In general terms, mass transfer can be described as the vaporization of the excess coating moisture at the coating surface and its transport into the surrounding air stream. Mass transfer (or evaporation) is a function of the difference in partial pressures existing between the water in the coating slurry and the moisture vapor in the surrounding air. The greater the difference in partial pressures (driving force), the greater the mass transfer or evaporation. Drying or mass transfer starts when the partial pressure of the excess water at the coating surface becomes greater than the water vapors partial pressure in the surrounding air stream.

To put into prospective the role of heat and mass transfer in the drying of coated paperboard requires a familiarity with the three phases of drying as described below.

- *Pre-heat* describes that phase which involves the heating of the paperboard, coating and water to the equilibrium drying temperature. Most of the energy transferred in this phase is used for heating or increasing the temperature of the coated substrate. Additionally, some small amount of evaporation does occur.

- *Steady state evaporation* describes the evaporation of water in proportion to the amount of heat transfer at the equilibrium drying temperature. Most of the drying or evaporations occurs during this phase. Since most of the energy is being used to evaporate water, the coating and paperboard temperatures tend to remain fairly constant.

- *Falling rate* describes the drying phase where the evaporation rate begins to decline due to the lack of moisture in the coating and the base sheet. Consequently the energy transmitted from the dryer causes the sheet temperature to rise.

The drying process can be represented by a typical drying profile as shown in Fig. 7.

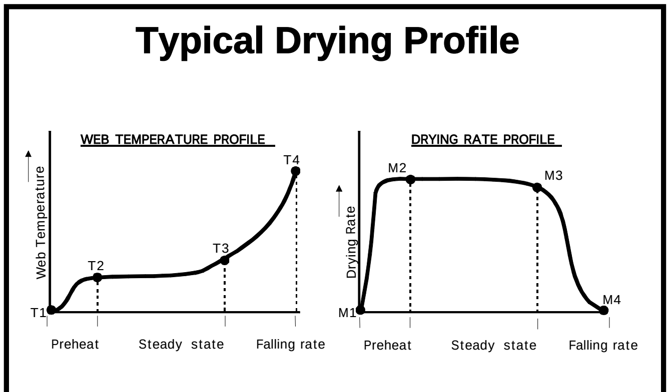

Fig. 7

The coated paperboard enters the dryer at a particular temperature (T_1) and moisture content (M1). The path from T_1 to point T_2 represents the initial drying phase commonly called warm-up or preheat. As additional heat is applied in the drying process the web will experience a decline in the rate of temperature increase and a corresponding rise in the rate of evaporation. The coated web will soon reach a temperature T_2 and remain fairly constant during much of the drying process. The drying rate will reach a level governed by the dryer operating conditions and remain essentially constant (M2-M3). This phase is called the constant rate phase. When available water is no longer present on the coating surface, drying begins to be effected more by the characteristics of the web than the conditions of the dryer and the drying rate begins to decline (M3). At this point the availability of water in the coating surface begins to limit the rate at which evaporation occurs. Eventually only the bound water is left which is released with increasing reluctance as these areas dry out. This will cause a reduction in evaporation (M3-M4) and result in some of the energy provided by the drying system being used to raise the temperature of the web (T_3). This is more commonly referred to as the falling rate phase of drying and continues until the web leaves the dryer as depicted in point M4. As the drying continues to lower moisture content, the exiting web temperature will continue to increase. If the web were to be dried to approach a bone dry condition its temperature would approach that of the drying air (T_4).

The uncoated side of the web will respond to the drying process differently than the coated side. Since the coating process starts with a base sheet which is quite dry, the process of coating on one of the surfaces results in little evaporation taking place from the uncoated side of the web. This will cause the temperature of the uncoated side of the web to rise creating a temperature gradient which will conduct the excess heat arriving on the backside through the sheet thickness to the coating, thereby contributing to its drying. Consequently, when the target web dryness is reached, the coating is apt to be wetter than the base sheet, particularly in an all air drying system. Over time, this difference will be dissipated by diffusion on the reel. This process is illustrated in Fig. 8.

Base Sheet and Coating Drying Rate Profile

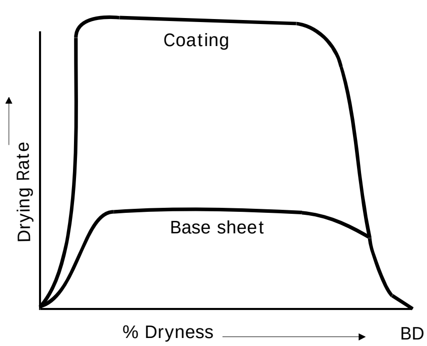

Fig. 8

Drying Systems for Coated Paperboard

The following is a list of some of the drying systems typically employed in drying of coated paperboard.

- Steam cylinders (cans)
- Air impingement dryers (arched idler roll and flat air cap)
- Air flotation dryers
- Infrared dryers

An overview of the general design of each dryer type and how the system can be applied to the drying process will be useful in selecting the proper drying system.

Steam Cylinder Dryers

Steam cylinder dryers have been used in the production of coated paper and paperboard for many years due to the many advantages offered by this arrangement. Specifically, steam cans offer:

- Positive web support with the elimination of long draws

- The coated sheet is dried on a flat surface reducing paper stress, cockle and curl.

- A reasonably efficient conversion of steam latent heat to drying energy resulting in an economical drying method

- Ease of threading and broke handling

A steam cylinder operates by introducing saturated steam through rotary unions. Drying is accomplished by conduction heat transfer from the internal steam source to the surface of the paper. As the steam condenses inside the dryer shell energy is transferred from the steam (heat of vaporization) to the web by conduction through the dryer shell and to the coated paperboard. Since all paper mills have a supply of saturated steam available this is the most widely used heat source. Typical steam cylinder diameters range from 4 to 6 feet (1220 to 1830 mm). Fig. 9 depicts a typical cross section of a steam cylinder.

Typical Steam Cylinder Dryer

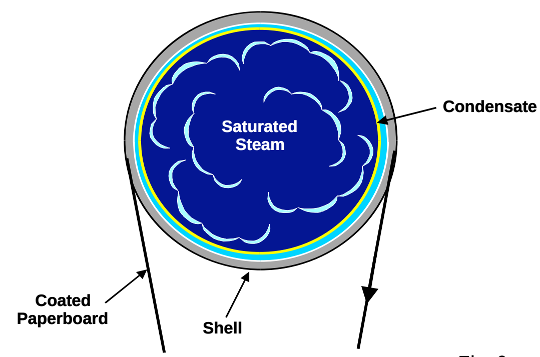

Fig. 9

For the production of coated papers, the use of steam cans requires that the coated side of the sheet be sufficiently dry to prevent sticking or picking of the coating on the hot dryer surface. Therefore, coated grades require some type of non-contact drying prior to the steam cylinders. This can be radiant drying (IR) or convection (hot air) or a combination of both.

Additionally it is advisable to have a non-stick surface on the first cylinder in contact with the coated side of the sheet. Cylinders should also be felted to maximize sheet contact and to ensure uniform heat transfer across the sheet. Felting will also increase contact friction through the section resulting in improved web tension and eliminate web slippage. Fig. 10 shows a typical steam can section.

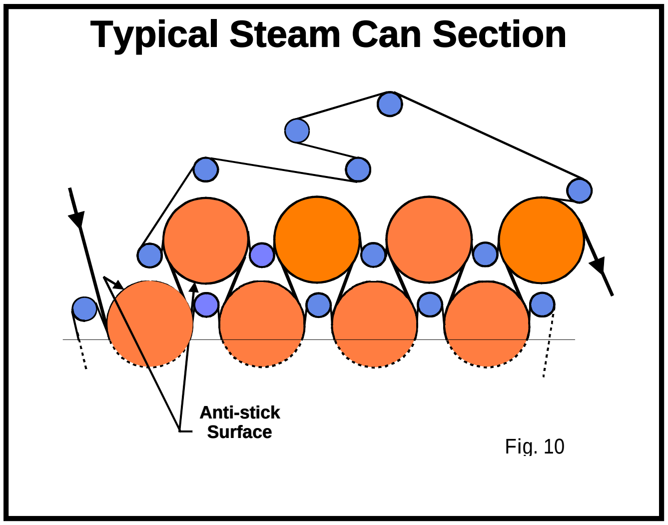

Fig. 10

Steam cylinders are frequently used for the final zone of coating drying after the possibility of coating picking has past. Depending on the drying arrangement, steam cylinders may or may not be required, and in most cases for paperboard drying are an option. They characteristically have low drying rates [0.5 to 3.0 lbs/hr/ft^2 (2.45 to 14.65 kg/hr/m^2)] and are unlikely to cause coating quality problems. Fig. 11 is a chart which can be used to estimate a steam cylinder's drying rate as a function of steam pressure.

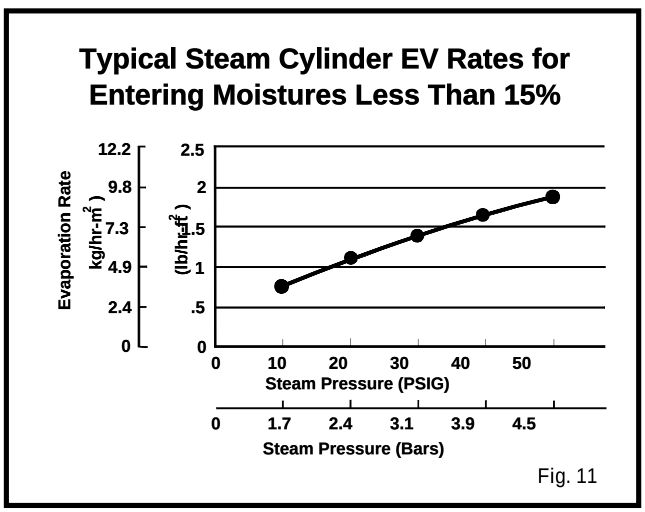

Fig. 11

Air impingement (arched idler roll and flat air cap)

The arched idler roll air impingement dryer has been used extensively for coated paperboard applications over the years. In these systems the web is supported on a series of rolls as it passes through the dryer. The uncoated side of the paperboard contacts the rollers with the top coated side subjected to medium to high velocity heated air. Fig. 12 depicts a typical slot nozzle configuration.

