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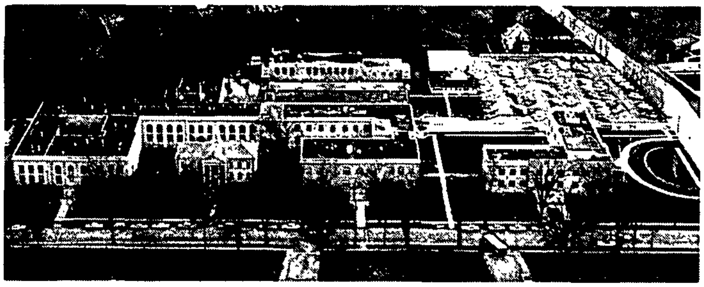

THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

DEVELOPMENT OF A COLD CORRUGATING PROCESS

CONTRACT NO. DE-AC02-79CS40211

TECHNICAL PROGRESS REPORT ONE

TO THE

U.S. DEPARTMENT OF ENERGY

NOVEMBER 7, 1980

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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INTRODUCTION

Research and development work on a cold corrugating process has been underway at The Institute of Paper Chemistry (IPC) for several years. This early work has proceeded through laboratory concept work, laboratory feasibility, pilot trials, and process optimization to the last stage--that being commercial evaluation and demonstration of a cold corrugating system. Financially, the project was supported in the early exploratory phases by the Institute; then by the Fourdrinier Kraft Board Group (FKBG) of the American Paper Institute through the laboratory feasibility studies; and in the recent work on process development, pilot trials, and process optimization, funding has been provided jointly by the IPC and FKBG. Although process development work is continuing, the process has been developed to the point where commercial implementation and evaluation is realistic. To accomplish this goal, it is necessary to provide a first prototype cold corrugator in a box plant for use in commercial production. This large task, combined with the process work, is being carried out as a cooperative project under the combined sponsorship of the IPC, FKBG, and the U.S. Department of Energy (DOE). The Union Camp Corporation (UCC) has been contracted by the IPC to provide the host site for the commercial cold corrugator.

To document previous process development work, three progress reports have been issued. Since issuance of the last progress report, much new information has been developed and the scope of the project expanded substantially. There is a need, then, to issue this fourth progress report. Progress reports are usually prepared to update and add to previously issued reports and, as such, often contain all of the detailed information inevitably generated from a major project. This report will deviate somewhat from that pattern for a number of good reasons. The cold corrugating process has reached a point of development where some companies are beginning to evaluate the process in terms of their own operations. To best serve this purpose, a single comprehensive document devoid of extraneous detail is needed. This requires omission of some details and inclusion of some previously reported information as well as treatment of essential new information. This report is intended to serve this function as the fourth progress report. Other progress reports treating narrower subjects in more detail will be issued later.

This report is presented in three parts. Part I will describe the results of process development work to date; Part II will describe the cold corrugating system to be installed for commercial evaluation of the process; and Part III will present a brief economic analysis of the process.

PART I - THE COLD CORRUGATING PROCESS

Any corrugating process, whether hot or cold, has only two process elements: forming or fluting of the corrugating medium and bonding of the medium to the liners. There are two bonding processes: medium to single face liner and medium to double face liner--the first characterized by short duration, high pressure combining, the second by long duration, low pressure combining. Successful cold corrugating requires that the forming and both bonding operations be accomplished without heating of the paperboard components. In this manner, the production of combined board can be accomplished with little or no process heat, less machinery, and less electrical drive energy. In Part I, the two process elements will be described and a quantitative process assessment will be presented.

COLD FORMING

One of the two fundamental subprocesses in a cold corrugating process is that of forming the flutes without heat or shower steam, i.e., a cold forming process. A successful cold forming process must exhibit good runnability which is usually exemplified by the absence of flute fracture over the commercial speed range, acceptable flute formation, good release between the corrugating medium and the corrugating rolls to avoid the build-up of debris or picking on the rolls, and acceptable structural properties of the single face web. While there is considerable evidence that corrugating medium properties can be optimized with respect to cold forming and the achievement of the above objectives, no effort has yet been directed to this end. It has been assumed from the outset that these objectives are to be achieved, insofar as possible, with present-day medium properties.

Flute Fracture - Runnability

Whether formed hot or cold, a corrugating medium always sustains some structural damage. Visible damage is referred to as flute fracture and is indicative of a useless product. The conditions at the onset of fracturing are often used as indicators of runnability. These conditions may relate to the paper, the pretreatment of the paper, or to the machine/process. Less severe damage, i.e., invisible damage, may be of importance too and this will be treated later in the discussion of structural properties.

Fracture may occur as a bending failure at the outer surface of the flute tip or, more commonly, it may occur as a tensile failure on the flute flank. The latter will be considered first.

In the forming process, the corrugating medium is in contact with several flute tips as shown in Fig. 1. Because of the take-up factor, the medium is being drawn into the labyrinth at a speed greater than the surface speed of the corrugating roll. Relative motion between the medium and the flute tip gives rise to a tension force given by:

$$T = T_o e^{\mu\theta}$$

where T_o = tension in the free web

μ = coefficient of friction between web and roll

θ = total angle of wrap to point in question

Clearly the tension value is largest when θ is largest which corresponds to the center of the labyrinth. This is where tension induced fractures are believed to occur.

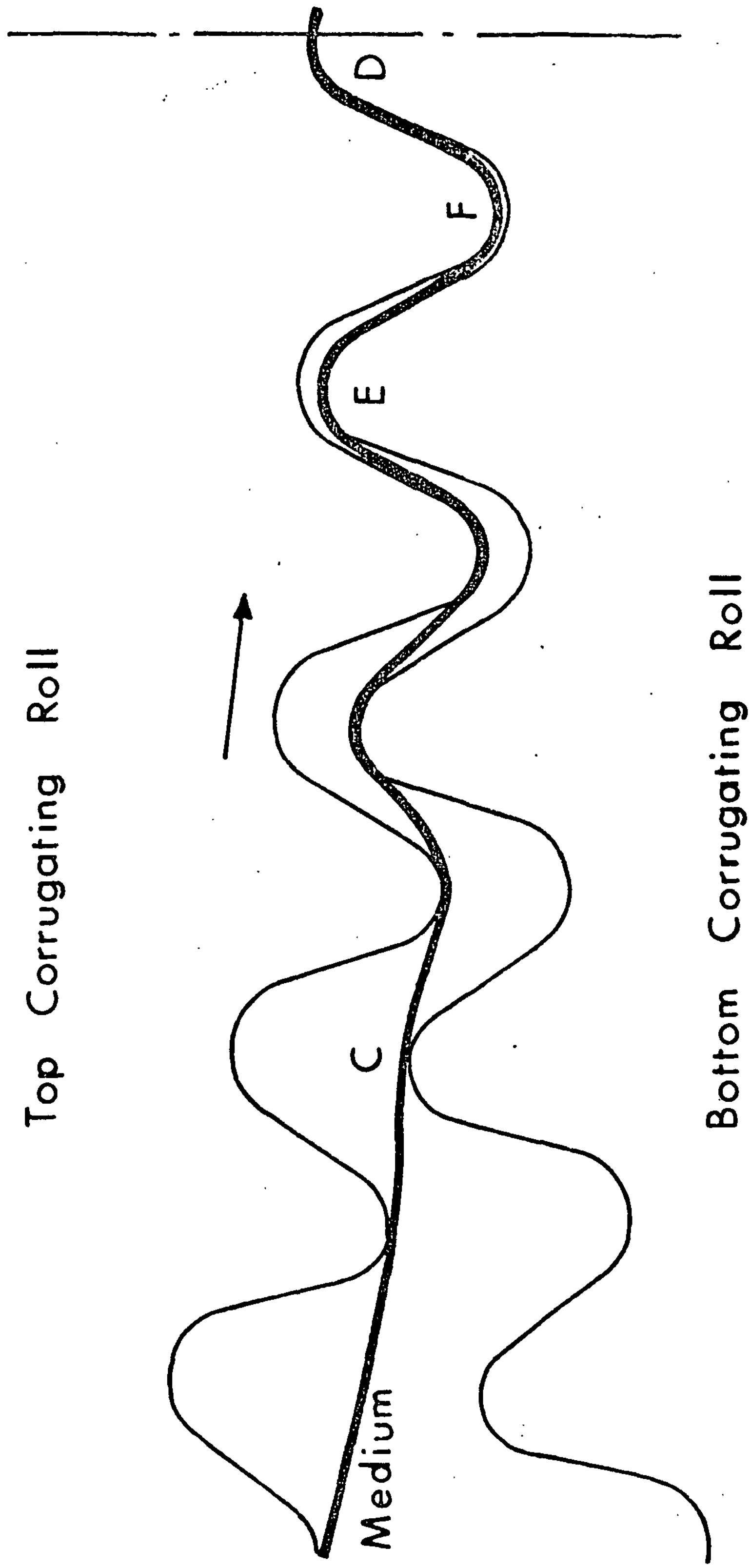


Figure 1. Labyrinth Corrugating Rolls

Web stiffness or resistance to bending will also contribute to tension build-up and may be a factor in the fracture of heavyweight or very dry mediums. For lightweight or moist mediums, however, friction induced tension is believed to dominate the fracture picture.

To minimize tension build-up and hence the propensity for fracture, one may reduce initial tension T_o, friction coefficient μ, contact angle θ, or all three. Contact angle is a function of flute geometry (flute type) and roll diameter (number of flutes in contact with the web). Smaller rolls are favored for reducing fracture but other factors impose a practical lower limit. Contact angle may be reduced somewhat by minimizing web wrap around the top corrugating roll. The small contact angle between each flute and the medium makes this a small contribution, however.

Initial tension T_o may be minimized by using an active tension controlled feeder to deliver the web to the forming nip. Sufficient tension must remain, however, to ensure adequate web tracking. With proper design, such tension control systems can eliminate tension variations due to out-of-round roll stock or other sources and hence the possibility of web fracture due to momentary over-tensions.

To minimize the friction coefficient, the most important contributor to the tension build-up, it is possible to change the corrugating roll surface properties, to change the paper surface properties by pretreatment, or both. In hot corrugating, friction is reduced by heating the rolls and the medium, by treating one or both with oil mists or sprays, by pretreating the medium with polyethylene, and so on. Pre-steaming the medium raises moisture content which generally increases friction but, as will be shown later, generally raises the failure strain limit as well so that for proper moisture conditioning, the overall tendency to fracture is minimized.

For cold corrugating, heating of the rolls and heating and steaming of the medium are excluded. Special roll surface properties or pretreatment of either the rolls or the medium to reduce friction are all practical, however. Up to the present, most attention has been paid to the use of medium pretreatment as a means of reducing friction and hence the tendency to fracture. Recent data suggest that major gains can be made through improved roll surface properties and that it is also possible to improve medium properties for cold forming. These factors are being purused and will be discussed more fully in later reports.

Bending-induced fractures occur because of excessive tensile strain in the outer fibers at the flute tip. In the absence of shear, the outer surface of the medium must extend by about 7% to accommodate the flute shape. Failure occurs at about 3% elongation. Hence, since failure rarely occurs, shear deformation must be taking place to reduce the net strain to a value below the failure level. In addition to the bending and shear strains, the medium is also under substantial tension-induced strain and transverse strain from the forming forces (top roll loading). The tension tends to promote failure whereas the transverse component may actually reduce the tendency to failure. Bending failures are more likely in heavy, dry mediums and the tendency to bending failure can also be reduced by reducing tension levels. Hence, all the mechanisms for preventing tensile fractures may reduce the tendency toward bending fracture as well. An important factor, however, is the medium moisture content at the time of forming.

In summary, the following steps can be taken to minimize the possibility of web fracture during cold forming.

1. Use corrugating rolls with the lowest possible friction coefficient. New roll surfaces are under investigation.

2. Avoid wrap of the top corrugating roll by the medium.

3. Prefeed the medium directly into the forming nip under the lowest workable tension.

4. Use the smallest practical roll diameter.

5. Pretreat the medium with a friction reducing agent--low melting point wax being a good example.

6. Run mediums with higher than normal moisture content--7-8% is a good target.

All of these factors except 5 relate to machine or paper variables which can be adjusted to help cold forming. In mapping studies on the experimental single facer, a number (about 35) of 26 lbs/MSF mediums were evaluated to determine runnability. These were tested with a normal machine with normal C-flute corrugating rolls (i.e., without attention to Items 1-4 and 6) both with and without medium pretreatment. All were successfully cold formed at commercial speeds and web tensions by using treatment agents; those mediums with friction coefficients below 0.4 (about half of all mediums tested) were successfully cold formed at commercial speeds and tensions without any form of pretreatment.

In addition to their benefit in reducing friction and hence the propensity for fracture, medium treatment agents also play a role in minimizing high-low formation and maximizing medium release properties. These will be discussed below.

<u>Flute Formation - High-Lows</u>

Flute caliper for cold formed board is always significantly higher than for hot formed board, usually by several mils. Despite the difference in caliper, draw factors are about the same for both processes, thus clearly establishing that the cold process utilizes the medium more effectively. Since the additional caliper resulting from cold forming is not required from a board performance point of view, commercial cold corrugators should be designed to yield board calipers comparable to those for the hot process. This may result in a reduction of the draw factor by a proportionate amount and hence a reduction in medium consumption. Extensive hot and cold forming comparative tests show that this difference may be as much as 2%.

In the cold process, the medium is formed cold and without moisture addition. Thus, there is no postforming shrinkage due to cooling and drying. Also, flute tip compression on a cold formed flute is about 1/3 that for a hot formed flute. These two factors are believed to be the principal contributors to the increased caliper and medium utilization efficiency.

Another formation characteristic of importance is flute height differentials or high-lows. These can be minimized in cold forming by using proper pretreatment agents, by careful finger adjustment, and by using forming pressures (top corrugating roll loads) about 25% above those used for hot corrugating. Under these operating conditions, high-low differentials generally average 2.0 mils or under which is regarded as acceptable. As in hot corrugating, the use of fingerless single facers is expected to eliminate or substantially reduce flute height differentials. Mapping samples from many different mediums are now available for analysis to determine the impact of medium properties on high-low formation. These data will be presented in a separate report.

In detailed studies of flute geometry, as measured by a very accurate laser profile gage, geometric differences between flutes from the hot and cold forming processes were found to be small and, if anything, favorable to cold forming. The cold formed flutes were higher in caliper, usually more symmetric, and usually exhibited a lower leaning tendency.

Paper Roll Release Characteristics

As the corrugating medium passes between the corrugating rolls, it is subjected to high transverse pressures. Under these conditions, there is some tendency for loose fiber, pitch or bark particles, or other forms of surface debris to adhere to the corrugating rolls, a phenomenon called picking. If excessive, such debris can cause a localized defect in the formed sheet or, in extreme cases, can lead to the necessity to stop the machine and clean the rolls. Such tendencies can be reduced by enhancing the release properties between the medium and the rolls. In hot corrugating, this is accomplished by the high temperature of both the medium and the rolls.

In cold corrugating, the frequency of picking is believed to be related to at least the following factors:

1. Release properties of the treatment agent.
2. Surface finish and material of the corrugating roll.
3. Medium surface properties including cleanliness and the presence of loose shives or nonfibrous particles.
4. Dryness of the corrugating rolls--because the rolls are cold, any stray water vapor condenses on the rolls and contributes to picking.
5. Corrugating roll flute profiles may also be a factor in the picking process.

Medium treatment agents that reduce picking tendencies have been developed and used successfully. In addition, a simple air-jet web cleaner has proved effective in removing loose material and reducing picking frequencies. Finally, the use of vapor barriers and air purges to keep water vapor rising from the adhesive application equipment from reaching and condensing on the cold corrugating rolls has been of great help. All three techniques are used on the pilot and laboratory machines. Similar features will be built into the commercial machine as discussed later in this report.

In addition to those techniques now in use to minimize picking tendencies, various practical roll surface treatments may be of even greater value. These are now being explored with data to be available shortly.

Medium Treatment Agents

From the foregoing discussion, it is evident that pretreatment of the corrugating medium is an effective means of enhancing cold forming, particularly for some mediums. Progress Report One (1) presents the results of a broad study to find the best agents and application schemes for this approach. Out of this early work, one of the best materials identified is a blend of 93% Mobilwax 130 (a low melting point wax), 5% stearin, 1% graphite, and 1% silicone oil. In this mixture, the wax and graphite are believed to be effective in preventing flute fracture, stearin is believed to act as a release agent to reduce fiber picking, and the silicone oil is added because it tends to improve high-lows. Treatment does not, in any way, interfere with other corrugating processes.

Application of treatment agents can be accomplished by molding the mixture into solid bars and then abrading the material onto both sides of the sheet in a nip formed between two bars. An apparatus for accomplishing this task on a 98" pilot machine is shown in Fig. 2. Application rates vary with hardness of the medium treatment agent (MTA), sheet roughness, nip angle, and web tension but typically amount

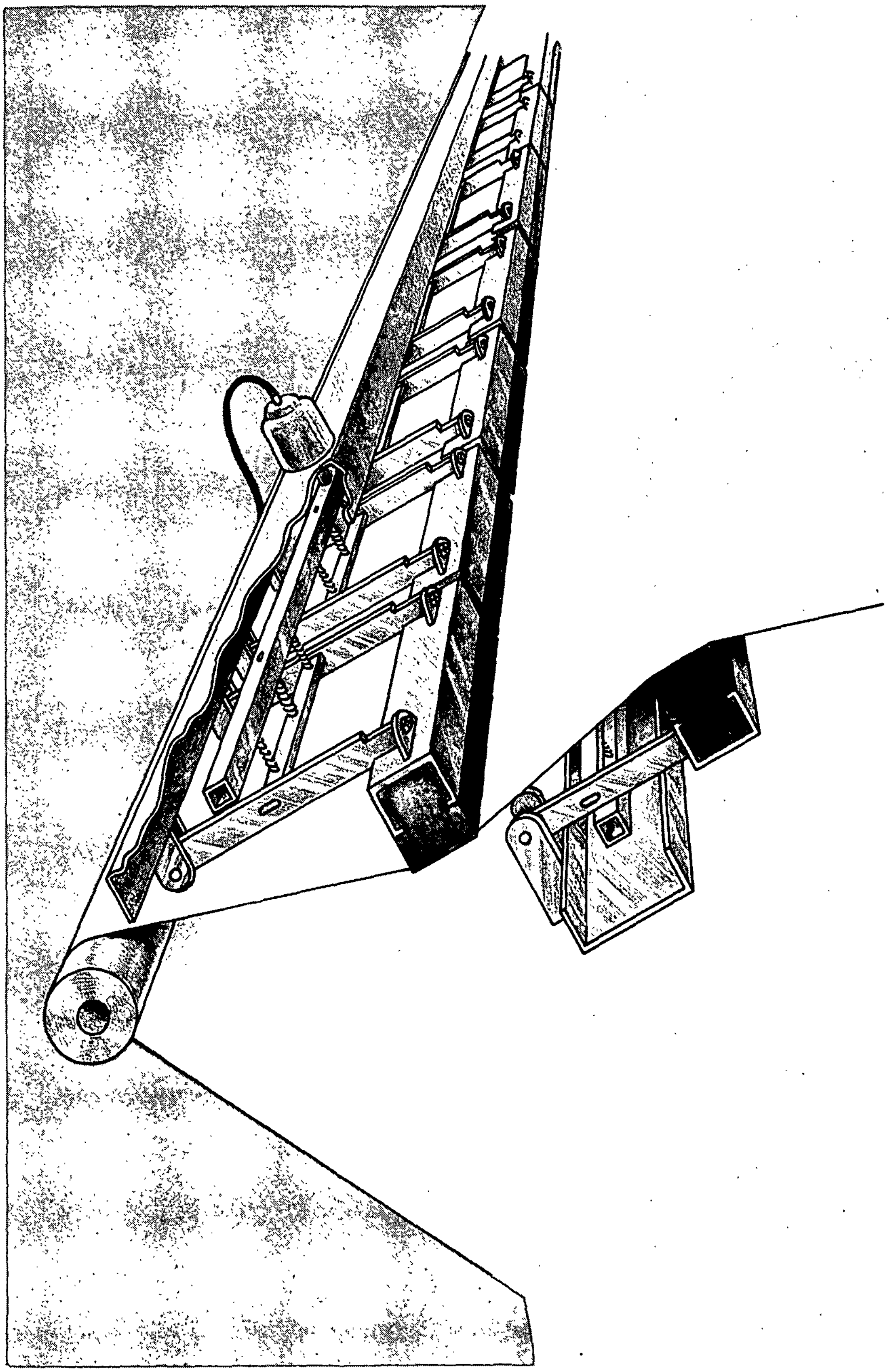


Figure 2. MTA Applicator System

to only a few pounds per million square feet. Costs typically averaged less than a penny per thousand square feet.

Other treatment agents have been developed and can be used. Some of these are described in Progress Report Three (3).

Corrugating Roll Surface Properties

Corrugating roll surface friction and release as measured against a corrugating medium are extremely important to the cold forming process. It has been shown, for example, that mediums with a friction coefficient (as measured against a steel surface) below 0.4 can be successfully cold formed without pretreatment; those with friction coefficients above 0.5 can not be cold formed without pretreatment; those between may go either way depending on other properties.

A new permanent surface treatment process has become available which should lower friction and improve release while retaining roll life. A corrugating medium with a friction coefficient against steel of 0.57 shows a coefficient of 0.16 when tested against this new material. Another medium with a coefficient against steel of 0.27 also shows a coefficient of 0.16 against the new material. Based on these results, a set of existing A-flute rolls is being reworked to apply the new surface for test purposes. Comparative data will be available shortly.

Medium Properties

No attention has yet been paid to the direct modification of medium properties to enhance their cold forming characteristics. This may be a subject of future work.

COLD SETTING ADHESIVES

The second major element in the cold corrugating process is the adhesive used to combine the components. It is in the area of adhesive preparation, handling, application, and bonding that the cold process differs most radically from the hot process. For this reason, the adhesive system must be treated as an entity when considering the cold process. It has been the experience at the Institute that any compromises attempted in areas concerning the adhesive have resulted in complications in the process with accompanying reductions in performance. This report will examine all of the key elements in the adhesive system.

The process of bonding in cold corrugating is quite different from that in hot corrugating. The adhesive for cold corrugating is hot and water based so the rate of bond development is determined by how quickly the adhesive can be cooled and dried. In the hot corrugating process, the adhesive is cold and forms a bond as it gelatinizes and dries from heating. In the cold process, there are no large temperature gradients to assist in the mass transfer.

Cold corrugating adhesive follows the "setback" principle. The adhesive is kept warm and provides bonding capability as it cools and loses moisture to the liners and medium in the combined board. Tests have shown that the cooling of the adhesive is not as critical to bond formation as is the loss of moisture. The adhesive is applied warm to maintain its fluidity and as an aid to the transfer of water from the adhesive.

Previous reports (2,3) have dealt with various aspects of the cold corrugating adhesive system. These are reviewed as necessary to present an overall state-of-the-art picture. Specific items of hardware are discussed and recommended where experience has shown that alternatives limit the process or are entirely unacceptable. Details are provided regarding every aspect of the adhesive system, from formulation through bonding. Ongoing research is also discussed.

Formulation

Conventional hot corrugating uses starch adhesives with relatively low cost. To be cost competitive with the hot process, cold corrugating adhesives have been developed which also use starch as the main ingredient. While both hot and cold corrugating adhesives are water based, the ratio of starch to total adhesive volume is much higher for the cold corrugating adhesive (about 33% solids) than for the hot corrugating adhesive (about 20% solids). Thus, the water applied to the corrugated board in the cold process for each pound of starch is about half that applied in the hot process. Also, successful bonding can be achieved at lower adhesive application rates with the cold process thus requiring the corrugator metering systems to work at lower application rates.

The cold corrugating adhesive is prepared by adding chemical modifiers to a starch/water slurry and cooking the resulting mixture with steam in a jet cooker. The cooker provides for holding the starch at the cooking temperature and at an elevated pressure until the cooking process is completed. Upon exit from the cooker, the hot adhesive is pH adjusted with caustic. The cooker will be described in more detail in the next section.

Numerous adhesive formulations have been tried during the development work. The current formula has been selected for its combination of low cost, consistency of preparation, long-term stability, and good bonding characteristics. The slurry proportion based on a 100 lb bag of starch (90 lb starch, 10 lb moisture) are as follows:

Pearl Corn Starch	100 lb bag
Water	65 liters (17.2 gallons)
Ammonium Persulfate	123 grams (0.27 lb, 0.3% on dry starch)
Boric Acid	82 grams (0.18 lb, 0.2% on dry starch)

After all items are mixed together in the slurry, a measurement of specific gravity or Baume' is taken and either starch or water is added to adjust the slurry to a 36% solids level. The slurry is cooked at $140^{\circ}C$ and 60 psi pressure by mixing it with 150 psi steam in the cooker. The cooker is constructed to maintain the cooked adhesive under these temperature and pressure conditions for 180 seconds. After that time, the adhesive is released to atmospheric pressure and sodium hydroxide (NaOH) is added to raise the pH to 9.0 to 9.2. The addition of steam and the sodium hydroxide solution to the adhesive lowers the final adhesive solids content to about 33%. After cooking, the adhesive is held at $190^{\circ}F$ to $195^{\circ}F$ until it is applied to the medium flute tips.

Each of the elements in the adhesive plays an important role. A discussion of each element and its function, along with key characteristics, is given on the following pages. A discussion of the finished adhesive is also included.

Starch

The starch used for the adhesive formulation described above is commercial grade pearl corn starch. The moisture content of the starch can vary slightly depending on manufacturer, batch, and whether bulk or bag supplies are being used. This necessitates a check on slurry solids concentration by specific gravity or Baume' before cooking if close control of the solids content is desired. In production situations, it may be possible to eliminate the solids check since slight variations in adhesive solids have not produced noticeable differences in adhesive bonding rate. Final bond strength does seem to increase slightly with solids content although the effect of increasing solids alone has not been isolated.

A slurry solids level of 41% represents the upper limit for successful conversion in the jet cooker. This corresponds to a final adhesive solids level of about 38%. The operating level is presently set at 36% solids to insure that all of the starch is cooked out or thinned in the conversion process to yield the most stable adhesive with time and to give the highest final bond strength.

Water

A limited number of experiments has shown that water hardness, alkalinity, and suspended solids have no appreciable affect on the quality of the final adhesive (4). The pH of the water does have an affect because it contributes to the final pH of the slurry before cooking. The pH of the slurry will affect the starch conversion process in the cooker and alter the final adhesive viscosity and molecular weight. Too low a pH will cause the adhesive to be thin while too high a pH will cause the adhesive to be too thick. Best results are obtained with the final slurry pH in the range of 6.0 to 7.0. A low slurry pH can be adjusted by the addition of caustic to place the pH in the proper range. A consistent box plant water supply should obviate any need for batch-to-batch slurry adjustment in commercial practice.