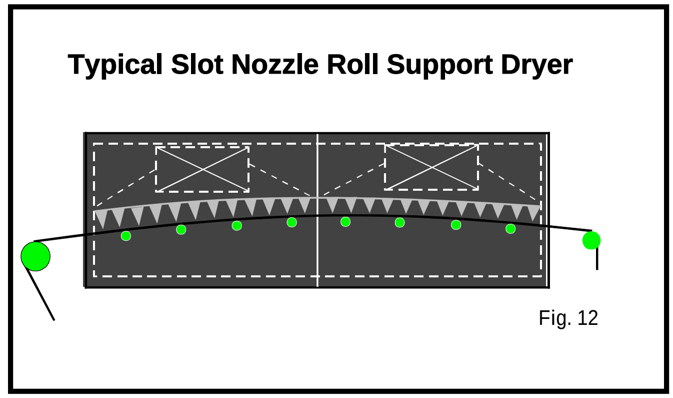

Fig. 12

While several nozzle designs are used, round holes and slot nozzles are by far the most common arrangements employed. The typically preferred arrangement is slot nozzles due to their ability to provide a continuous air jet flow across the entire web width. Slot nozzles with slot width ranges of 1/8 to 1/2 inch (3-12 mm) are typically placed 1 to 2 inches (25-50 mm) above the web and are usually positioned above each web support roll. Typical slot spacing is from 6 to 12 inches (150-300 mm) depending on the application. This arrangement will provide reasonable heat transfer without causing the web to sag or flutter excessively between rolls. Typical slot nozzle evaporation rate arrangements are shown in Fig. 13 for a 1/4 inch (6 mm) slot orifice on 6 inch (150 mm) centers.

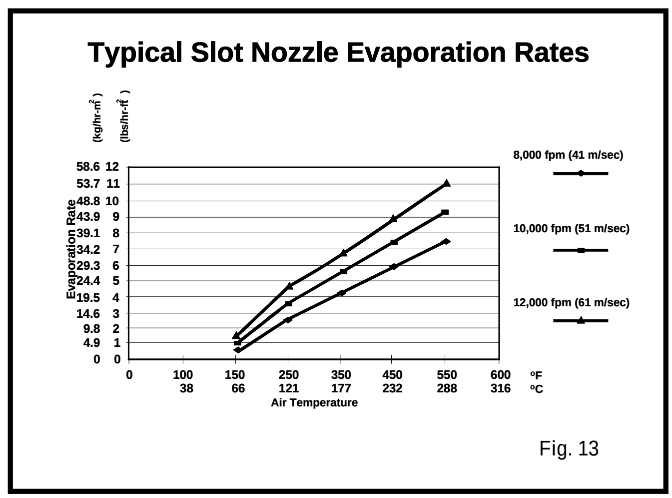

Fig. 13

Some advantages of the idler roll support dryer include its ability to transport the web at low tension levels while maintaining the web at an absolute fixed distance from the impinging air nozzle. The disadvantage of this design is the amount of web drag created by the roller's friction. Each roller requires a certain amount of force to turn it which is generated by the surface contact with the moving web. By design, the web does not have a large wrap angle (2.5 to 5 degrees) around each roll. Consequently, there are times when the small wrap angle doesn't provide enough contact to turn the idler rolls at web speed. This has the effect of causing the web to slide over the slower turning roller. This problem is easily overcome by driving the rollers with a tendency-drive that functions to remove the inherent friction of the roller but doesn't transmit enough torque to turn the rollers. Therefore the friction free roller turns via a positive drive whenever the web moves.

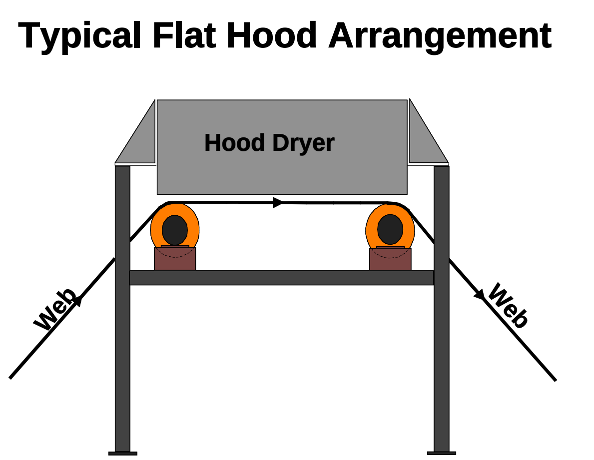

Fig. 14

Another style of impingement dryer which has seen use in drying coated paperboard is the flat hood arrangement shown in Fig. 14. This design uses what is traditionally called a hole bar nozzle with round holes rather than slots for air impingement. At both entry and exit of the dryer is a driven roller to support the sheet approximately 1 to 2 inches (25-50 mm) below the hole bars. In the traditional flat cap design the traveling paperboard sheet forms the bottom of the dryer and functions as a barrier so that the return air can be drawn back into the hood where it would be recirculated and exhausted.

The heating system and supply air system will generally be either steam or gas fired and is normally located in an area adjacent to the drying system to minimize interconnecting duct runs if possible. If the required supply air temperatures are below 350°F (177°C), saturated steam can be used as the heating medium. For supply temperatures over 350°F (177°C) it will be necessary to use natural gas with supply temperatures rarely exceeding 600°F (315°C) for most coating applications. With these levels of operating temperatures, the dryer enclosure needs to be designed to keep the hot air from escaping into the machine room and the enclosure needs to be insulated to keep the other surfaces at a safe operating temperature around 120°F (48°C).

Air Flotation Dryers

Development of air flotation drying technology provided a means of eliminating idler rolls while offering the enhanced benefit of two sided drying. A diagram of a typical flotation dryer is shown in Fig. 15.

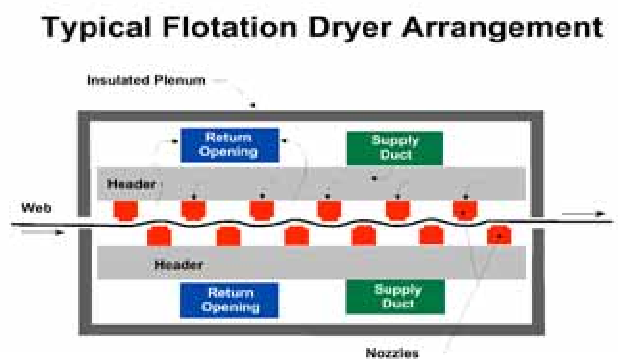

Fig. 15

The operation of a flotation dryer is quite simple. A heating and air supply system delivers heated air to the nozzles or air bars above and below the web. Arranged in a staggered configuration, the nozzles create a pressure pad which supports the web as it passes through the dryer. The dryer supply air is heated by a gas burner or indirectly by a steam coil.

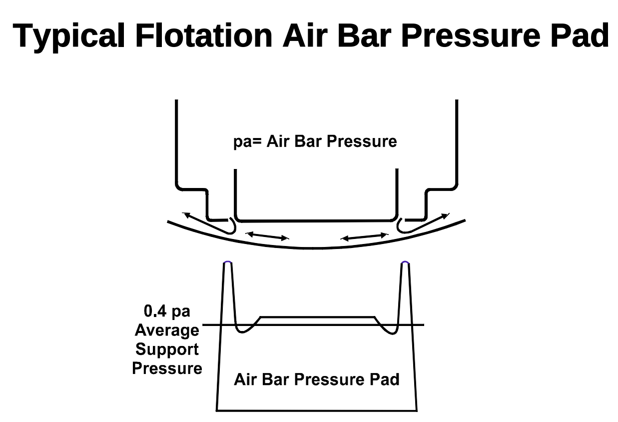

Fig. 16

Air bar designs have evolved over the years and have resulted in a number of designs. The predominate design for coated paperboard is a two slot pressure pad air bar. The design of this air bar consists of two slots separated by a flat support area between slots. Air exiting the slots converges toward the center of the support area between the slots creating a pressure pad along the top of the air bar as shown in Fig. 16. A good dual slot air bar will convert as much as 40% of the nozzle supply pressure to cushion pressure which is used to create the supporting pressure pad. It should be noted that not all air bar designs are equal since some have reduced heat transfer capabilities and excessive fan power requirements.

The primary criteria for designing a good nozzle system lies in having the arrangement that provides superior web handling and drying characteristics. The nozzle system needs to maintain adequate clearance to prevent contact while the web is traveling through the dryer. Also important is the nozzles jet stability to prevent jet flip flop which exhibits itself as a condition where all the air exits through only one of the slots. Typical operating nozzle velocities range from 5,000 fpm to 12,000 fpm (25 m/sec to 61 m/sec).

Materials of construction are typically a combination of mild steel, aluminized steel and stainless steel. Construction types can vary from panelized to all welded construction with 3 to 4 inches (75-100mm) of insulation sandwiched between the internal and external surfaces. Access to the dryer's internal areas and air bars is through a retraction arrangement. Common retraction systems are the clam shell pivoting design from the gear side or a screw jacks system which lifts the top half of the enclosure above the bottom half. Retraction heights are typically 16 to 20 inches (400-500mm).

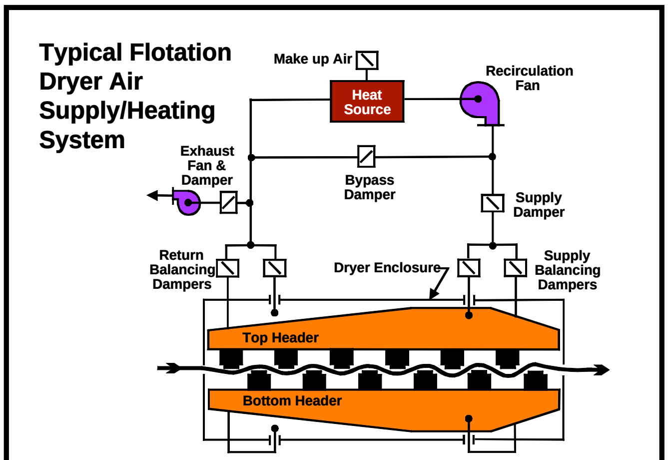

Fig. 17

Flotation dryers normally use a draw-through air supply system where the heat source is located on the suction side of the fan as shown in Fig. 17. This configuration will always deliver a constant air velocity regardless of varying air density which will result in a constant nozzle velocity.

Like the arched idler roll dryers, the air systems are designed for using either saturated steam or natural gas. Operating temperatures can range from 350 to 600°F (177 to 315°C). The air system is normally located on the back side of the dryer enclosure and connected through interconnecting ductwork.

The performance of an air flotation dryer is dependent not only on the air bar design, but also on the return air system. After leaving the nozzle area, return air is collected and recirculated back to the heat source fan arrangement. The exhaust air is extracted from the recirculating air prior to the heating plenum. Dryer exhaust volumes are sized to keep the enclosure internal pressure slightly negative and operating at a humidity level of less than 0.1 pounds of vapor to pounds of dry air.

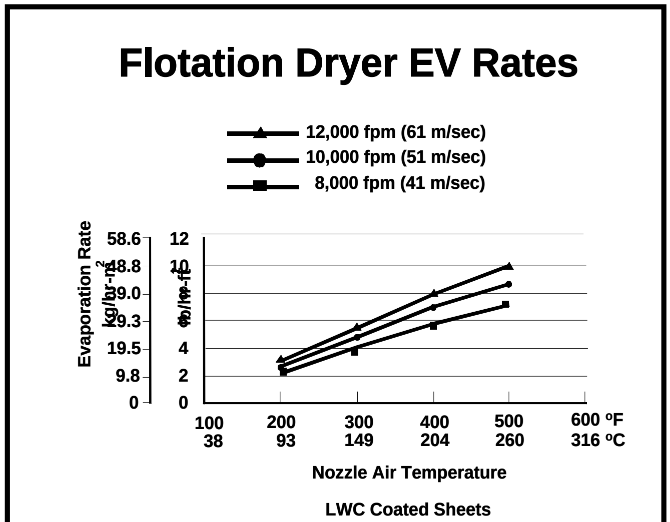

Fig. 18

Drying rates for flotation dryers are controlled by adjusting air temperature and air velocity as delivered to the web. Fig. 18 can be used as a general guide to the drying capabilities of a typical flotation dryer.

Infrared Dryers

Infrared drying systems have seen extensive use in coated paperboard applications over the years due to their high energy capabilities and are typically used in conjunction with other forms of drying, particularly at the start of the drying process. The wide acceptance of the use of infrared energy for drying has led manufactures to improve the systems.

The principle behind the operation of IR systems comes from the fact that any object or material that is warmer than its environment will radiate infrared energy as a result of the atomic excitation of the material. This IR energy will travel in the form of electromagnetic waves at the speed of light until it strikes another material where it can be absorbed, reflected or transmitted.

Electromagnetic waves often called radiant energy occur over a wide range of wavelengths. For paperboard drying purposes we are only interested in IR radiant energy falling in the 1 to 8 micron range. This is due to the high level of absorption of radiant energy into both the paperboard and coating in this range as shown in Fig. 19. For the example shown, the absorption of radiant energy into the base sheet and water appear to be optimum at 2.8 microns.

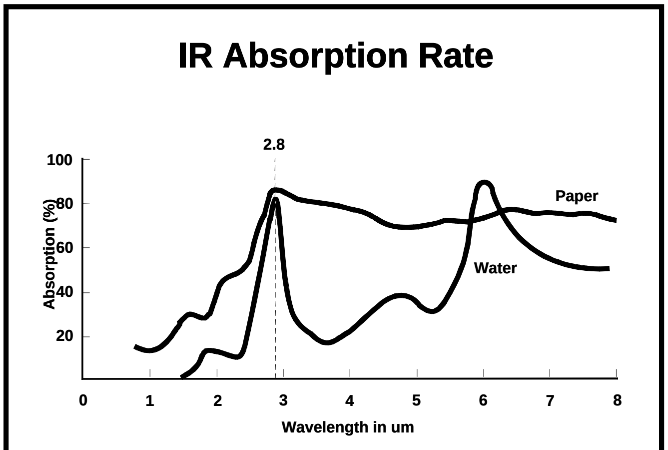

Fig. 19

It is well known that the emission spectrum of radiant energy generated by the operation of an infrared dryer is a function of the surface characteristics and the operating temperature. Higher operating temperatures result in the increased generation of shorter wavelength radiation while lower operating temperatures result in an increase of longer wavelength radiation.

Regarding the absorption of radiant energy, longer wavelengths are more strongly absorbed by water while shorter wavelengths characteristically penetrate deeper into the base sheet. The absorbency of IR energy is also dependent on the thickness of the material and the wavelength of the radiant energy. Fig. 20 shows that as the base material increases in weight more of the transmitted radiant energy is absorbed while the absorption in the 10 micron film of water remains relatively constant.

The energy efficiency of IR systems should not be confused with the efficiency in conversion of input energy to infrared energy. For drying comparisons, the energy efficiency should be a measure of the energy deposited into the sheet in comparison to the energy actually consumed.

Gas infrared systems are more widely used for drying coated paperboard due to their lower cost and the better match of the wavelength of the energy emitted on heat transfer efficiency. The most common type of gas IR used in drying coated paper is the surface combustion burner. These systems use a metal or porous refractory from which gas is burned creating a radiant surface.

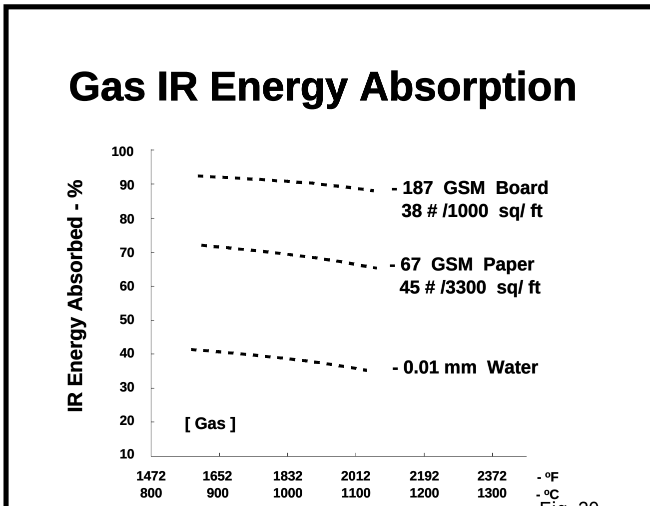

Fig. 20

Every infrared system consists of a group of individual modules referred to as emitters. Emitters are heated to a temperature of approximately 2000^{o}F (1093^{o}C) by the combustion of natural gas. When used as a means of drying coated paperboard, gas IR systems are normally arranged in rows with each burner or emitter about one square foot. A typical arrangement of the emitters is shown in Fig. 21.

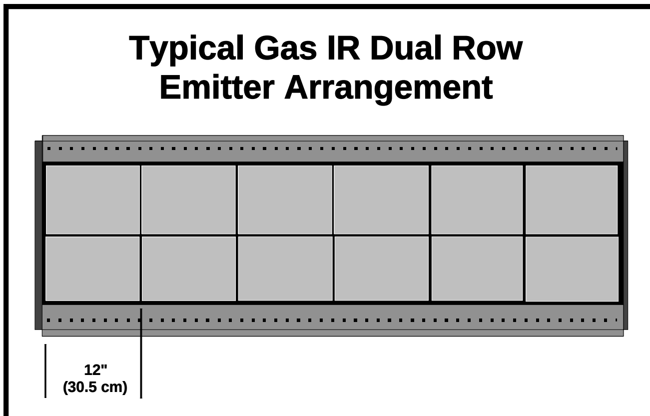

Fig. 21

Complementing the emitter arrangement is an air flow system which functions to remove exhaust gases and remove evaporated water. The purpose of this is to breakup the laminar layer of air and vapor on the surface of the sheet which decreases the surface vapor pressure and hinders water removal. Additionally the airflow keeps the moving coated web from touching the surface of the emitter and functions to cool the unit on shutdown. A schematic cross section of a gas fired IR dryer is shown in Fig. 22.

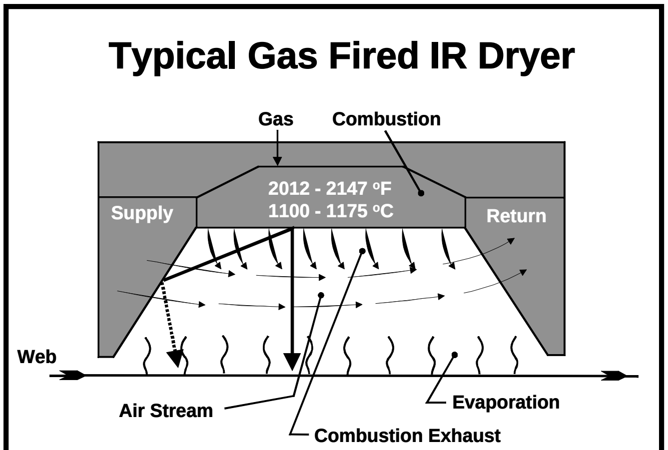

Fig. 22

The primary advantage of using IR as compared to other drying technologies is its ability to transfer energy into the sheet at reasonably high rates without drying the surface coating.

Application of Drying Systems

Drying arrangements for coated paperboard can include a combination of the drying systems (steam cans, air impingement, air flotation, and IR) as discussed in the previous sections. The primary task is to determine the optimum combination and corresponding dryer length required to properly dry the applied coating. To start this process, one needs to have a simple and practical method of estimating the removal of water from the coating and to more specifically determine the contribution of each dryer technology. This can be accomplished by determining the average drying rates of the equipment we are considering and applying this information to the drying process. Drying rates are most commonly expressed in terms of pounds of water evaporated per unit width or area per hour.

As we have previously noted in the discussion on drying, the drying process is described as three distinct phases; sensible heating---where the sheet temperature increases and drying begins, steady state evaporation---where energy is consumed for free water evaporation while the sheet temperature remains fairly constant, and falling rate---where the sheet temperature increases as free water becomes scarce and the evaporation rates begin falling. Fig. 23 shows the three phases in the drying process in conjunction with a typical dryer arrangement.