Ammonium Persulfate (AP)

The ammonium persulfate acts as a viscosity-reducing reagent for the starch in the conversion process. The final adhesive can be described as a hydrosol mixture of amylose and amylopectin, each reduced in molecular weight from the level it had as a component of the unmodified pearl corn starch. The amylose and amylopectin are chemically altered by the acid hydrolysis during the cooking phase (pH levels of cooked adhesive are around 2.5 to 3.0), by the oxidation due to the peroxidic structure of ammonium persulfate, and by the action of the hot alkaline environment (after pH adjustment) on unaltered glucose or already oxidized glucose units. The first two of these three chemical reactions are the direct result of the amount of ammonium persulfate added to the slurry.

The strength of the dry ammonium persulfate degrades with time when exposed to moisture in the air. Care must be taken to avoid exposing the crystals to the atmosphere for long periods of time or on a repeated basis.

The action of the AP on the starch also becomes less effective if the AP is allowed to be present in the slurry for too long a time before the cooking process. In the batch cooking process, the AP is added with just enough time before cooking to insure complete dissolution and mixing (about 5 minutes). In continuous cooking operations, the AP will be metered into the slurry stream just ahead of the cooker.

Boric Acid

The boric acid added to the slurry does little to the conversion process in the cooker. It helps to create an acidic atmosphere in the slurry which assists in the reduction of the size of the starch molecules and thereby lowers the amount of AP required by a small amount. Its main value, however, occurs after the cooking and post addition of NaOH where the boric acid turns into borax. The borax serves as a thickening agent and produces an adhesive with faster bond rate development.

Technical grade boric acid is used in dry form. It is much more stable than the AP and no special precautions are necessary.

Sodium Hydroxide (Caustic, NaOH)

As mentioned before, the addition of caustic to the hot, cooked adhesive produces further changes in the molecular size and chemical structure of the starch. The specific nature of the reactions taking place in the adhesive is unknown.

Two methods of adding the caustic have been used. In the early development work at the Institute, the caustic was added to the hot adhesive in the adhesive holding tank after completion of a batch cook. This was done under atmospheric conditions and with a propeller-type mixer for agitation. The amount added was determined by measuring the pH of the adhesive in the tank. Reactions that occur after cooking and before pH adjustment change the final adhesive stability and viscosity. These variations are amplified by the poor consistency of this type of addition. More recently, adhesives have been prepared by injecting the caustic directly into the jet cooker piping downstream from the back pressure valve. After caustic injection, the adhesive flows through a static mixer, then through a flash chamber, and finally to the adhesive holding tank. The injection method is now preferred and recommended because it halts the acidic reactions as soon as possible after the adhesive exits the cooker pressure section and provides for more thorough mixing of the caustic with the adhesive. Long-term stability of the adhesive is improved and better repeatability from batch to batch has been observed.

The caustic is handled as a solution of 50% NaOH in water. The details of the metering and injection system are discussed in the section on the jet cooker.

The final adhesive pH is important in terms of adhesive stability, with a pH of 9.0 to 9.2 being preferred.

Setback Adhesive

The finished adhesive emerges from the jet cooker at about 210°F and is allowed to cool to about 195°F. Cooling below this temperature results in a partially irreversible increase in viscosity and should be avoided until bonding is desired. High viscosities may limit bonding rates and increase the difficulty of pumping and metering. The recommended temperature for the adhesive in the holding and distribution system is 195°F ± 5°F.

A Brabender amylograph-viscograph is used to measure the low shear rate viscosity and the temperature viscosity history of a sample of the adhesive after cooking. These measurements provide an important indicator of the degree of thinning of the starch polymer and show, indirectly, the effect of thinning agents and conversion conditions.

The low shear viscosity is also important as an indicator of the ease with which a given material may be pumped and handled in an adhesive system. The current setback adhesive formula should have a final viscosity of about 250 Bu (Brabender units). Viscosities over 500 Bu are avoided because of the added difficulty of pumping and handling. In production, a Brookfield or similar viscometer could be used in place of a Brabender to measure the low shear viscosity for handling.

At higher shear rates, setback adhesives are shear thinning. High shear viscosity is an important property of the adhesive in determining its performance in adhesive applicator systems. The Institute recently obtained a Haake RV-2 high shear viscometer to assist in further analysis of adhesives under conditions of high shear. The Haake, shown in Fig. 3, is fitted with a special sample holding unit to maintain the adhesive under controlled temperatures.

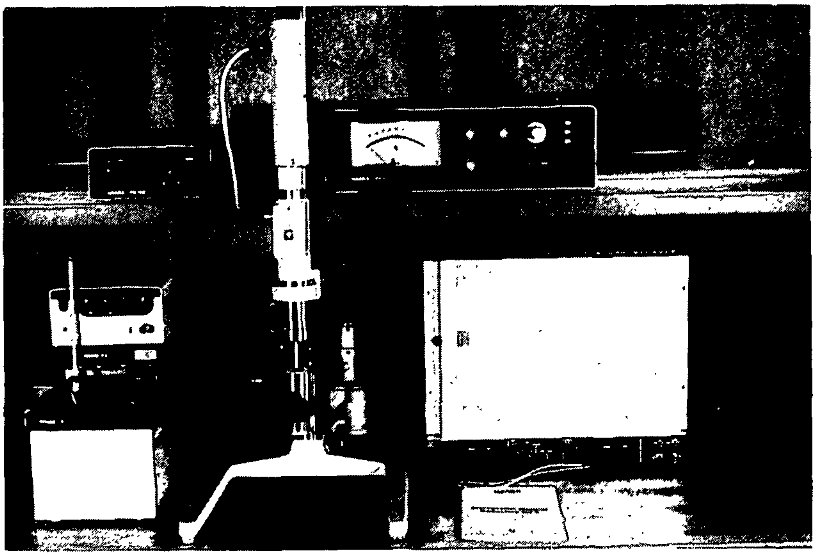


Figure 3. Haake RV-2 High Shear Viscometer

It is common for setback adhesives to show a 25-30% decrease in viscosity over the shear rate range from 0 to 20,000 $sec.^{-1}$. By comparison, a conventional corrugating adhesive would show an 80% decrease over the same range. Thus, at the high shear rate conditions encountered in the nip of corrugator two-roll metering systems, setback adhesives have at least twice the viscosity of conventional adhesives. This has an important impact on metering as discussed later.

Adhesive viscosity remains relatively stable for as long as 4-5 hours provided the temperature is maintained as indicated and moisture loss from the adhesive is kept to a minimum. Any loss in moisture increases the solids content and therefore tends to cause an increase in viscosity. Moisture loss is driven by the elevated temperatures needed to maintain the adhesive.

Cooking Procedures and Equipment

The Institute has used two cookers for the past few years in the manufacture of setback adhesive according to the formula just described. One is located at the site of the plant trials and the other is located at the Institute. The cookers were constructed quite differently but were modified in time until they are now very similar. Several minor differences still exist and these will serve to illustrate alternative methods to achieve successful adhesive preparation. Fig. 4 is a schematic of a complete adhesive makeup and handling system.

Adhesive preparation starts by mixing a slurry of starch, water, and chemical modifiers in a large tank. Since the slurry is acidic, stainless steel is recommended for the tank, pump, and all lines. Mixing of the slurry can be accomplished via a propeller-type mixer. The slurry pump can be of the Moyno or Waukesha type. The Moyno is preferred because of its smoother supply of starch to the cooking jet.

Some measure of the slurry flow rate is desirable, especially for R & D purposes. Mechanical bobs or rotameters are not recommended because of their sensitivity to particulate suspensions and specific gravity changes. Ultrasonic or other types of non-contact meters are also sensitive to specific gravity and hence will only be accurate at one starch solids concentration. The Institute has been using a Micro-Motion Mass Flowmeter which provides a true measure of the weight of slurry in pounds flowing to the cooker. It is insensitive to starch concentration and not affected by entrained air which might be present from the mixer.

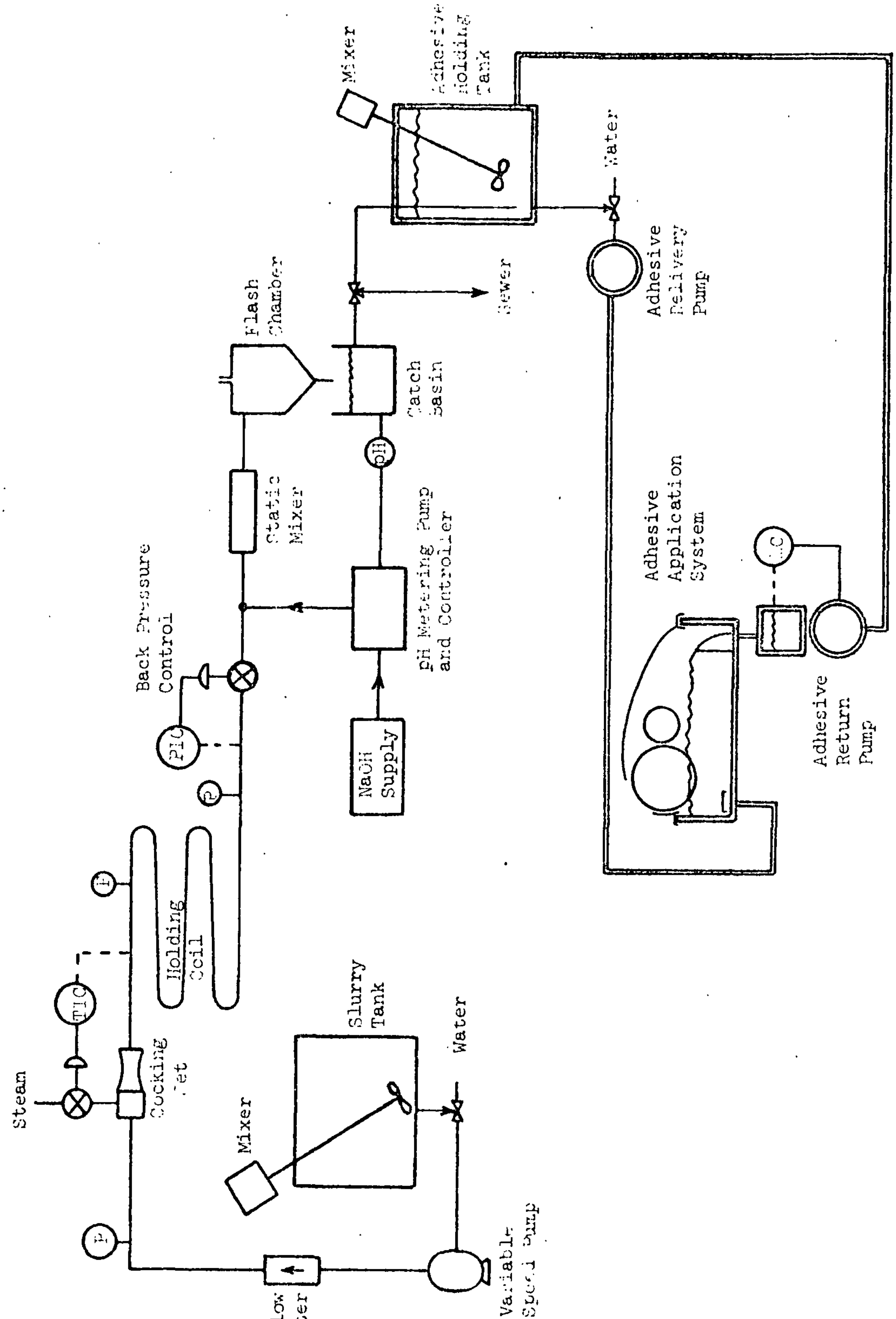


Figure 4. Schematic Diagram of Adhesive Make-Up and Handling System

Both cookers in use were constructed from parts originally furnished by the Grain Processing Corporation as one cooker. The cooking jets for both cookers are specially modified Penburthy Jet Pumps. Cooking can also be accomplished by a device called a hydro-heater if it is suitably modified for use with starch.

The temperature of the cooking process is determined by the amount of steam flow and the pressure in the holding coil of the cooker. In the Institute cooker, the steam flow is regulated by a manual valve while the operator reads a temperature indicator. The cooker for the plant trials contains an automatic sensor, recorder, and control valve to maintain a set temperature without operator intervention. Either system is acceptable but the automatic system provides for more consistency and is a must for production applications. A cooking temperature of 140°C is used for the setback adhesive. Lower temperatures decrease the amount of cooking of the starch and increase the viscosity of the adhesive.

The pressure of the cooking process is controlled by a back pressure control valve at the end of the holding coil. The cooker at the Institute has a specially modified valve obtained through the Grain Processing Corporation. Pressure is controlled by a spring in the valve which has an external adjustment for setpoint. The cooker used for plant trials has an automatic valve, recorder, and pressure sensor. Either method of pressure control is acceptable for production use. The cooking pressure is set at 60 psi for the 140°C cooking temperature.

The holding coils for both cookers are constructed of stainless steel tubing and sized to provide a holding time of about 2½ to 3 minutes. Lower holding time may prevent complete cooking of the starch and lead to a higher viscosity and possibly to a less stable adhesive. Longer holding times are allowable but are of no value in improving adhesive properties.

The caustic is injected into the adhesive stream immediately after the back pressure valve. It is handled and stored as a liquid--50% solution of NaOH in water. It is highly corrosive and requires either stainless steel or plastic parts for the storage tank, pump, and lines. The line pressure at the point of injection is above atmospheric requiring a positive displacement pump. The amount injected must be accurately controlled and evenly distributed over the cooking cycle. This dictates that a metering pump be used and that it provide some way to adjust the flow rate of the caustic. The setting of the pump is determined by measuring the pH of the adhesive exiting the cooker. At the Institute, this is done periodically during the cooking cycle by an operator who then makes mid-course corrections to achieve the desired final value. It has been found that these corrections can be reduced to almost none with experience and careful monitoring of cooker flow rate. Once set, a good metering pump should be able to supply caustic at the proper rate with little attention. The second cooker operates with an automatic pH control system. The sensing electrode is mounted in a small catch basin just under the flash chamber to minimize the time required to detect a pH change resulting from a change in the caustic rate. This eases the problem of pump control. pH electrodes for this elevated temperature environment are not perfected, but new electrodes are constantly being evaluated as the state-of-the-art improves. A stainless steel static mixer is located in-line after the caustic injection to provide uniform mixing as quickly as possible and with a minimum of energy.

The cooking process can be accomplished by starting and ending the cook with water and steam or just steam in the cooker. The slurry is valved on or off as desired. When starting with water and steam, the water is heated in the cooker to 140°C and then the slurry is valved on and the water off. At the end of the cooking cycle, the process is reversed. A change in steam pressure is required as the valves are shifted since it takes more steam to heat the water than it does to cook the starch. A change in pump speed may also be required because of differences in flow properties of water and slurry. Both start-up and shut-down interfaces must be discarded with a loss of both starch and energy.

Recently, the cooker at the Institute has been modified to permit start-up and shut-down on steam alone. A manual valve has been added to bypass the pressure control valve. This valve is opened during start-up and shut-down to let the steam flow through the cooker at atmospheric pressure. With this procedure, all the cooked starch may be saved. This approach is also better suited to the automatic control expected on commercial equipment, as described in a later section.

<u>Handling and Application Systems</u>

Adhesive handling and application can be broken down into two distinct areas. One area concerns the requirements for storing and transporting the adhesive from the cooker to the single facer and glue machine. This is defined as adhesive holding and distribution. Most of this technology is well known and involves taking proper precautions to avoid heat and moisture loss in the adhesive.

The second area involves the metering and transfer of the adhesive from an adhesive pan onto the corrugating components. Much work has been done regarding the metering aspects--both theoretical and experimental. However, only a limited amount of experimental work has been done on the transfer of adhesive to the components. Although enough is known to proceed in this area, more work remains to complete the picture.

Holding and Distribution Systems

Fig. 4 also shows a typical adhesive handling and application system incorporating a two-roll metering system. Adhesive from the cooker is stored in and distributed from a large, covered, and agitated holding tank. The agitator speed is kept slow to minimize foaming, moisture loss, and stirring energy consumption. The tank is water jacketed and insulated. Hot water is maintained at the desired adhesive temperature or slightly above and circulated through the tank jacket. All adhesive circulation pumps and lines are also water jacketed and insulated insofar as possible. Flexible connections are made with hose and kept as short as possible.

The holding tank and pump system for use at the Institute is mounted on a movable cart to allow easy transportation of the adhesive from the cooker to the corrugator. The system used for plant trials is hard piped with separate holding tanks for the single facer and glue machine. Connecting lines are made of black iron pipe to minimize cost and because usage is infrequent. Stainless steel piping is initially recommended for all production installations since the corrosive nature of adhesive is not well established. It may be possible to use black iron but more experience is needed before such a recommendation can be made.

Pumps used for circulating adhesive have been of the Tuthil-type positive displacement gearotor. They perform well considering that the adhesive is water based and does not provide much lubrication. Pump speeds are kept to the minimum necessary via the use of D-C motors and SCR controllers. In addition, the return pump at each glue pan is fitted with a sump and level sensor to control pump speed based on the amount of adhesive to be returned to the holding tank.

Adhesive pans for the machines are custom designed with water jackets on all sides and the bottom. Bottom jacketing alone was found to be inadequate. Pan jackets are designed to provide for a serpentine flow path for the water which eliminates "dead" spots. Close-fitting covers are provided on the pans where possible. Sliding covers are used to cover applicator rolls during the times when the webs are not in contact with the applicator rolls. This type of cover is especially critical on the single facer where moisture lost from the adhesive may condense on the cold corrugating rolls and cause the medium to stick. Pans and covers are insulated on the outside to retain heat and protect personnel.

Adhesive can not be allowed to stagnate anywhere in the system pans or lines. A constant flow is required to maintain adhesive properties. Adhesive pans are supplied with a surplus of adhesive, as in hot corrugating, with special dams in the pans as required for wetted width control.

Best results are obtained when all applicator and metering rolls or blades are heated. This is most easily accomplished by connecting them to the warm water recirculating system.

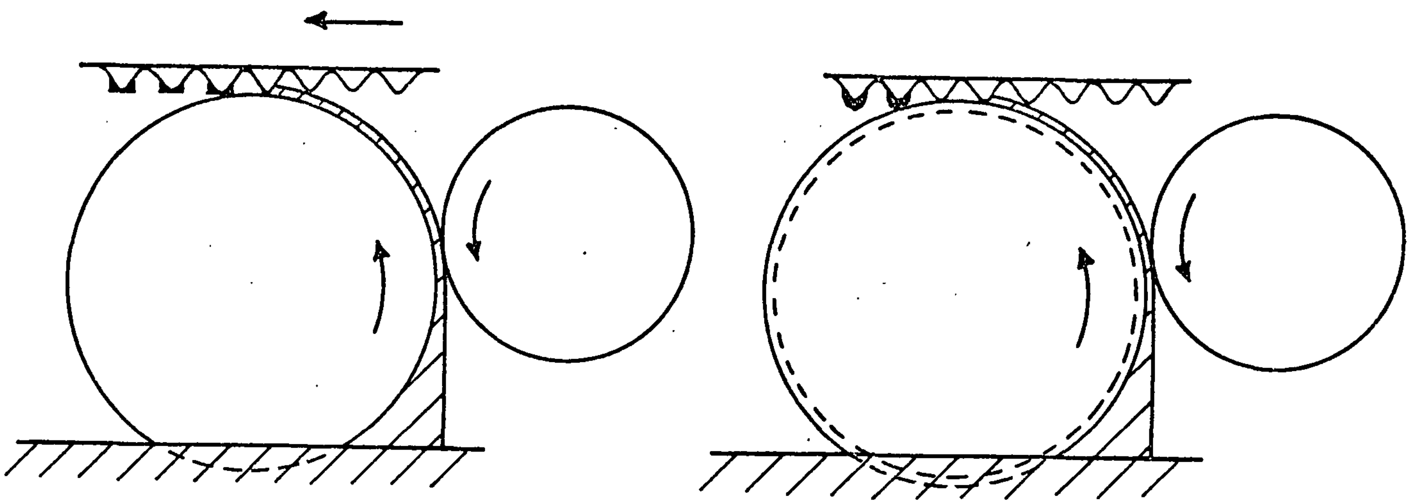
The system as described for the plant trials has operated satisfactorily during runs as long as 2½ to 3 hours on a single cook of adhesive and with no noticeable loss in adhesive bonding capability. Capacity limitations in this system preclude longer runs.

Metering and Application Systems

Adhesive application is a two-stage process in which a thin film of adhesive is metered onto an applicator or transfer roll and then transferred to the flute tips of the medium as the tips contact the roll. The amount of adhesive applied to the flutes is a function of many variables, one of which is the amount of adhesive that is metered onto the applicator roll. Application rate, therefore, is most easily controlled by regulating the amount metered onto the applicator roll.

Conventional corrugators usually utilize a two roll adhesive system for both the single facers and glue machines. At the single facer, both rolls are smooth. At the glue machine, a smooth metering roll (or doctor roll) is normally used with a die engraved gravure transfer roll. In both cases, the two rolls rotate in the same direction so that their relative motion in the nip between the two rolls is opposite. This opposite motion shears the liquid picked up as the transfer roll dips into the adhesive pan and leaves only a thin film on the transfer roll to be carried onto the flute tips.

The nature of the transfer roll, smooth or gravure, determines the distribution of adhesive on the flute tips. This is shown in Fig. 5. Contact with a smooth roll tends to squeeze the adhesive off the tip and onto the shoulders of the flute. The gravure roll transfers adhesive from cells to the flute tip where it remains to provide a uniform coverage. More adhesive will be applied if a film is allowed to remain on the surface of the roll. At the single facer, bonding is dependent on moisture transfer induced by the high pressures generated as the pressure roll is forced against the lower corrugating roll. The absence of adhesive at the center of the flute tip resulting from the use of a smooth applicator roll impedes this process and hence the efficiency of bonding. For this reason, a gravure roll is preferred at the single facer. A gravure roll is also preferred at the glue macine since bonding rate and bonding efficiency (bond strength per unit of adhesive) are both maximized by applying a thin uniform film



Smooth Applicator Roll
Transfer to Shoulders of Flutes
Very Little on Tip

Gravure Applicator Roll
Transfer to Tips of Flutes
More Adhesive Applied

Figure 5. Application of Adhesive to Flute Tips

to the flute tip. Setback adhesives have rheological characteristics which are qualitatively similar to conventional adhesives in that they are shear thinning. Quantitatively, however, setback adhesives thin less and hence have higher high-shear viscosities. Consequently, for a given gap setting between the metering and applicator rolls in a two-roll metering system, the film of adhesive on the applicator roll will be thicker for a setback adhesive than for a conventional adhesive. For hot corrugating, a 10 mil gap between rolls typically results in an adhesive film thickness of 5 mils or less (5). For setback adhesives, that same 10 mil gap would result in an adhesive film of nearly 10 mils. Conversely, to adhieve less than a 5 mil film with setback adhesives, the gap in a two-roll system must be set at 5 mils or less. Work on an experimental two-roll system has proven this out as can be seen in Fig. 6. This 5 mil gap has been achieved

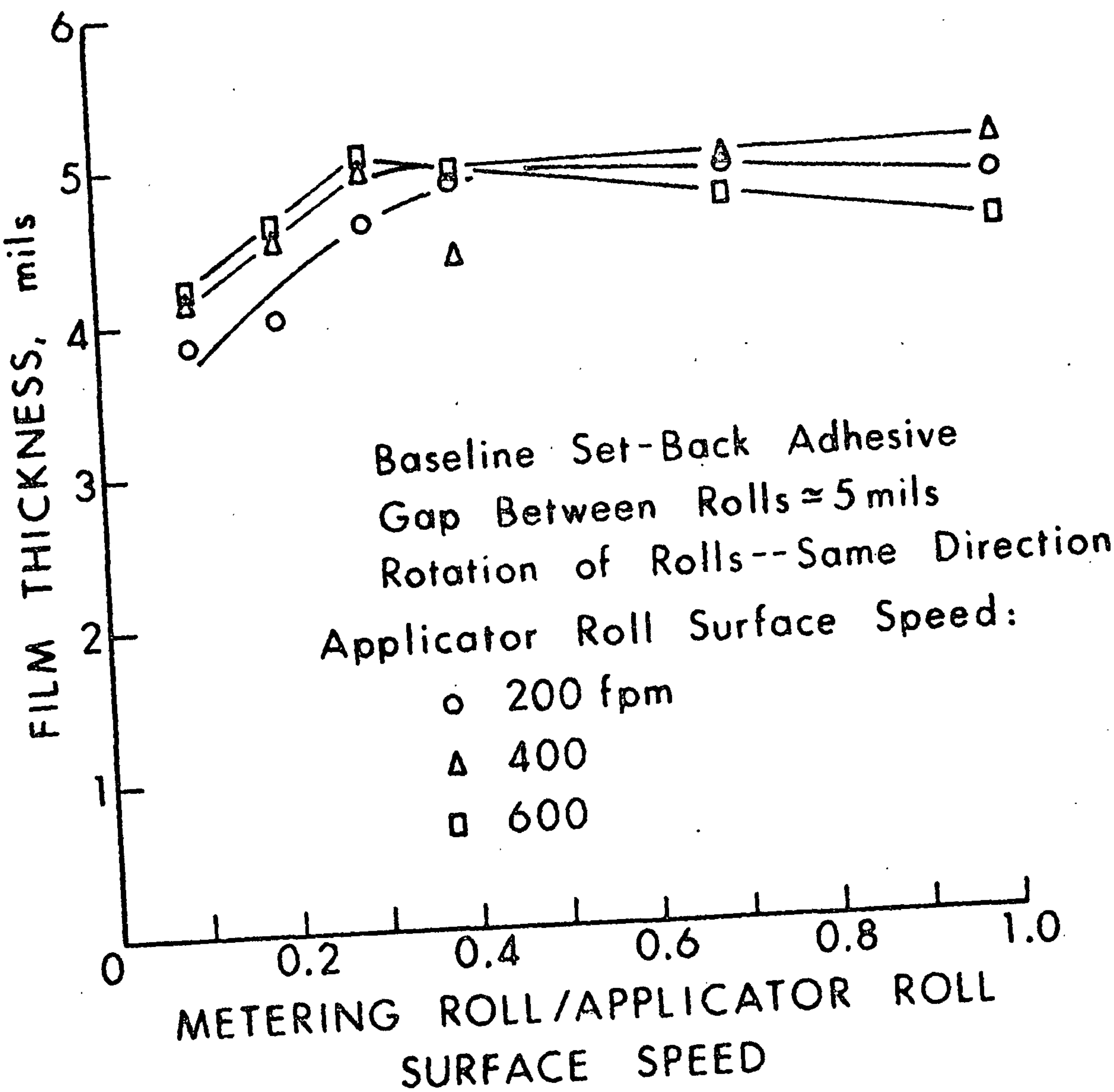


Figure 6. Two-Roll Metering System Characteristics at Metering Gap ≈ 5 mils

on the Institute single facer and on the single facer used for the plant trials but is below the practical limit for commercial operation of two-roll systems as they are currently designed and maintained. Even at the low gap of 5 mils, the minimum setback adhesive application rate has been 1.0 to 1.2 lbs/MSF on the 12" wide Institute single facer and over 1.5 lbs/MSF on the wider machine used for plant trials. Successful commercial operation will require control of equivalent films of 1.0 to 2.0 mils in thickness.