In determining a dryer layout, we need to apply the above drying considerations in view of actual equipment performance. This can result in the use of IR drying for sensible heating and initial drying, followed by some type of air drying for the majority of the drying by steady state evaporation followed by steam cylinder dryers to complete the drying process. Just how much drying should each arrangement provide has been the subject of numerous papers and discussions. The primary focus of much of the research has centered around how to predict the optimum drying rates and how the drying configuration can either enhance or degrade the coating appearance. The conclusions drawn from this work is that there are no hard set rules to determine the drying contribution of each component and much depends on the coating formulation. Basic practice in the industry is varied depending on the amount of water to be removed and available space for the drying equipment.

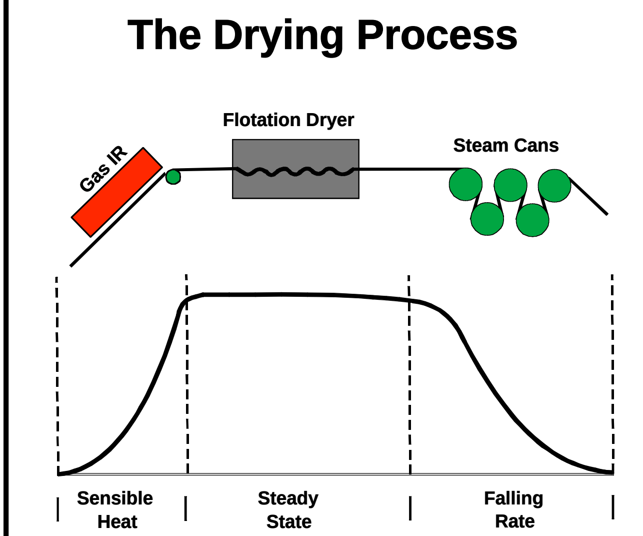

Fig. 23

The most productive way to put into practice the above information is to develop an example which is characteristic of a coated paperboard application and determine the drying strategy and corresponding dryer lengths required. To start the process, we need to define the parameters of a typical coated paperboard application.

Typical paperboard coating application:

- basis weight .... 42 lbs/1000 ft^2 (205 gsm)
- % moisture 6%
- coat weight.............. 2.5 lbs/1000 ft^2 (12.2 gsm)
- sides coated............ one
- coating solids.......... 60%
- operating speed....... 1000 fpm (305 mpm)

For this example, we will select a drying strategy which will divide the drying load between gas IR, air drying and steam cylinder drying as follows:

- Gas IR-----increase coating from 60-72% solids
- Air-----increase coating from 72-85% solids
- Cylinders-----increase coating from 85-94% solids

Fig. 24 illustrates the arrangement of the drying systems for our selected drying strategy. Here the gas IR provides the necessary warm-up and drying to bring the coating solids to 72% which is typically described as the critical solids concentration or immobilization point. A convective or air drying zone will then be used to take care of the critical drying region from 72-85% solids with steam cans taking care of the remaining drying requirements.

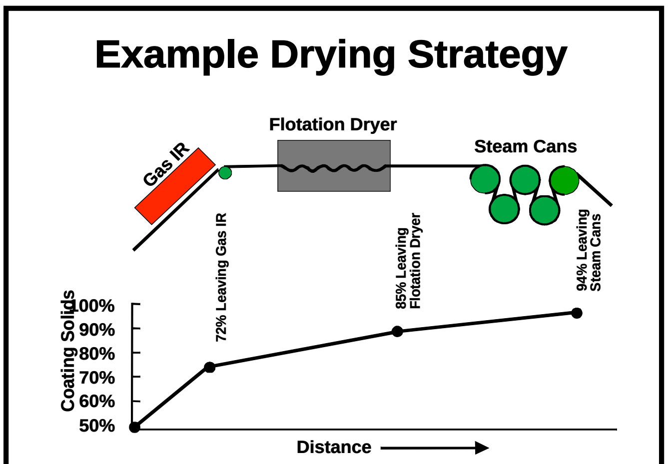

Fig. 24

Using some common basic equations, we can conveniently determine the approximate dryer lengths for each drying section.

Step 1 Estimate the IR drying section

Accepted practice is to use gas IR at the beginning of the drying cycle due to the systems ability to provide high intensity drying while occupying a very small space. For our example we will use an input energy of 20,000 Btu/hr-ft^2 (54,200 kcals/hr-m^2) and a leaving sheet temperature exiting the gas IR of 170^{o}F (76^{o}C). In actual practice, the determination of this temperature is difficult and is normally estimated to be between 160 to 190^{o}F (71-88^{o}C). Additionally, the gas IR energy input can also vary depending on operating parameters.

With the gas IR unit functioning in the pre-heat phase, we will need to determine the sensible heat load and the evaporation load to take the solids from 60-72%.

First we will calculate the sensible heat load to raise the temperature of the paperboard and coating from 100 to 170^{o}F (37-76^{o}C). This is done by using the following equation:

$$Q = WT/RM \times S \times 60 \times SH \times (T_2 - T_1)$$

where:

Q = Energy per foot of width (Btu/hr-ft-width)
WT = Basis weight (dry) of paperboard (lbs)
RM = Ream size (sq. ft)
S = Production speed (fpm)
SH = Specific heat of substance (Btu/lbs-^{o}F)
T_1 = Sheet temperature entering the IR dryer (^{o}F)
T_2 = Sheet temperature exiting the IR dryer (^{o}F)

Calculating the sensible heat loads.......

Q paperboard = [42 lbs x 0.94)/1000 ft^2 x 1000 fpm x 60 min/hr x .35 Btu/lbs-^{o}F x (170 - 100^{o}F)
= 58,036 Btu/hr-ft wd

Q moisture paperboard = [42 lbs x 0.06]/1000ft^2 x 1000fpm x 60 min/hr x 1.0 Btu/lb-^{o}F x (170 - 100^{o}F)
= 10,584 Btu/hr-ft wd

Q coating solids = 2.5 lbs/1000 ft^2 x 1000 fpm x 60 min/hr x 0.5 Btu/lb-^{o}F x (170 - 100^{o}F)
= 5,250 Btu/hr-ft wd

Q water in coating = [(2.5lbs/.60 - 2.5lbs)]/1000 ft^2 x 1000 fpm x 60 min/hr x 1.0 Btu/lb-^{o}F x (170 - 100^{o}F)
= 7,000 Btu/hr-ft wd

Adding all the sensible loads....

Qt = Qpaperboard + Qmoisture paperboard + Qcoating solids + Qwater in coating
= 58,036 + 10,584 + 5,250 + 7,000
= 80,870 Btu/hr-ft wd

Next calculate the evaporation load to remove enough water to reduce the coating solids from 60 to 72% with the gas IR dryer.

First determine the water load by using the following formula:

$$EV = CW/ RM \times S \times 60 \times (R1-R2)$$

where;

EV = water evaporated per foot of width (lbs/hr-ft wd)
CW = coat weight (dry) (lbs)
RM = ream size (ft^2)
S = production speed (fpm)
R1 = ratio of water to solids entering the dryer
R2 = ratio of water to solids exiting the dryer

$EV = 2.5$ lb/1000 ft^2 x 1000 fpm x 60 min/hr x (40/60 - 28/72)
= 41.67 lbs/hr-ft wd

Next determine the energy required to evaporate to coating moisture...

Qev = EV x 1000 Btu/lb
= 47.67 lbs/hr-ft wd x 1000 Btu/lb
= 41,670 Btu/hr-ft wd

Adding the sensible load with the evaporation load.....

Qt = 80,870 Btu/hr-ft wd + 41,670 Btu/hr-ft wd
= 122,540 Btu/hr-ft wd

Next estimate the length of the IR dryer needed...

IR est length = Qt/IR sheet input energy
= 122,540 Btu/hr-ft wd/20,000 Btu/hr-ft^2
= 6.14 ft

Therefore use 6 feet of gas IR or approximately 6 rows.

Step 2 Estimate the flotation air dryer section.

To do this we first need to calculate the water to be evaporated to reduce the coating solids from 72 to 85% by the above formula.

EV = 2.5 lb/1000 ft^2 x 1000 fpm x 60 min/hr x (28/72 - 15/85)
= 31.86 lbs/hr-ft wd

Using an average air flotation dryer evaporation rate of 6 lbs/hr-ft^2. (30 kg/hr-m^2) we can calculate the length of dryer required.

air dryer length = EV/dryer evaporation rate
= 31.86 lbs/hr-ft wd/6 lbs/hr-ft^2
= 5.3 ft

We would select a 5.5 foot (1.7 m) flotation dryer for this application.

Step 3 Estimate the steam cylinder drying section.

Final drying with steam cylinders offer the advantage of drying in the falling rate phase while the paperboard is held in contact with a smooth surface. Steam cans have been shown to be an effective way of removing moisture from a sheet in the falling rate phase.

For this phase of drying we will use an average drying rate of 0.5 lbs/hr-ft^2 (2.44 kg/hr-m^2) with 5 foot (1.5 m) diameter cans.

First we will need to calculate the water load to reduce the coating solids from 85 to 94%

EV = 2.5 lbs/1000 ft^2 x 1000 fpm x 60 min/hr x (15/85 - 6/94)
= 16.9 lbs/hr-ft wd

Second we will need to determine the effective length of each steam cylinder assuming a wrap angle on each cylinder of 220 degrees.

Effective cylinder length = π x dia. of each cylinder x (angle of wrap/360)
= 3.14 x 5 ft x 220/360
= 9.59 ft

With this information we can determine the number of steam cans we will require.

Number of cylinders = moisture to be evaporated/cylinder effective length x cylinder ave. evaporation rate
= 16.9 lbs/hr-ft wd /(9.59 ft per cyl x 0.5 lbs/hr-ft^2)
= 3.5 cylinders

We would roundup to 4 cylinders.

The entire drying process is represented in Fig. 25. The top graph illustrates the sheet temperature profile, the middle graph shows the coating solids and the bottom graph shows the evaporation rate. The IR dryer can be seen to elevate the temperature along with accomplishing some of the drying. Note that the temperature will drop in the open draw between the IR dryer and the air dryer because of continued evaporation thereby using energy stored in the moving sheet. The IR system has been selected to dry the applied coating solids from 60-72%. The air drying system will be used to complete the drying process in the steady state drying phase which results in a constant temperature and a constant evaporation rate to occur. The final steam cans will further dry the sheet in the falling rate phase which results in the sheet temperature rising and the evaporation rate to decrease.

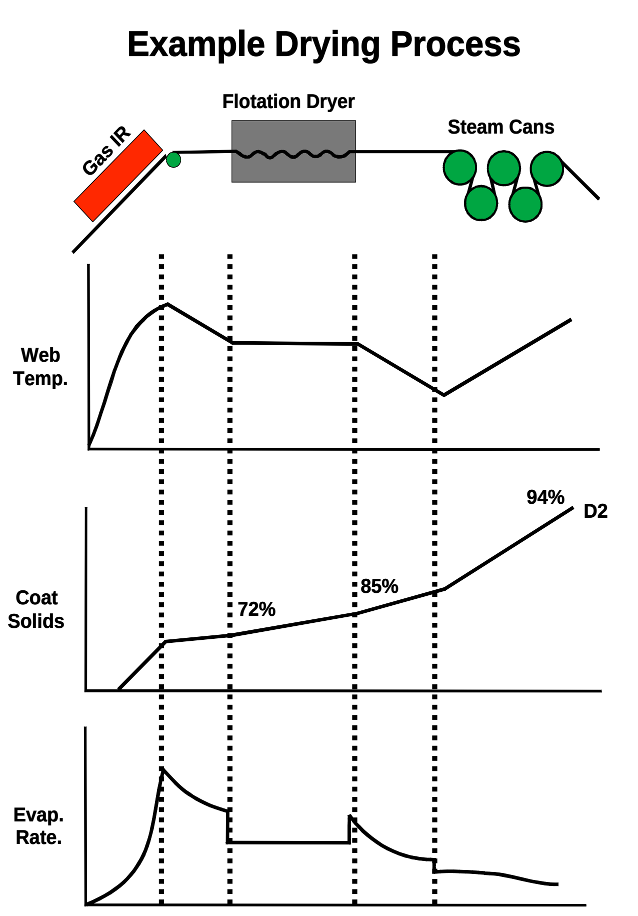

Fig. 25

Web Cooling

Web cooling is not commonly discussed due to the wide familiarity of the need to cool the web prior to downstream operations. Typically, cooling is done by either leaving an open draw between operations or in some cases, traditional chill roll arrangements are employed where practical. As machine speeds increase and space becomes even more of a problem, mills have had to look to alternative technology to handle the cooling requirements.

Cooling webs to temperatures below 130^{o}F (55^{o}C) prevents operational problems from developing on calendar stacks and provides a suitable temperature to rewind without the typical problems normally associated with high sheet temperatures. It is typical to find sheet temperatures hovering in the area of 160 to 180^{o}F (70 to 80^{o}C) in the "dry end" of a paperboard machine. A cooling operation needs to efficiently and economically lower the web temperature some 30 to 50^{o}F (0 to 10^{o}C) without damaging the coated surface and within the minimum space possible. This is especially true for board applications where the weight of the board makes an excellent "heat sink" and is more difficult to cool.

The development of air flotation drying technology provides non-contact web handling while offering the enhanced benefit of two sided drying. This same arrangement can be used to effectively cool a web by using ambient or chilled air instead of heated air.

The operation of a flotation cooler is quite simple. An air supply system delivers ambient air to the nozzles or air bars above and below the web. Arranged in a staggered configuration, the nozzles create a pressure pad that supports the web as it passes through the dryer. A diagram of a typical air flotation cooler is shown in Figure 26.

We'll use several examples to illustrate how flotation technology can be used to cool and stabilize a coated web efficiently and within a minimum space.

In our first example we have a paperboard web which has been coated twice and dried with gas IR following each coater. The first coater is a rod pre-coater followed by six rows of gas IR. A second finished coat is applied via an air knife coater with 8 rows of gas IR used to dry the coating prior to being calendered just prior to the reel.

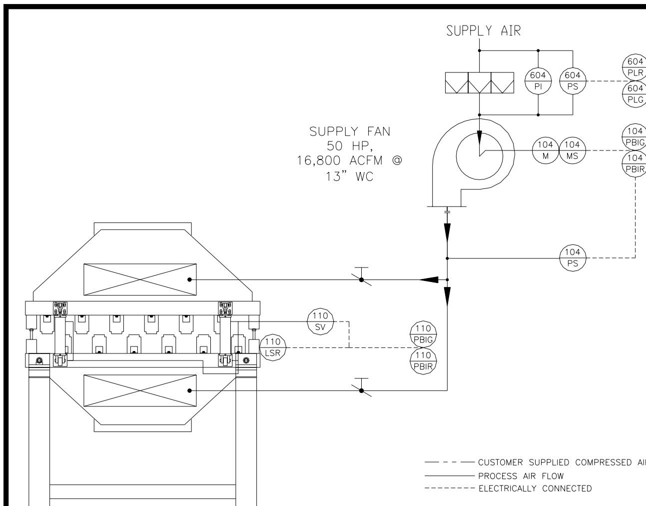

Fig. 26

The problem this particular mill was facing is roll picking at the outboard calendar stack prior to the reel at the design production speeds [450 fpm (137 m/min)]. The mill's initial solution to correct the problem was to slow up and this approach did indeed correct the immediate picking problem. However, the mill was losing valuable production and a better solution to the problem needed to be found

In the mill's view, the picking problem was due to a lack of drying. Consequently, the mill took the approach of considering additional gas IR drying following the last coater and was discussing this arrangement with various IR suppliers.

A simple analysis of the overall coating arrangement suggested that the mill had plenty of drying with the current gas IR configuration and the real problem was one of a coating surface temperature being too hot. Consequently, having a hot [170°F (75°C)] coating surface temperature entering the calendar stack was the real problem in this application and not a lack of drying as was originally thought.

To prove this hypothesis, a more rigorous analysis needed to be completed. The mill coating data used to develop the drying profile is shown below. Using this date allows us to look more closely at the drying dynamics as the paperboard is coated and dried.

Cooling Applications Data:		CASE #1
Web Description		
Web Type		Paperboard
Basis Sheet Weight (OD)		47.40 lbs/ream
Ream Size		1000 ft^2
Base Sheet Moisture Before Coater		4%
Final Moisture Desired at the Reel		6%
Production Speed		450 fpm
Sheet Width		93 inches
Coating Data	Precoat	Top Coat
Coater Type	Rod	Air Knife
Dry Coating Weight	2.0 lbs/ream	3.34 lbs/ream
Application Solids	58.7%	40.2%
Sheet Temperature	250°F	n/a
Drying Arrgmnt.	6 rows IR	8 rows IR

Results of a detailed drying analysis is graphically displayed in Fig. 27 and shows the relationship of sheet temperature and coating solids versus web path.

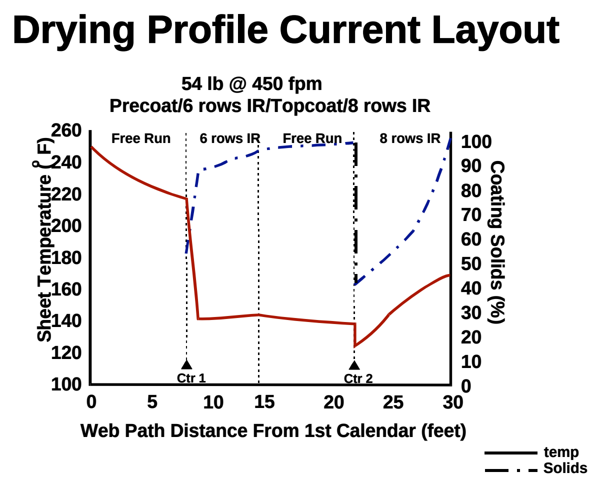

Fig. 27

Note the 170°F (77°C) web exit temperature leaving Coater #2 with 8 Rows of Gas IR. Contrast this with overall coating solids levels just prior to the calendar stack. While the coating would be considered "dry," the elevated temperature is a concern.

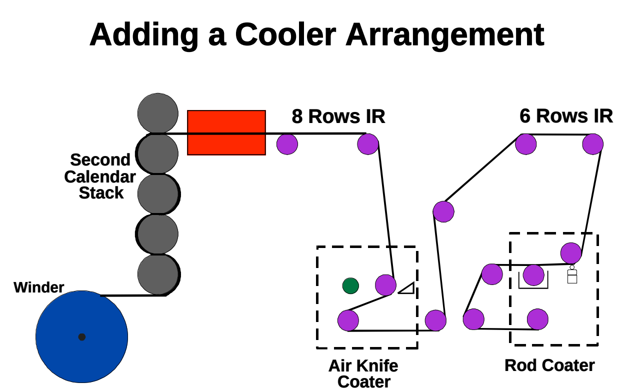

Fig. 28

Considering the problems with high coating temperatures, it is very apparent that the solution to the problem was to add a short cooling section following the exiting gas IR arrangement and prior to the existing calendar stack. Fig. 28 shows the addition of a short cooling section following the gas IR drying section. A general arrangement of the cooling system supplied is shown in Fig. 29with an actual picture of the unit in Fig. 30.

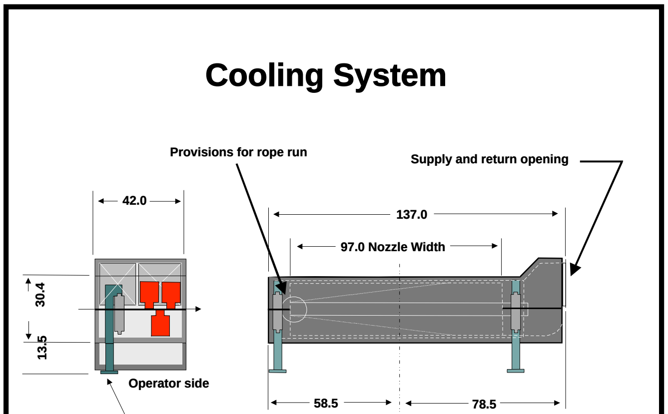

Fig. 29

Fig. 30

The cooling section coupled with the existing free web run would do two things, lower the web temperature by 20^{o}F (-7^{o}C) and lower the overall sheet moisture by another 0.5%. Having a sheet temperature in the 150^{o}F (66^{o}C) range versus 160 to 180^{o}F (70 to 80^{o}C) would allow the mill to transverse the calendar stack at the desired production speed without roll picking. Additionally, only 42 inches (1067 mm) of cooling is required due to the large difference in temperature of the coated paperboard sheet and the ambient air used for the cooling arrangement. This is illustrated in Figures 31.