An excessive amount of adhesive affects both hot and cold corrugating in a similar manner. The most obvious effect is an increased cost of production due to an increased consumption of adhesive. More adhesive also means more water is applied in the bonding process and this leads to increased warp and washboarding. The extra adhesive also inhibits the double face bond formation rate. In the hot process, compensation can be made by increasing the heat or the amount of contact of the board with the steam chests or reducing speed. In the cold process, no such means of compensation exists and extra adhesive requires a reduced running speed in order for the bonds to have enough time to develop sufficient strength to survive the slitting process. Finally, pin adhesion tests of final bond strength indicate very little change due to the amount of adhesive applied (in the cold process) within the range of 0.5 to 1.75 lbs/MSF.

The applicator system limitations on the cold single facer have been tolerated up to now since bonding can still take place at speeds up to 600 fpm with most setback adhesive formulations. It is recognized, however, that the excess moisture added at the single facer does limit double face bonding rate. On the glue machine, various steps have been taken to reduce the amount of adhesive applied to improve production speeds. After experiencing difficulty with the standard two-roll, gravure and smooth, commercial system in the plant trials, a trailing wiper blade was installed temporarily in the glue machine to doctor off all adhesive on the surface of the gravure roll. This reduced application rates to as low as 1.0 to 1.2 lbs/MSF and allowed good commercial board to be produced at speeds of 300 fpm. Above that speed, delamination of the double face liner occurred at the slitter wheels due to insufficient bond development.

A further reduction in adhesive application was deemed necessary to yield higher running speeds without modifying the adhesive formulation. An experimental gravure roll and scraper blade applicator was set up at the Institute to study the effects of different gravure patterns on application rate and distribution. Part of the system is shown in Fig. 7. The applicator roll is in the center of the photograph and an idler roll for wrap control appears at the left. Gravure patterns of 16, 25, and 30 quadrangular cells per inch were tried at various speeds and with various degrees of single face web wrap on the applicator roll. The 16 quad roll was nearly equivalent to the one in the Langston 131 glue machine at the site of the plant trials. It had a cell depth of 0.018". Adhesive application was measured by fluorescent dye techniques. Fig. 8 shows some of the results of that work as photographs taken under ultraviolet light. A uniform application of about 0.5 lbs/MSF was achievable with the 25 quad pattern at 600 fpm. The 30 quad roll transferred insufficient adhesive and with poorer distribution.

Based on the findings from the experimental applicator, a complete new glue machine was designed during 1980 for the plant trials using a 25 quad gravure roll with cell 0.012" deep and a 0.0045" bridge (space between cells). This unit, shown in Fig. 9, features a trailing scraper blade and a self-contained D-C roll drive. Corrugator speed can be matched exactly or varied by ±15%. This flexibility was provided because the speed of the applicator roll relative to the board speed has an affect on how much adhesive is transferred to the flute tips and where it is deposited. This machine also

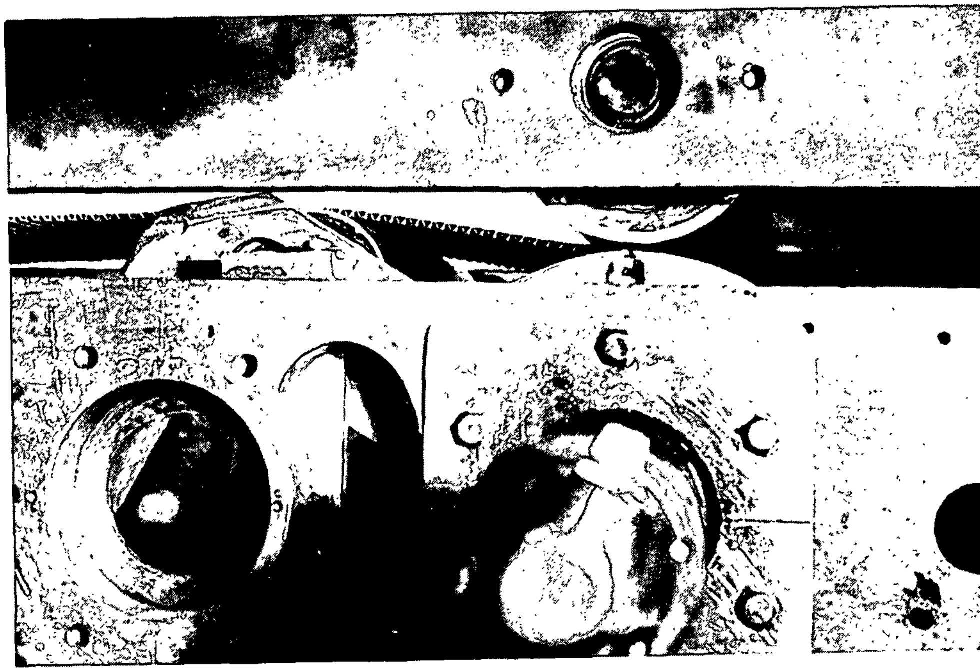
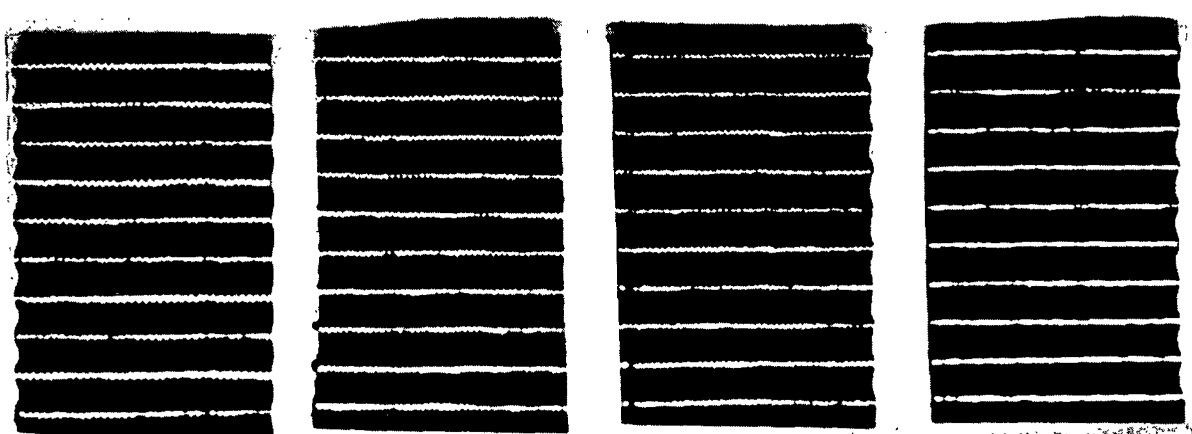


Figure 7. IPC Laboratory Glue Applicator with Single Face in Position



25 Quad, 600 fpm
Setback Adhesive
0.54 lb/MSF

30 Quad, 600 fpm
Setback Adhesive
0.40 lb/MSF

30 Quad, 400 fpm
Setback Adhesive
0.16 lb/MSF

30 Quad, 200 fpm
Conventional Adhesive
0.38 lb/MSF

Figure 8. Adhesive Distributions for Gravure Rolls on IPC Laboratory Glue Applicator

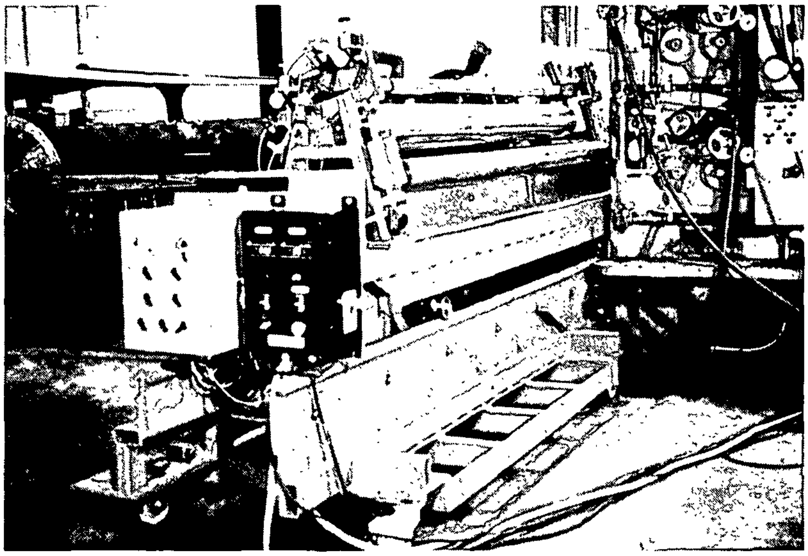


Figure 9. 98" Wide Experimental Glue Machine

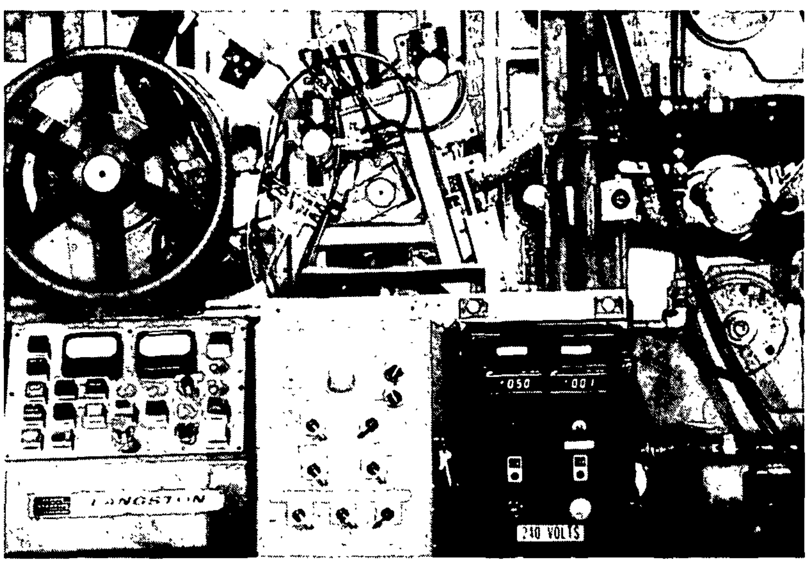


Figure 10. Experimental Glue Machine in Place Between Standard Glue Machine and Double Backer

includes a pneumatically controlled hold-down roll that runs with an adjustable gap to the applicator roll. Adhesive is contained in the base of the unit and recirculated through a shallow pan just beneath the applicator roll. On-board pumps provide for both adhesive and warm water circulation. The machine direction dimension of the machine was dictated by the space between the existing glue machine and double backer (Fig. 10). Since this unit was experimental in nature, it had to be removable for regular production. This was accomplished by providing rails on the existing glue machine and double backer on which the unit could be installed and removed.

A few trials have been made with this unit and the results are encouraging. Application rates in the range from 0.5 to 1.0 lbs/MSF with a fairly uniform distribution over the flute tips have been achieved.

Adhesive Bonding Characteristics

In previous sections of this report, the physical, chemical, and application characteristics of setback adhesives have been described. None of these characteristics has any relevance, however, unless the bonding properties of the adhesives are acceptable. Bonding strength must be viewed in terms of the time rate of bond development, the ultimate strength of the bond, the locus of bond failure, and the stability of these characteristics with age and environment. The purpose of this section is to present the bonding properties of the setback adhesive and better describe those elements of the process which affect bonding.

As discussed before, two different bonding conditions occur during corrugating. Bonding occurs under high pressure and short time intervals on the single facer and under low pressure and long time intervals on the double backer. Despite these differences, it is felt that a single setback adhesive can be used at both locations. Adhesive preparation and handling would become much more complex if two formulations were required.

Comments will be directed at two elements of bonding: final bond strength and bond rate development.

Final Bond Strength

Final bond strength is a measure of the force required to disrupt the bond joining the medium and liner. For a good adhesive, this strength will be at least 4 lbs/lineal inch of flute and the bond will fail by pulling fiber from the medium or the liner. If the bond fails by pulling fiber, then the cohesive strength of the adhesive is greater than the strength of one or more of the components and the adhesive has penetrated sufficiently to provide maximum bond strength. Both are important properties. Failure in the adhesive, i.e., without pulling fiber, implies that the adhesive is the weakest link in the bonding system. Final bond strength is typically evaluated by a standard pin adhesion test or by testing mature bonds on the double backer simulator discussed later.

Many different setback adhesive formulas have been evaluated with most giving excellent final bond strength, usually at least 5 lbs/lineal inch. Bond strengths are usually nearly the same for single face and double face bonds. At bond failure, fiber is almost always pulled from one component or the other with medium fiber failure being the more common. The current setback adhesive formula as described in this report demonstrates sufficient final bond strength even at application rates as low as 0.5 lb/MSF.

Bond Development Rate

Bond development rate is critical to the corrugating operation because freshly made board must have sufficient strength to withstand the slitting, scoring, and stacking operations that occur on the dry end of the corrugator. Machinery used for the normal production of corrugated board is not suitable for the evaluation of bond development rates. In production, it is possible to observe whether the green double face bond is strong enough to withstand the slitting and scoring operations but impossible to determine the strength or other characteristics of the bond before or immediately after the slitter. Hence, production scale equipment is poorly suited to adhesive optimization work.

To better evaluate setback adhesive bonds during the formation stage, a double backer simulator was built. This device performs all of the functions of a conventional double backer at an equivalent time relationship but on a smaller physical scale and at a slower speed. After making double faced board from a single face strip, adhesive, and liner, the instrument disbonds the newly formed strip one flute at a time. As the flutes are separated from the liner, a measure of the instantaneous bond strength of each flute is made. A strip chart recording of the test shows the strength of each flute vs. the age of the bond on that flute. Using the simulator, adhesives can be effectively compared with respect to rate of bond strength development by plotting bond strength as determined from the strip chart recordings. In addition, control adjustments on the simulator permit comparisons to be made for different values of production speed, combining pressure, glue application rate, component combinations, etc. A more complete description of the simulator appears in Appendix I.

The simulator has answered many questions about the bonding process and the factors that affect bond rate development for the setback adhesives used in cold corrugating. Some of these factors will be discussed in the remaining portion of this section.

Effect of Application Rate. Trials on the simulator were conducted to quantify the results seen during the plant trials; namely, that too much adhesive inhibits bond rate development. Fig. 11 shows the results in graphical form. The lower curve at a 12 mil film on a smooth applicator roll in the simulator represents about 2 lbs/MSF of dry starch applied. The middle curve at a 2.5 mil film corresponds to about 1 lb/MSF of starch. The vertical scale is a measure of bond strength over the 2" wide sample. The horizontal scale is a measure of the time between the combining of the components in the double backer and the point at which the bond strength is evaluated. For the corrugator used for plant trials, this time increment is 8 seconds at a running speed of 600 fpm. The bond strength differences at the 8-second point due to adhesive application rate differences are self-evident. In fact, a reduction in application rate from 2 lbs/MSF to 1 lb/MSF produces about a 30% increase in potential running speed. Also shown in Fig. 11 is a bond rate curve for adhesive applied at a rate of about 0.5 lb/MSF by a 25 quad gravure roll. This curve shows much faster bonding and would project a production speed increase of 60% over the 2 lbs/MSF application rate with a smooth roll.

Effect of Adhesive Temperature. Theoretical calculations of heat transfer for the cold bonding process were made using some simplifying assumptions. The results of this analysis indicated that a 2 mil adhesive film at 190°F applied to the flute tips of a medium would cool to 110°F within one-half second. At 600 fpm board speed, this

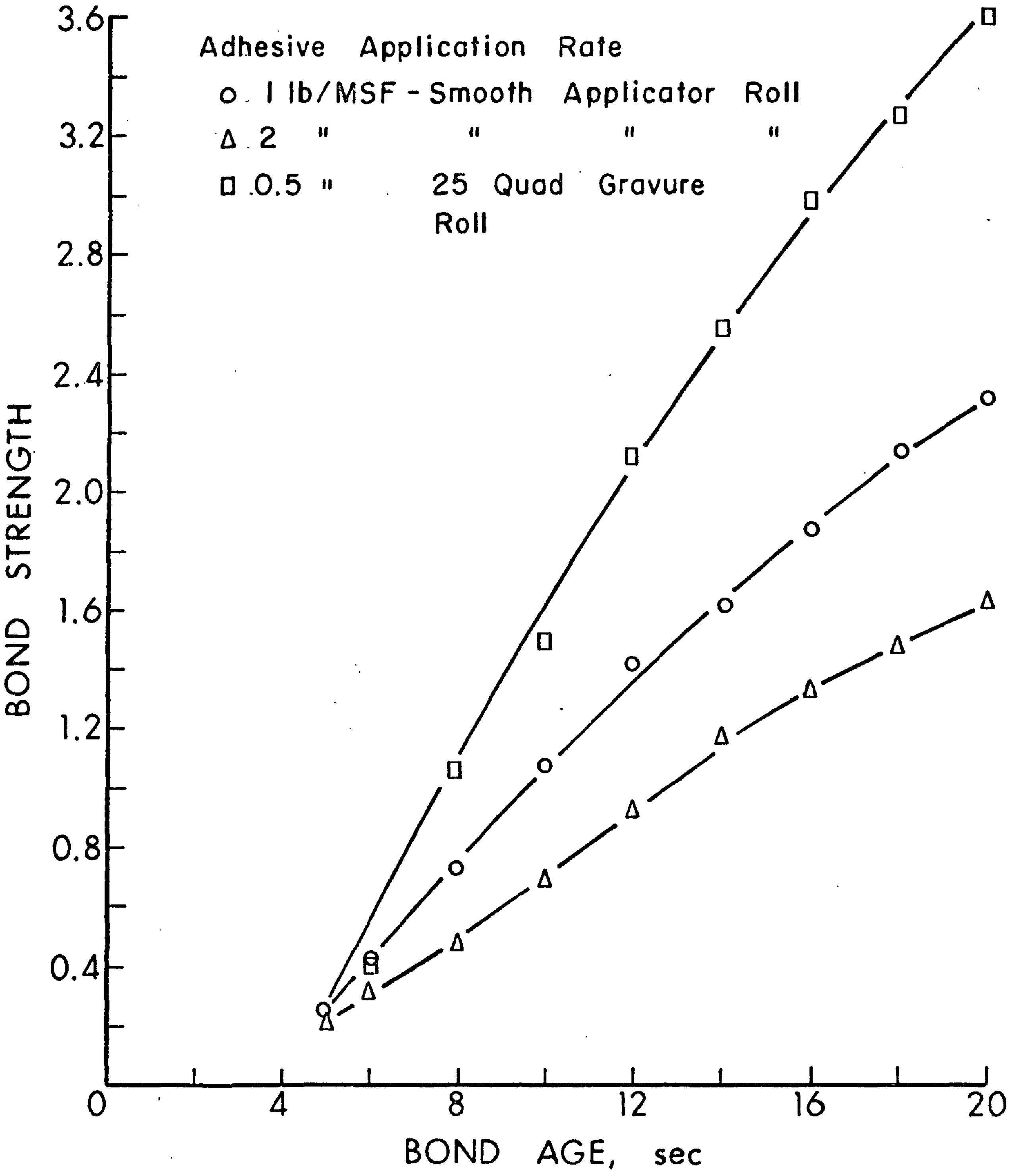


Figure 11. Effect of Adhesive Film Thickness on Bond Development

half-second represents 5 feet of board travel. Since the point of combining in the double backer is about 5 feet from the glue machine applicator roll, this means that the setback adhesive is cooled to nearly room temperature before the bond is made. This analysis was confirmed by simple touch tests during one of the plant trails at Burlington. In other words, double face bonding occurs with a cool adhesive.

The benefit from applying the adhesive hot was then investigated on the double backer simulator. Fig. 12 shows the results. Clearly, bond rate development is enhanced by higher application temperatures. Since the bonding temperature was relatively the same for all three application temperatures, the higher temperatures must promote better mass transfer and this better mass transfer must encourage faster bond rate development.

The simulator was used to investigate the role of mass transfer by bonding single face to medium and single face to liner in one test. Fig. 13 shows the results. The medium, being much more receptive to adhesive (and water) than the liner, showed much higher bond development rates in the early stages of bonding. The water drop value of the medium was 22 seconds compared to 600+ seconds for the liner. The final bond strength for the medium was lower than for the liner because of the weaker nature of the medium sheet. Mass transfer of the adhesive into the components is thus shown to be the key element in achieving fast bond rate development in the cold corrugating process.

Effect of Combining Pressure. It has already been stated that the high pressure in the single facing bonding process promotes mass transfer and hence bond development. The force at the point of contact between the medium and liner forces