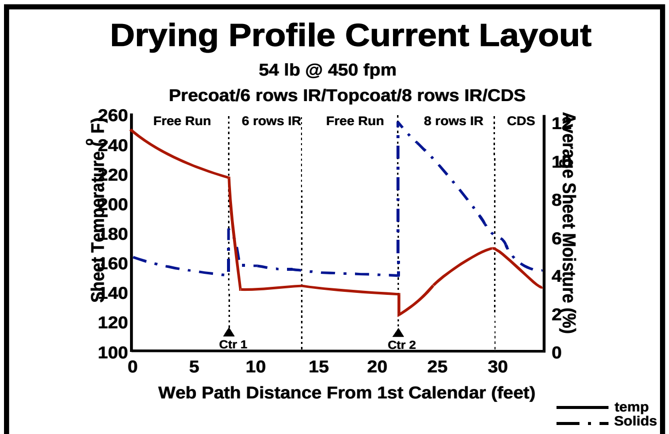

Fig. 31

As is typically the case with gas IR systems, the hot coated web leaving the IR needs to have a means to transport the moisture being evaporated away from the coated sheet. It is well known that IR systems are excellent devices to add sensible heat but are not so good at moisture removal.

In this particular example, the problem the mill had was one of having too much gas IR leaving the coated sheet temperature too hot and fluid thus picking off on the calendar stack rolls. Having a non-contact method of cooling, the sheet temperature eliminated any chance that the coating would be disturbed prior to contact with the calendar stack.

Looking back at Fig. 28 it can be seen that the web path required to enter the calendar stack from the top requires the cooling arrangement to be located some eight feet (2.5 m) off the floor line. The flexibility of the flotation cooling arrangement lends itself to this application quite nicely since the system can be located easily in this location.

A conventional chill roll stand would normally be placed on the floor level requiring transfer rolls to position the coated web to the chill stand. Of course, this arrangement would suffer from the same problems the mill would experience with the calendar stack prior to the insertion of a web cooling arrangement.

Next we will look at an example which requires more cooling than in the previous example. In this case the mill wished to reduce the temperature of the coated paperboard from 150 to 120°F (65 to 50°C) prior to the winder. A location was chosen for the cooler immediately following the dry calendar stack as shown in Fig. 32.

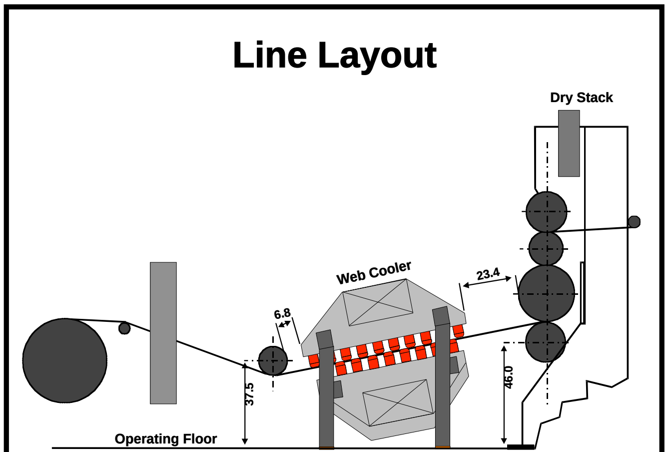

Fig. 32

The general applications data for this example is as follows:

Cooling Applications Data:

Web Type	Paperboard
Base Sheet Weight (OD)	56 lbs/ream
Ream Size	1000 ft^2
Base Sheet Moisture Before Coater	6%
Final Moisture Desired at the Reel	6%
Production Speed	650 fpm
Sheet Width	90 inches
Cooling Required	40°F (150 to 110°F)

To solve this application, a 5.5 foot (2 m) long cooler was selected and located just prior to the existing dry stack. Using a tightly packed nozzle arrangement operating at ambient temperature, this arrangement was able to complete the cooling requirements set forth by the mill.

Fig. 33 illustrates the performance of the cooler for 56 lb/1000 ft^2 board. Note the reduction in both temperature and moisture. In this particular application, the mill merely wanted to reduce the sheet temperature prior to the windup to prevent problems with winding too hot. Having a reduction in sheet moisture was an added bonus.

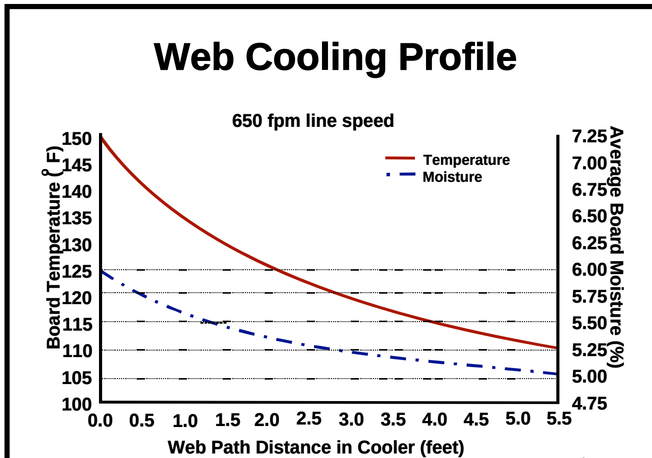

Fig. 33

Granted the mill could have easily used a chill roll stand to do the same job but this would have required the installation of transfer rolls to position the coated paperboard sheet to the chill stand. The mill would have to drive the chill stand and supply a chiller unit whereas the air flotation cooling system can easily be placed in the exiting web line and is designed so the operators are exposed to no moving components unlike a chill roll stand. Additionally, the maintenance requirements of a flotation system would be less than a mechanical chill stand.

Using air flotation technology as a cooling system is a practical application of a conventional proven technology. A flotation cooler can be placed conveniently in the existing web line and function~~s~~ to cool a coated web without having to contact the coated surface.

Curl Control

In paperboard production, one of the largest single sources of product waste is curl. Curl is responsible for jam-ups, off spec production, and loss of unconverted product.

Curl can be defined as the tendency for a flat piece of paper or paperboard to distort in a cylindrical shape as shown in Fig. 34. Curl can occur in the cross-machine direction (CD) or the machine-direction (MD). Cross-machine curl is caused by uneven drying; whereas machine-direction or roll-set curl occurs when paperboard that has been wound onto a core starts to take the shape or the set of the roll.

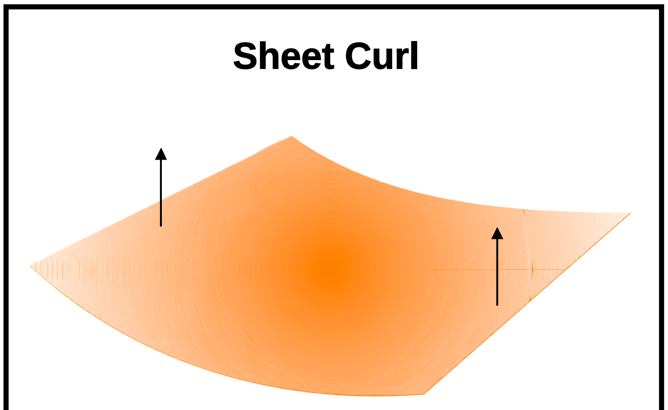

Fig. 34

Traditional attempts at solving this problem utilize mechanical decurl bars, “wet stacks” or homemade steam showers. Traditional steam showers are ineffective and provide more problems than benefits due to dripping, splitting, and streaking. Mechanical decurl bars provide limited decurling capabilities and often overstress the paperboard causing checking or surface disruptions along with de-lamination on multiple grades. Wet stacks leave the paperboard with a high moisture content which typically needs to be dried further.

For this discussion we are interested in cross-machine curl due to uneven moisture profile. This will cause fibers which have more moisture to be longer than fibers with less moisture. This will occur on the coated side of the sheet where coating moisture has dewatered into the base sheet as shown in Fig. 35. Henceforth, a paperboard sheet will therefore curl towards the dryer side of the sheet due to the fibers being shorter on this side.

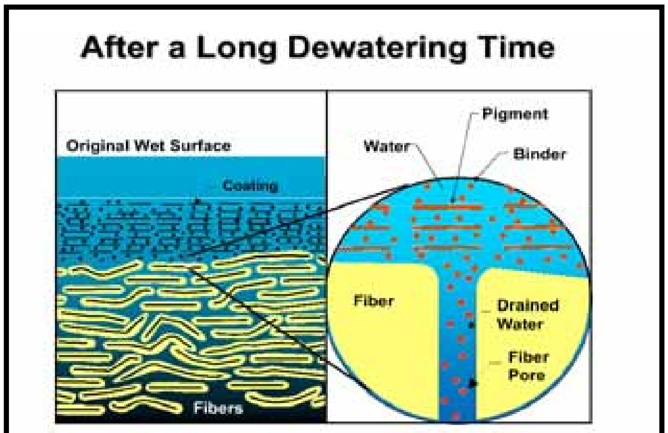

Fig. 35

As was discussed previously, the excess water in the coating will begin to migrate into the paperboard by moving into the fiber pore structure and by absorption into the actual fibers. The movement of water into the base sheet is termed dewatering and is the primary mode of water movement prior to the actual drying process.

The object of curl control is to reset the fibers of the paperboard to a flat position while preserving both the structural integrity and surface qualities of the paperboard. The use of flotation technology to enhance sheet curl control has gained interest in recent years, especially in paperboard operations. Depending on the degree of curl, a dual heat source, air flotation system can be used to correct curl problems online.

Flotation dryers typically use a single heat source and fan system to provide heated air to both sides of the web. Using a dual heat source system as shown in Fig. 36 allows the use of differential temperatures on each side of the sheet.

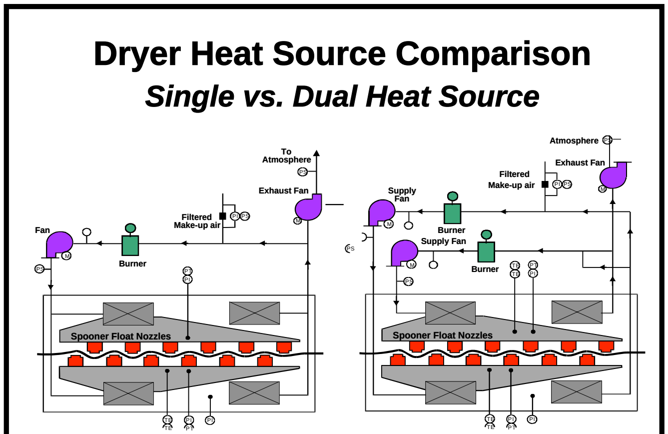

Fig. 36

The object of this arrangement is to operate the drying arrangement with increased temperatures on the “wet” side of the sheet versus the dryer side of the sheet. This will result in increased evaporation from the wet side causing the fibers to contract more than on the opposite side which is being subjected to lower temperature air.

As mentioned, this system is effective for moderate curl control and is more suitable for gas fired arrangements than for steam fired arrangements due to temperature limitation of steam fired systems. Properly designed systems can obtain 75 to 100^{o}F (25 to 40^{o}C) differential temperatures between top and bottom sections. It is difficult to achieve higher differentials because the spent air streams have a tendency to mix due to the design arrangement of the nozzles and exhaust areas. Even with this consideration, a dual zone arrangement can effectively help control troublesome curl in paperboard operations.

Air Turns: The Solution To Non-Contact Turning Problems

The development and application of metering size press technology and other two-sided coating technology has allowed mills to begin applying higher solids coatings at higher speeds. Consequently, problems were encountered with wet coating "picking" on the turning roll(s) and the lack of drying capabilities to "set" the coating prior to the introduction to the steam cylinders.

To address the quality problems being experienced, equipment manufacturers developed a means of non-contact turning which could be incorporated into the already tight space. The tight configurations of "on-machine" arrangements provided machine builders some difficult problems to solve.

Air turns were initially developed in the '70's and helped solve a wide range of problems of contactless web handling after coating and size press applications. In essence this product is a circular air flotation web handling system designed to allow a change of web direction without any surface contact. A typical air turn arrangement is shown in Fig. 37.

Modern day air turns employ the proven performance of twin slot pressure pad flotation air bars which have seen extensive use in flotation drying systems in "off-machine" coating operations. The air bars provide a stable cushion of air extending across the full width of the unit. These cushions provide full support to the sheet such that the flotation height is the same in the center of the sheet as it is at the edge of the sheet irrespective of the width of the sheet.

Typical Air Turn Arrangement

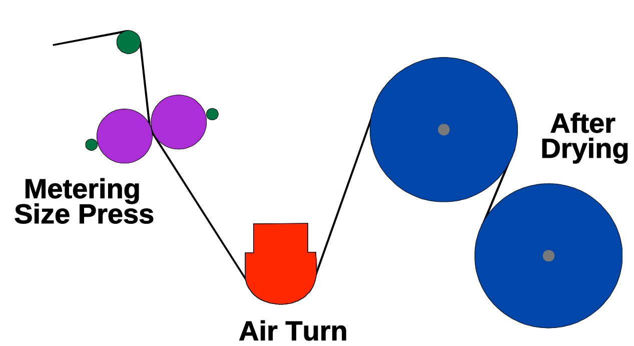

Fig. 37

In operation, these air bars generate a supporting air cushion between the surface of the air bar and the coated web being processed as shown in Fig. 38.

Typical Air Bar Pressure Pad

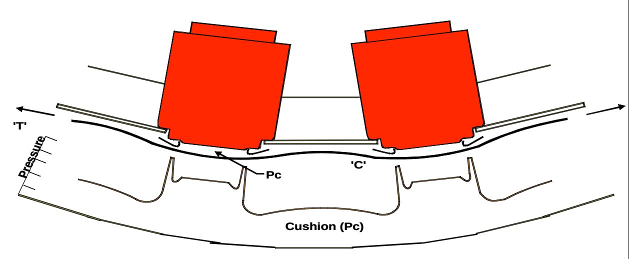

Fig. 38

The very best designs utilize regions of high and low pressure to bring about a perfectly symmetrical profile which in turn results in high clearance and firm web stability. Performance is directly related to the special aerodynamic effects brought about as the air exits from the slot outlets. The forces generated in the air flotation cushion need to be high in magnitude since these are used to effectively offset the force generated by the tension in the web. The modern air turn system embodies these features and benefits by using these same air bars arranged in a curve path as shown in Fig. 39.

Fig. 39

The flow channel areas provided between the air bars control the escape of air from the air cushion at the end of the air bars which provides additional support and minimizes the fan power required to operate the system. The flow of air throughout the area between air bar channels also imparts a smoothing effect to the sheet reducing wrinkles and creases.

Modern air turn systems are designed to accommodate the following operating requirements typically found in coated paperboard applications:

- Non-Contact Web Handling
  The distance between the coated sheet and the surface of the air turn should be at least _ inch (6 mm) to insure trouble free operation without the possibility of contact and contamination of the coated surface during operation.

- High and Low Tension Capabilities
  With the operating tension ranges varying, the air turn needs to be capable of handling tension ranges of _ to 10 pli, while maintaining the clearance mentioned above.

- Web Turning Angles
  Due to the many configurations available today, air turns need to accommodate wrap angles of 20 to 180 degrees.

- Air Turn Width and Diameter Flexibility
  Today's applications require flexibility in design to accommodate a range of web widths. Radius's typically range from 21.65 to 31.50 inches (550 to 800 mm).

When used in conjunctions with the latest coater designs, modern air turns provides increased product quality and machine runability. Depending on the coater design attributes, air turn configurations can result in a number of orientations.

One typical arrangement is for the placement of the air turn below the coater as was shown in Fig. 37. In this configuration the coating can be applied to both sides of the sheet and turned in a non-contact fashion towards the after dryer section.

Vertical configurations have the air turn unit placed above the coater as illustrated in Fig. 40. The successful development of this form of coating arrangement has largely depended upon the availability of a suitable air turn system. Both arrangements are successfully functioning in paperboard applications.

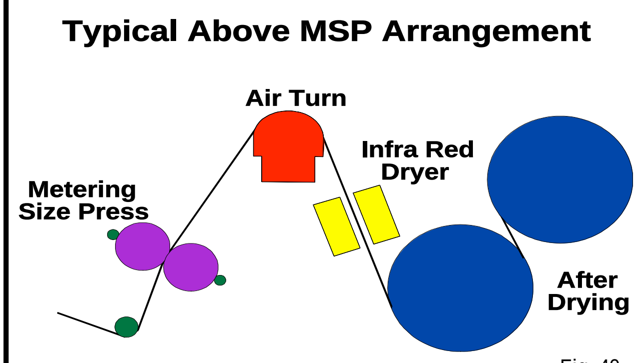

Fig. 40

Heated Air Turns

As has been mentioned, the primary development of the air turn was to overcome handling problems. It was not envisioned that air turns would have any effect on drying performance following the coating operation. However, mill supervisors, where air turns are in operation, notice that extra machine speed could be achieved following the introduction of the air turn unit.

This can be attributed to the impingement effect from the pressure pad nozzles that provide forced ventilation on the web sheet traveling over the air turn. The air turn, having ventilated the surface of the sheet, insures that the air boundary layer on the surface of the coated sheet is removed.

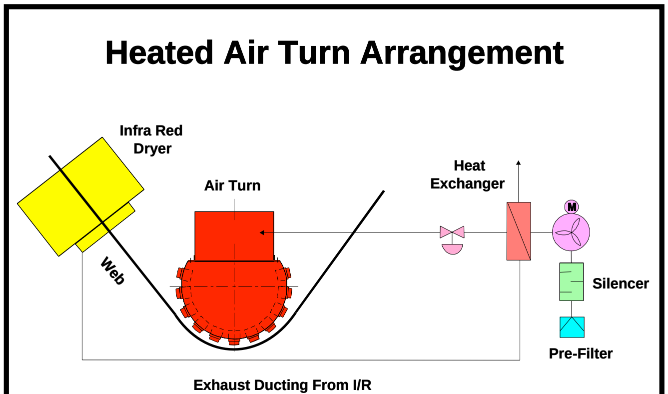

Fig. 41

It is possible to use heated air turn supply air for the purpose of conditioning and/or drying the web as it passes around the air turn. In this arrangement, the air turn supply air is normally drawn in from the machine room through a prefilter unit and then passed through an air to air heat exchanger before being delivered to the air turn unit (Fig. 41). If a gas IR system is used, the exhaust air can be used as a source of energy.

The primary reason for using heated air is to provide supplemental energy to the coated sheet which is being cooled from the evaporation of moisture from the surface of the sheet. Depending on the temperature of the sheet and the drying application, an air turn can develop single-sided drying rates over the surface of the air turn as shown in Figure 42.

Limited drying can, therefore, be achieved even when ambient air is applied and no form of IR heating is used prior to the air turn. In this situation, the temperature of the coated sheet is between 140 and 170^{o}F (60 and 77^{o}C) due to the on-machine nature of the application. The primary drawback to this arrangement is that the drying is single-sided and constrained due to the short effective drying length of a typical air turn. Actual practice will show that the overall coated sheet temperature entering the air turn, coupled with the angle of wrap, is of much greater importance to improving the drying performance capabilities of air turn systems.

Typical Air Turn Drying Potential

SHEET TEMP	EV RATE	DRYING RATE
100^{o}F	1.0-2.5 lbs/hr-ft^2	1.7-8.3 lbs/hr-ftw
(38^{o}C)	4.8-12.2 kg/hr-m^2	2.5-18.4 kg/hr-mw
170^{o}F	10-18 lbs/hr-ft^2	16-60 lbs/hr-ftw
(77^{o}C)	48.8-87.9 kg/hr-m^2	23.8-89.3 kg/hr-mw

Fig. 42

New Generation Air Flotation Drying

In the pursuit of more efficient flotation dryer technology, manufacturers have developed a new breed of technology that on the average has two and one half times more drying capability than current designs. How did they do this? By changing the internal arrangement of air bars to pack more air bars per unit area than what the industry had used previously.

For some mills it is neither convenient or suitable to use gas IR for coating applications. This presents a difficult problem since space is at a premium in most applications and typically there is little room to increase the length of convective flotation drying. This situation has led to the development of a high performance drying system which combines the heat transfer capabilities of a gas IR system with the web handling and mass transfer capabilities of a conventional flotation dryer (Fig. 43).