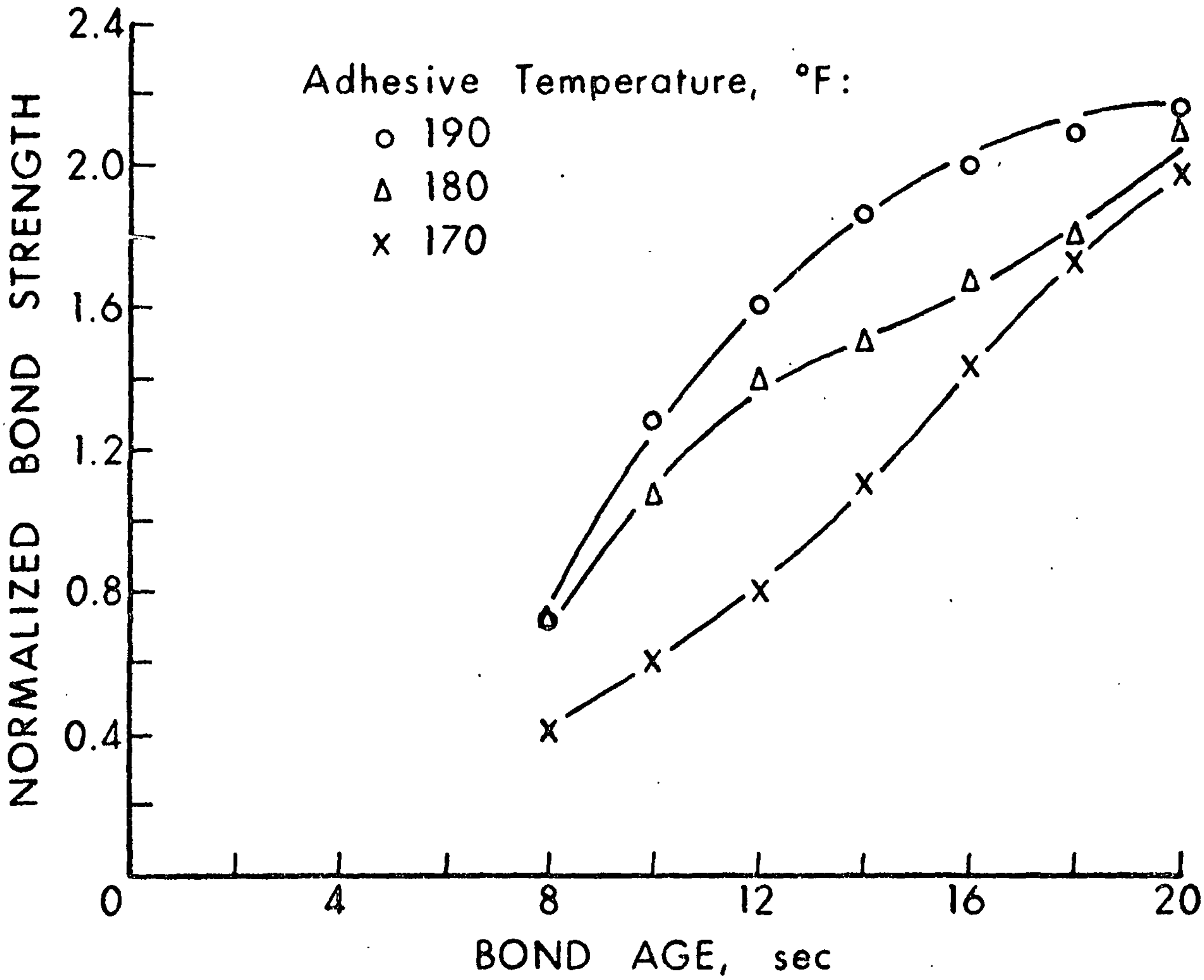


Figure 12. Effect of Adhesive Temperature on Bond Development

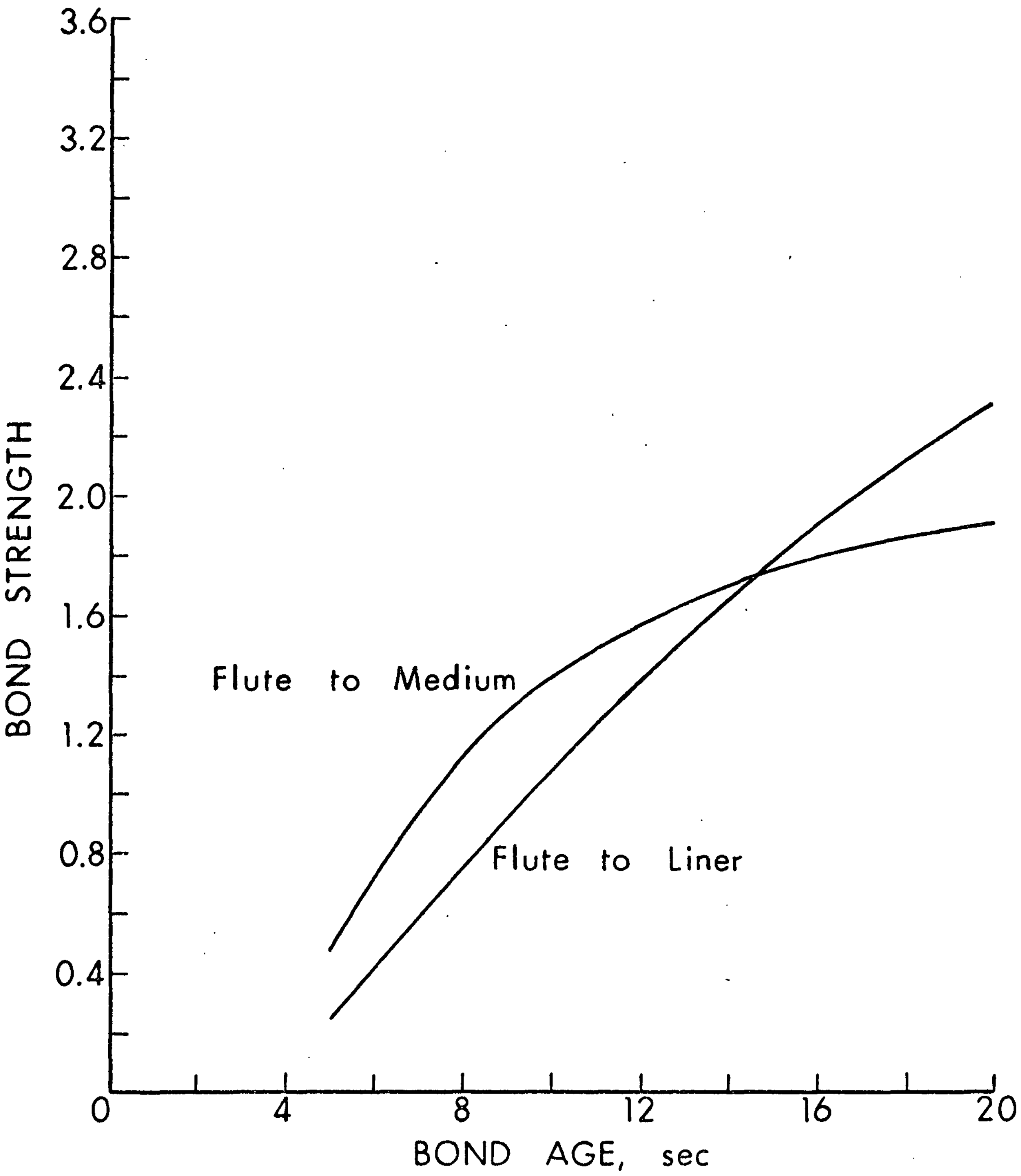


Figure 13. Comparison of Flute to Medium and Flute to Liner Bond Development

adhesive to penetrate into the Z-direction of both sheets. This force is most effective if the adhesive is distributed in a thin film over the active portion of the flute tip. Single face bonding rate is also enhanced by operating at somewhat higher values of pressure roll loading. Penetration of adhesive to a depth of 0.004" is common and to a depth of 0.008" occurs occasionally on the single face bonds.

In the double facing process, penetration occurs more slowly because of the low force involved. Bonding pressures in commercial double backers due to belt weight and weight rolls are typically on the order of 0.1 to 0.2 psi. Since combined board can stand at least 2 psi without permanently deforming, some additional pressure can be applied to assist in bond rate development. The early stages of bond development are the most critical in terms of mass transfer of the adhesive so increasing combining pressure near the combining end of the double backer is most beneficial. This has been demonstrated on the double backer simulator and will be implemented on the commercial machine.

The machine used for the plant trials in Burlington has a very low loading rate at the combining point despite the fact that all weight rolls are in place. This low rate of loading impedes rapid bonding at the low application rate of 0.5 lb/MSF because it is insufficient to cause good contact between the lightly coated flute tip and the liner. A double backer belt pull-down roll has been added between the tail pulley and the first weight roll. This roll will provide a pressure of about 0.5 psi for the first foot of the double backer. More importantly, this additional roll will insure good contact between the single face board and the liner. These desired effects have been demonstrated in recent trials.

Water-Resistant Adhesives

The development of a water-resistant adhesive is a necessary step for the overall commercial acceptance of the cold corrugating process. Cold bonding depends upon moisture leaving the adhesive for bonds to form between the liners and medium. When making water-resistant combined board, the component liners and medium are especially treated to inhibit this moisture transfer process. Therefore, the challenge is to develop an adhesive that is water-resistant but penetrates rapidly to promote fast bonding.

To date, the development work on water-resistant adhesives has been concentrated around starch as the base material. This was done for two reasons. One is economics. Starch remains as the most economical material to use for an adhesive and one of the goals in cold corrugating development has been to provide a new technology with equal or lower operating costs in all areas. The second reason involves the chemical nature of starch. As described previously, starch is a mixture of amylose and amylopectin. The amylose part of the starch, when cooked, is inherently insoluble in water. The cold corrugating adhesive, after cooling and losing moisture, is relatively insoluble due to the presence of some quantity of amylose. Consequently, all of the efforts at making a water-resistant adhesive have been centered around increasing the amylose portion of the starch.

Wet Strength Determination

A test method has been selected to quantitatively evaluate the wet strength of various adhesive formulations. Water-resistant liner of 42 lbs/MSF basis weight and medium of 33 lbs/MSF basis weight were obtained from member companies. These were hot corrugated on the Institute experimental single facer using a commercial wet strength adhesive. Strips of this single face board were cut for use on the double backer simulator. The simulator was then used to make combined board strips with a water-resistant double face liner and the test adhesive on the double face side.

The combined board strips made in this manner receive a 24-hour soak and inspection for signs of delamination caused by adhesive failure. In the early stages of wet strength adhesive development, this soak was followed by a wet bursting strength test. Subsequent experimentation showed that wet burst values are not a strong function of wet bond strength and the wet burst test is no longer used.

The wet samples are now submitted to a "thumb test" and a wet shear test. The "thumb test" is a subjective evaluation conducted according to TAPPI Method T812 SU-70, Ply Separation of Solid and Corrugated Fiberboard (wet). While this test is successful to a degree in evaluating wet bond strength, it is subjective in nature and does not provide a convenient way of comparing one adhesive with another. In order to obtain a quantitative measure of final wet bond strength, a wet shear procedure was chosen from several tests described in the literature (6). In this test, the 2" wide strip of combined board made on the simulator is cut to a length of 10 flutes with extensions left on the opposite liners. The single face liner extension is clamped to the test plate and the double face liner extension is clamped to a movable joint connected to a test instrument. A special fixture was built to accommodate six specimens at one time and allow the entire test to be run without handling of the specimens. Fig. 14 shows the device with specimens in place. Samples are clamped in the fixture when dry and the complete fixture is immersed for 24 hours. At testing time, the samples are drained, the fixture is clamped in an Instron, and the specimens are tested one at a

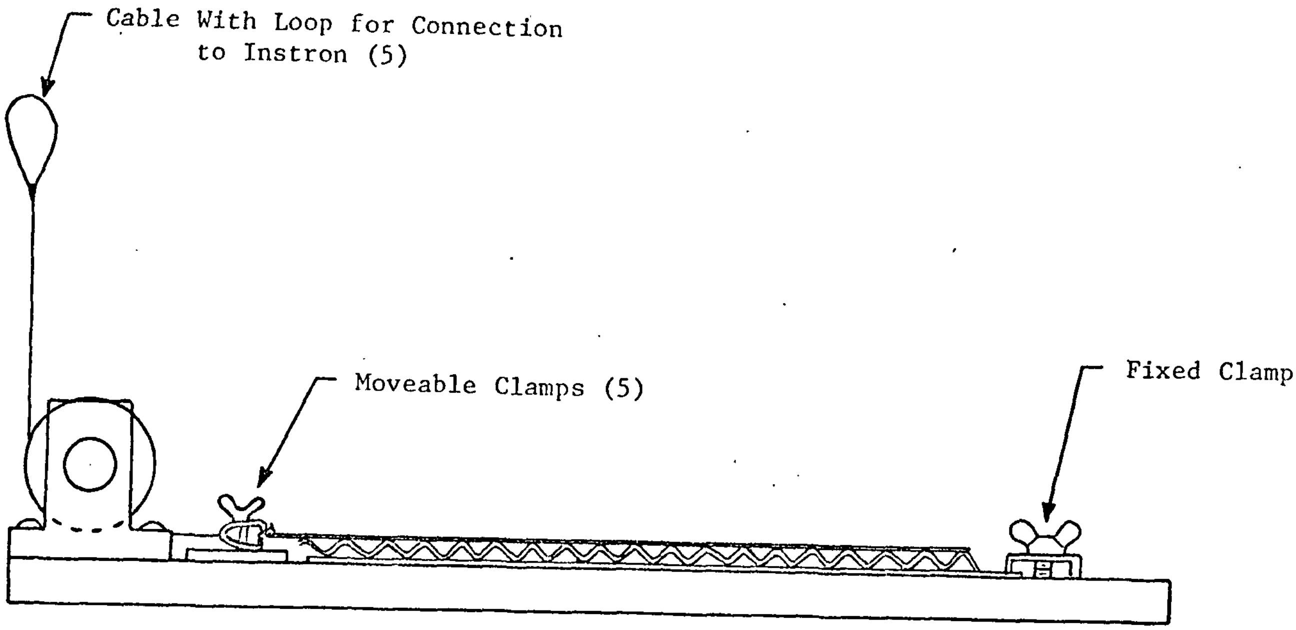


Figure 14. Wet Shear Strength Test Fixture

time via a cable attached to a hook on the movable clamp. The testing rate is 0.2 inches/minute. This test has allowed for much easier comparisons to be made between adhesives.

Reference Tests on Conventional Water-Resistant Board

Several samples of regular production hot corrugated water-resistant board were tested in the wet shear test fixture in order to obtain representative numbers for comparison purposes.

A 90-33-90 lbs/MSF basis weight C-flute wet strength board and a 42-33-42 lbs/MSF basis weight C-flute wet strength board were selected from the regular production of a member company. The heavy weight board failed in wet shear at an average value of 15.15 lbs. The failures occurred in the single face glue line. The lighter weight board is the equivalent in basis weight to the combined board that is made via the cold process on the simulator. The wet shear tests with that board failed at the single face glue line at an average load of 7.2 lbs.

Development of a Cold Corrugating Water-Resistant Adhesive

Several commercial starches are available with higher than normal amounts of amylose. Conventional pearl corn starch as used in the cold corrugating adhesive has about 23% amylose. Some starch companies offer a special starch blend for use in formulating water-resistant hot corrugating adhesive with amylose contents in the range of 50-52%. Other formulations are available at even higher amylose content.

The initial trials on water-resistant cold corrugating adhesives were made with a 50-52% amylose starch called Hydro-Pruf purchased from American Maize Products Company. Since this is a special blend for water resistance, other ingredients may be included which have not been determined. This starch was used in place of the conventional pearl corn starch with no other changes to the formula. When cooked at the standard 140°C temperature and 60 psi pressure, the Hydro-Pruf formula produces a water-resistant adhesive but with an unstable viscosity. Adhesive made with the injection method of adding caustic is more stable than adhesive made with the post addition method of adding caustic, but neither one would be acceptable for production use. For reference purposes, the best wet shear strength value of the Hydro-Pruf adhesive was found to be 7.9 lbs.

It is shown that cooking at higher temperatures provides increased stability for the amylose portion of starch adhesives. When the Hydro-Pruf formulation is cooked at 160°C and 80 psi, the viscosity becomes nearly as stable as the nominal cold corrugating adhesive. However, no measure of water resistance can be found.

Another American Maize Products Company product called Amylomaize VII (AM VII) has about 70-75% amylose. When this starch is used in place of the pearl starch in the nominal formula and cooked at 160°C with the caustic injection method of pH control, a viscosity stable, water-resistant adhesive is produced. The wet shear strength value of this adhesive was found to be 8.4 lbs. It should be noted that cooking AM VII at 140°C and/or post adding the caustic instead of injecting it in-line produces adhesives of unstable viscosity. Table I summarizes all of the wet shear values discussed.

Table I

Wet Shear Strength Values

Combined Board	Adhesive	Wet Shear, lbs
90-33-90	Commercial Hot Corrugating	15.15
42-33-90	Commercial Hot Corrugating (as received)	7.2
42-33-90	Hydro-Pruf Cold Corrugating (unstable)	7.9
42-33-90	AM VII Cold Corrugating	8.4

Sufficient trials with the AM VII have been run to determine that a threshold application rate exists somewhere between 0.5 and 1.0 lb/MSF. Below this level, poor water resistance exists even though good combined board can be made on the simulator. Above this level, more adhesive will not appreciably increase the wet shear strength of the board. At an application rate of about 1 lb/MSF for each side, the AM VII adhesive would cost about 56¢/MSF.

Further development work in the area of water-resistant adhesives is planned as discussed in the next section.

Remaining Work/Objectives

While cold corrugating is ready for evaluation as a commercial process, additional development work is planned in the area of adhesive technology in order to optimize operation and increase appeal to the industry. Specifically, three regions of interest have been designated: rate of bond development, improved water resistance, and technology of adhesive application.

The rate of bond development will always be of interest as faster machine speeds are possible due to increases in the rate of forming, combining, and handling of the final product. Each generation of corrugator offers an increment of operating speed above the previous generation. Many possibilities exist for achieving higher bond rate development. Additives to the present formula and completely new formulations are two areas that are continually being explored. The effect of solids content on bond development rate needs to be better understood so that the solids to moisture ratio can be optimized. The double backer simulator will remain as the key tool to be used since it can easily accommodate changes in adhesive application, distribution, components, and combining pressures, all of which are important in bond development.

The development work on water-resistant adhesives is in its early stages when compared with the efforts made for the majority of the cold corrugating process. Very little production-type experience has been gained with the water-resistant formulas. The AM VII formula, while apparently strong enough to meet minimum commercial wet strength, still needs to be closely examined for possible improvements in stability, final bond strength, and bond rate development. Of course, additives to the AM VII adhesive or completely different formulations need to be investigated after a better understanding of the basic formula is achieved.