Based on a conventional air flotation dryer but incorporating several patented modifications, this new flotation drying system will fit into the normally "tight" areas available yet deliver an enormous energy punch like gas IR resulting in large amounts of mass transfer.

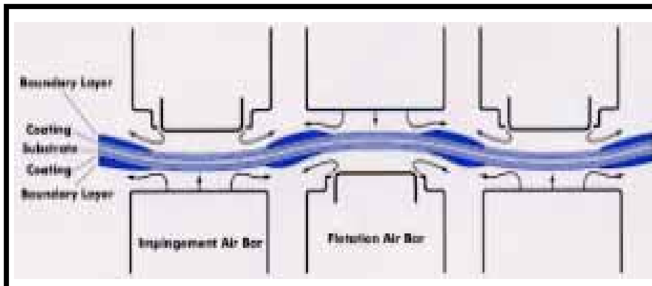

Fig. 43

By utilization of high temperatures in the range of 750 to 850^{o}F (400 to 450^{o}C) combined with nozzle velocities up to 13,750 fpm (70 m/sec) this arrangement can provide an interesting alternative to gas IR. The typical dryer length is between 3.3 and 6.5 feet (1 and 2 m) for the normal range of coating applications.

This dryer system features an integration of proven air bar technologies to develop an evaporation rate equivalent to or exceeding that of a gas IR system. The effective nozzle system for the patented design calls for the insertion of intermediate air bars to be placed between the conventional air flotation air bars as depicted in Fig. 44.

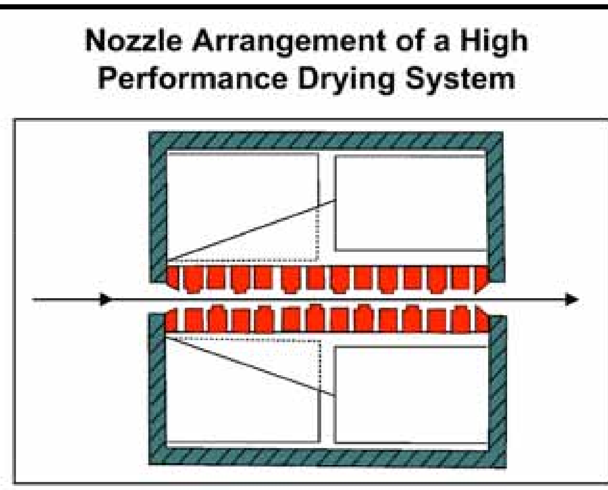

Fig. 44

Like the conventional flotation dryer, flotation air float nozzles are situated above and below the web path in conventional fashion but are supplemented by an equal number of non-air float, high impingement nozzles each arranged with a series of holes designed to maximize heat transfer.

A largely conventional heating system is used to power the dryer with all the usual features including air filtration, fresh air fan, gas burner or other heat source, recirculation fan, exhaust fan, and hot bypass to enable the entire system to continue running when the dryer is opened.

When compared with a conventional air flotation drying system of similar overall dimensions, we can see that by increasing the two important aspects of heat and mass transfer, together with an increase in impinging air velocity, it results in performance as shown in Fig. 45.

High Performance Air Flotation Drying Potential (6.5 feet length)

EV RATE	DRYING RATE
25-40 lbs/hr-ft^2	162-260 lbs/hr-ftw
(122-195 kg/hr-m^2)	(241-387 kg/hr-mw)

Fig. 45

Combined Systems: Gas IR and Air

While it has previously been stated that high performance drying and gas IR drying offer alternative systems, it has long been considered that the ideal drying system for coating applications would be the combination of the two systems. Using gas IR to provide sensible heat together with the excellent mass transfer effect of the high performance air drying system described above is an ideal combination.

Infra-red or IR is an excellent means of imparting an intense concentration of sensible energy to the web, and this helps to both immobilize the coating and minimize the binder migration effect. Drying, however, is a combination of both heat and mass transfer and for a major amount of evaporation to take place within a given system; an external air system is necessary to carry away the evaporated water vapor.

Seeing the advantages of having gas IR closely coupled with convective air flotation drying~~,~~ has led several manufacturers to offer a combination system (Fig. 46). In this arrangement which is conveniently packaged in a single enclosure, gas IR is used to provide sensible heat and the drying of the coating to the immobilization point. An air drying section uses the energy from the gas IR exhaust as make-up air to the preceding air flotation section resulting in improved energy efficiencies. The amount of gas IR and convective air can be tailored to meet the application requirements.

Combining Gas IR with HPC

RED air Combi ™

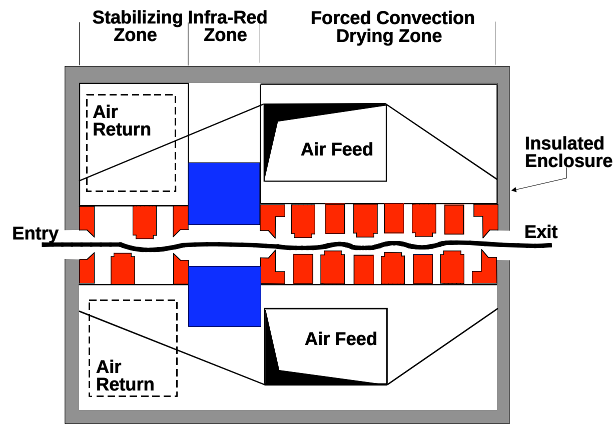

Fig. 46

A major step forward in the development of the combined dryer is the ability to provide stable sheet flotation by the application of high velocity air movement at the sheet surfaces, while simultaneously ensuring that air movement does not adversely affect the function of the highly sensitive infra-red emitters. Careful nozzle design also prevents overspill of high temperature air from the dryer enclosure.

Air Supply/Heating System

RED air Combi ™

A Recirculation Fan
B Gas Burner for Flotation Zone
C Damper Actuators
D By-pass Damper
E Exhaust Fan
F Fresh Air Inlet
G Retraction System
H Combustion System
I Gas Supply for Infra-Red Zone

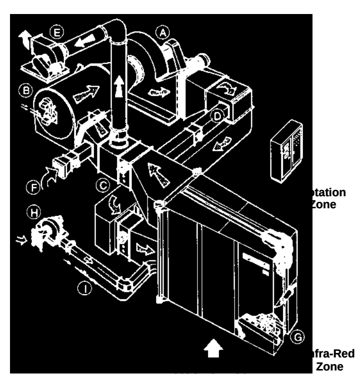

Fig. 47

The air system depicted in Fig. 47 shows that the return air from both the air flotation dryer and the infra-red system are combined so that none of the energy is lost—as would normally be the case with a conventional, stand alone, infra-red system where a substantial volume of the recirculation air is exhausted at each pass.

The exhaust air which will ultimately be sent to the atmosphere is at relatively high temperature and humidity which makes it suitable to be passed through an "air to air" heat recovery unit in order to pre-heat make up fresh air and gas burner combustion air.

In addition, the energy normally lost in the conventional infra-red system through reflection, transmission and side scatter, etc. is fully maintained in the insulated enclosure of this dryer arrangement. The overall thermal efficiency of the combined system will naturally be better than the efficiencies of the individual systems. In fact, efficiency levels far in excess of 60% are predicted for the combined system. A major feature of the combined system is that a highly efficient overall energy balance can be achieved.

The compact design, energy efficiency and web stability of combined systems provides many advantages in coating applications. Benefits of the combined IR/HPC dryer can be summed up as follows:

- Maximum drying rate with minimum machine space requirement
- Correctly proportioned IR/air for high productivity and product quality
- Stable web flotation throughout both sections for improved runability
- Integration of techniques and equipment
- Efficient energy usage

The combination of infra-red sensible energy input and convected air mass transfer enables extremely high drying rates to be achieved within a confined space, without any compromise in coat quality and resultant surface printability.

SUMMARY

Today's coating applications will typically have a combined dryer arrangement to take advantage of the benefits each system has to offer. Having a general understanding of the design attributes of each dryer type and how the systems can be applied in the overall drying process will be beneficial in making the right drying strategy decision.

LITERATURE CITED

1. K. Hagen, "Effect of Drying", Chapter 3 in Binder Migration in Paper and Paperboard Coating, TAPPI Press: Atlanta 1993, pp. 39-59.
2. W.L. Bracken, et., "Drying", Chapter 4 in The Coating Processes, TAPPI Press: Atlanta 1993, pp. 153-173.
3. P. Collette, "Surface of Coated Grades Enhanced by High-Intensity Infrared Drying", *Pulp & Paper*, May 1990, pp 89-95.
4. E.D. Cohen, E.J. Lightfoot, and E.B. Cutoff, "A Primer on Forming Coatings", *Chemical Engineering Progress*, September 1990, pp. 30 - 36.
5. J. Perry, "Flotation, Infrared Drying Boosts Efficiency of Paper Coating Stage", *Pulp and Paper*, May 1989.
6. T. Smith, "Heat Transfer Dynamics" *TAPPI Journal*, August 1994, pp. 239.
7. D.W. Lawton, "Drying Systems for Coated Paperboard", 1995 Coated Paperboard Short Course notes, TAPPI Press: Atlanta 1994, paper 2-2.
8. N. Plowman, "What is Paper Coating", *Graphic Arts Monthly*, January 1992, pp. 104.
9. K. Hagen, *TAPPI Journal* 72(5): 77 (1989).
10. G. Engstrom, *Svensk Papperstidnung*, B107 (1983).
11. E.Bowden, "Non-contact Drying and Turning—the 'On-Machine' Technology of the Nineties". Paper presented at the 44th Annual General Conference, 1990.
12. Mr. Trefz, "Theoretical Aspects and Practical Experiences for Film and Coated Offset Grades", *TAPPI Journal*, Vol 79, No. 1, January 1996.
13. J. Dunlop, "Contactless Web Handling and Drying", 1991 Coating Conference, TAPPI Press: Atlanta 1991.
14. Spooner's REDair Combi™ Brochure.
15. G. Swift, "Drying Options Following Size Press Metering Coaters", presented at the PITA Water Removal Conference, York, UK, 5/6 December 1995.