Underlying all of the above work on adhesives and bonding is a fundamental area of which little information is known. The transfer of adhesive from a roll to the surface of the medium is an area critical to both the hot and cold corrugating processes. Much work has been done on the metering of adhesive in the nip of the two-roll system (4). A similar effort, both theoretical and experimental, needs to be done for the transfer of the adhesive onto the fibrous surface. Medium characteristics, relative speeds, time of contact, pressure, and adhesive rheology are but some of the factors whose influence on transfer need to be identified. These relationships will serve to assist in the design and development of applicator systems needed to handle higher speeds and new adhesives as they become part of the process.

STRUCTURAL PROPERTIES

Some discussion of the properties of the products of the cold corrugating process is needed to demonstrate that a properly constructed cold corrugating system will make commercially acceptable boxes. During the early stages of process development, much work was done in the area of performance comparison between hot and cold corrugated components. That material will be reviewed in this section along with appropriate comments regarding new developments occurring since the last report (3).

Single Face Board

All of the initial process development work was done on the IPC laboratory single facer. Investigations of bond strength vs. adhesive application rate (i.e., gap between metering and application rolls on a conventional two-roll system) and vs. speed were discussed in great detail in Progress Report Two (2). In general, it was noted that the setback adhesive performed on the single facer just as conventional adhesive did. More adhesive resulted in higher bond strength (pin adhesion) and higher speeds resulted in a reduction in bond strengths, presumably because of a corresponding reduction in application rate.

Trials on the full size single facer at the pilot installation in Burlington, Wisconsin, show similar results. A representative comparison of board characteristics for single face board produced on that machine is shown in Table II. These data are representative of the performance achieved over the speed range from 100 to 600 fpm and are taken from an 85" web on the 96" machine.

Table II

Comparison of Single Face Board Parameters for the Hot and the Cold Corrugating Process

Parameters	Typical Values Cold Board	Typical Values Hot Board	Units
Caliper	163 (4.14)	154 (3.91)	mils (mm)
Bond strength	14 (96)	11 (76)	psi (kPa)
Edgewise compression	31 (5.43)	30 (5.25)	lb/inch (kN/m)
Flat crush	25 (172)	27 (186)	psi (kPa)
Flute height differentials	1.6 (0.041)	1.8 (0.046)	mils (mm)

Notes: 1. Medium - 26 lbs/MSF (126 g/m^2). NSSC - Concora 53 lbs (235 N).
2. Liner - 42 lbs/MSF (203 g/m^2) kraft.
3. Hot and cold board made on same machine.

Briefly stated, the cold board compares favorably with hot board in every respect except flat crush which is usually lower. Some of this difference is due to the higher caliper of the cold board. It is expected that roll profile changes will ultimately be made to reduce caliper to be equal to current hot production values. The remainder of the flat crush difference is the subject of ongoing research at the Institute into the basic process of flute formation for both the hot and the cold process. This work is expected to lead to improvements in both processes as a means of obtaining sufficient box performance while using less fiber.

Combined Board and Boxes

Several combined board trials have been conducted specifically for the comparison of finished product properties. To evaluate the cold process, consideration must be given to all the usual board properties and to production speeds with due consideration for the limitations imposed by the highly simplified pilot equipment.

As previously mentioned, successful operation of the single facer at 600 fpm has been routinely accomplished. The stop-start, short-term nature of the combined board trial precludes operation of the single facer at a sustained high speed, however. This, plus the fact that the adequacy of single facer performance was well established before combined board trials started, resulted in a decision to operate the single facer continuously at a slow speed during most of the combined board trials. This is reflected in the data table presented below.

For illustration of combined board and box performance characteristics, data from two test runs, one conducted on October 22, 1978, and the other on January 29, 1979, are presented in Tables III and IV, respectively. For the October 22 test, Table III, a relatively high viscosity adhesive was used. This adhesive was also somewhat unstable because of the presence, in the finished adhesive, of some uncooked starch which continued to degrade in the hot alkaline environment of the holding system. Despite these difficulties, this particular adhesive gave reasonably good production speed performance on the double backer.

Table III

Component, Board, and Box Data From Pilot Trials

SF Liner: 42 lbs/MSF kraft
Medium: 26 lbs/MSF NSSC - 40% OCC
DF Liner: 42 lbs/MSF kraft

Component Properties		October 22, 1978 Test A
Basis weight	SF liner	41.2
	Medium	27.4
	DF liner	41.2
Caliper	SF liner	12.6
	Medium	12.3
	DF liner	12.6
Medium water drop		45
Cobb size	SF liner	31.6
	DF liner	31.6
CD ring crush	SF liner	12.6
	Medium	6.1
	DF liner	12.6
Mullen	SF liner	97
	DF liner	97

Operating Conditions		A1	A2	A3	A4
SF speed		200	200	200	200
DF speed		300	500	400	650
Liner preheat		No	No	Yes	Yes
Board Properties					
CB caliper		170	171	169	169
Pin adhesion	SF	122	111	105	114
	DF	104	99	103	96
Burst		238	230	228	227
Puncture		190	188	190	187
Edgewise compression		39.9	38.0	37.6	37.2
CB flat crush		23.3	23.5	23.8	25.0
Box Properties					
Top-to-bottom compression		760	720	710	700
Deflection		0.57	0.56	0.54	0.56

Note: Standard RSC box for 24 No. 2½ can = 16 x 12 x 9 inches.
Glued manufacturers joint with tab inside. Stitched bottom, glued top flaps.

This test was conducted with 42 lbs/MSF kraft liners and a 26 lbs/MSF, 50% OCC medium. Salient results from this test are as follows:

1. Combined board of good quality was produced at double backer speeds of 500 fpm with a totally cold double face liner (Column A2).

2. Top production speeds of 650 fpm were achieved with liner preheating (Column A4).

3. All board and box properties except flat crush are equal to or better than those for board produced from the same components utilizing the hot process.

4. Flat crush values are low partially for the reasons discussed earlier with respect to single face board flat crush values and partly because of flute distortion caused by drag in the simply converted double backer section. The double backer hot plates are covered with a polyethylene sheet to reduce frictional drag on the single face liner as the belts pull the board through the machine. However, some distortion of the flutes could still be occurring.

For the test conducted on January 28, a stable, lower viscosity adhesive was used. Corresponding data are shown in Table IV. Test B was conducted with a bleached kraft liner on the double face side; Test C with a 42 lbs/MSF kraft liner on both sides; Test D with a 69 lbs/MSF kraft liner on the single face side and a 42 lbs/MSF kraft liner on the double face side. This particular adhesive has a lower production speed limit than that used in the October 22 test. Otherwise, the comments above are applicable. Particular attention is called to the box compression results from Tests B and C which show exceptionally high top-to-bottom strength.

Washboarding and warp are both strong functions of the amount of adhesive applied as well as the solids fraction in the adhesive. Deficiencies in the two-roll metering system used in the pilot single facer have been discussed previously. As improvements have been made in the reduction of adhesive applied at the glue machine, double face washboarding has become nonexistent. In the most recent trials, warp

Table IV

Component, Board, and Box Data From Pilot Trials

SF Liner: Test B and C - 42 lbs/MSF kraft
Test D - 69 lbs/MSF kraft
Medium: 26 lbs/MSF NSSC - 40% OCC
DF Liner: Test B - 42 lbs/MSF bleached kraft
Test C and D - 42 lbs/MSF kraft

January 28, 1979

Component Properties		B	C	D
Basis weight	SF liner	43.5	43.5	69.0
	Medium	27.4	27.4	27.4
	DF liner	40.4	43.0	43.0
Caliper	SF liner	12.6	12.6	----
	Medium	11.3	11.3	11.3
	DF liner	10.2	12.4	12.4
Medium water drop				
Cobb size	SF liner	39.7	39.7	
	DF liner	32.2	43.2	43.2
CD ring crush	SF liner	15.3	15.3	
	Medium	6.0	6.0	
	DF liner	14.2	15.8	15.8
Mullen	SF liner	97	97	
	DF liner	91	106	106

Operating Conditions		B1	B2	C1	C2	D1	D2
SF speed		200	200	200	200	200	200
DF speed		200	400	300	400	200	500
Liner preheat		No	NO	No	No	Yes	Yes
Board Properties							
CB caliper		167	166	168	169	171	172
Pin adhesion	SF	113	115	126	118	135	130
	DF	111	123	124	122	137	132
Burst			218		254	295	298
Puncture		198		204		261	
Edgewise compression		45.6	44.4	49.3	47.7	61.2	60.0
CB flat crush		24.2	24.2	26.3	26.1	26.4	25.4
Box Properties							
Top-to-bottom compression		850	840	910	820	1140	1170
Deflection		0.56	0.49	0.51	0.49	0.81	0.68

Note: Standard RSC box for 24 No. 2½ can = 16 x 12 x 9 inches.
Glued manufacturers joint with tab inside. Stitched bottom, glued top flaps.

has been a function of the balance of application rates between the two glue stations and the amount of time between the two points of application. Nearly flat board in both cross-machine and machine directions has been made at double backer speeds in the range of 500 fpm when all conditions have been correct. One double backer run in excess of 600 fpm produced board of 0.22 warp factor (0.25 allowable per C.I.D.) (7) in both the machine and cross-machine directions even though some double face liner delamination occurred at the slitter edges. These results indicate that proper application rates, correct web tensions, and moisture controls in a commercial machine should lead to the production of flat, dry board with little warp or washboarding. Production runs to minimize warp can not be made on the pilot facility at PCA due to the many compromises made to avoid major machinery changes. A thorough study of the influence of the cold process on warp will have to wait until the first machine designed fully for the requirements of the cold process is available.

PART II - COLD CORRUGATING EQUIPMENT

The Institute of Paper Chemistry has entered into a contract with the U.S. Department of Energy for the commercial evaluation of the cold corrugating process. In support of this contract, IPC has entered into a subcontract with Union Camp Corporation to provide the host site for the cold corrugator. The site will be at Union Camp's Savannah, Georgia, plant. The cold corrugating equipment will be installed in an existing corrugator line. New equipment, necessary for the commercial evaluation of cold corrugating, includes a single facer, glue machine, double backer, slurry make-up system, adhesive preparation and distribution system, and an instrumentation system. The purpose of Part II of this report is to describe these items of equipment and present general information about the commercial evaluation portion of the project.

In the context of the commercial evaluation project, the cold corrugating system may be regarded as being made up of the process, the corrugator, an adhesive make-up and distribution system, the data acquisition system, and a data base. On the corrugator, the single facer, glue machine, and double backer require designs modified to accommodate the cold process. An adhesive system quite different from that presently used is also required. Collectively, these four units constitute the so-called risk machinery since they involve new design features. All remaining corrugator units are unaffected by cold corrugating and constitute the non-risk machinery, so named because there is no new risk in their design and operation. The non-risk equipment will be supplied by the host company. While intended primarily for acquiring data during the experimental portions of the commercial evaluation program, the data acquisition system will also provide information from which to identify the instrumentation required for second generation commercial machines. A commercial evaluation data base, useful for

for assessment of the process and future application of it, will be generated during the commercial evaluation phase.

The new equipment named on the previous page will be installed in an existing corrugator to provide single-wall cold corrugating capability. Additionally, there are C-flute and B-flute single facers in the line to give a parallel hot double-wall capability for at least the early phases of the project. The single facers are equipped with Langston Model J.P. roll stands and Butler splicers. The dry end equipment consists of a Langston rotary shear and triplex, a Koppers direct drive knife, and Martin automatic stackers. All of the cold corrugating equipment will be capable of operating at 650 fpm and accommodating 96" wide paper.

In order to minimize disruptions to normal production, each piece of the cold corrugating equipment will be installed separately and thoroughly checked out before the next piece is installed. The order for installation will be slurry and adhesive preparation and distribution system, single facer, glue machine, and double backer. The instrumentation for each item will be installed with the item. With the exception of time needed to conduct tests to prove out each piece of equipment the corrugator will be capable of normal hot single or double-wall production until the double backer is installed at which time only cold corrugating production will be possible.

All of the equipment being purchased utilizes designs based on the best available hot corrugating equipment redesigned in the minimum way for cold corrugating. This design philosophy offers several advantages: it helps to minimize design expenses for this project, it will simplify conversion back to hot corrugating machinery if necessary, and it will help establish the requirements for retrofitting of hot machinery to cold corrugating equipment.

Requests for quotation were sent to Langston Company, S & S Corrugated Paper Machinery Co., Inc., and Koppers Company for the single facer, glue machine, and double backer. Koppers and S & S submitted proposals for all three items and Langston submitted a proposal for the double backer only. Koppers was selected as the vendor for the single and the glue machine and S & S will provide the double backer.

Grain Processing Corporation, SAECO, R. L. Ringwood Company, and Adhesive Mixing Equipment received requests for quotation for the slurry make-up and adhesive distribution system and the thermo-chemical conversion unit. Grain Processing submitted a quotation for the latter only and the other three vendors quoted both systems. SAECO was selected as the vendor for both units. For the data acquisition portion of the instrumentation system, requests for quotation were sent to Hewlett Packard, Analog Devices, and Digital Equipment Corporation. Analog Devices was the vendor selected.

At the present time, the original equipment schedule is being maintained with major milestones identified as follows:

Slurry and Adhesive System Installation	February, 1981
Single Facer Installation	June, 1981
Glue Machine Installation	June, 1981
Double Backer Installation	July, 1981
Instrumentation Installation	February-July, 1981
Evaluation to Specifications	August-December, 1981
System Mapping	December, 1981-June, 1982
Demonstrations	December, 1981-June, 1982

SINGLE FACER

A Koppers 98" C-flute fingerless single facer has been ordered for the cold corrugating commercial evaluation. Fig. 15 illustrates the features of the single facer.

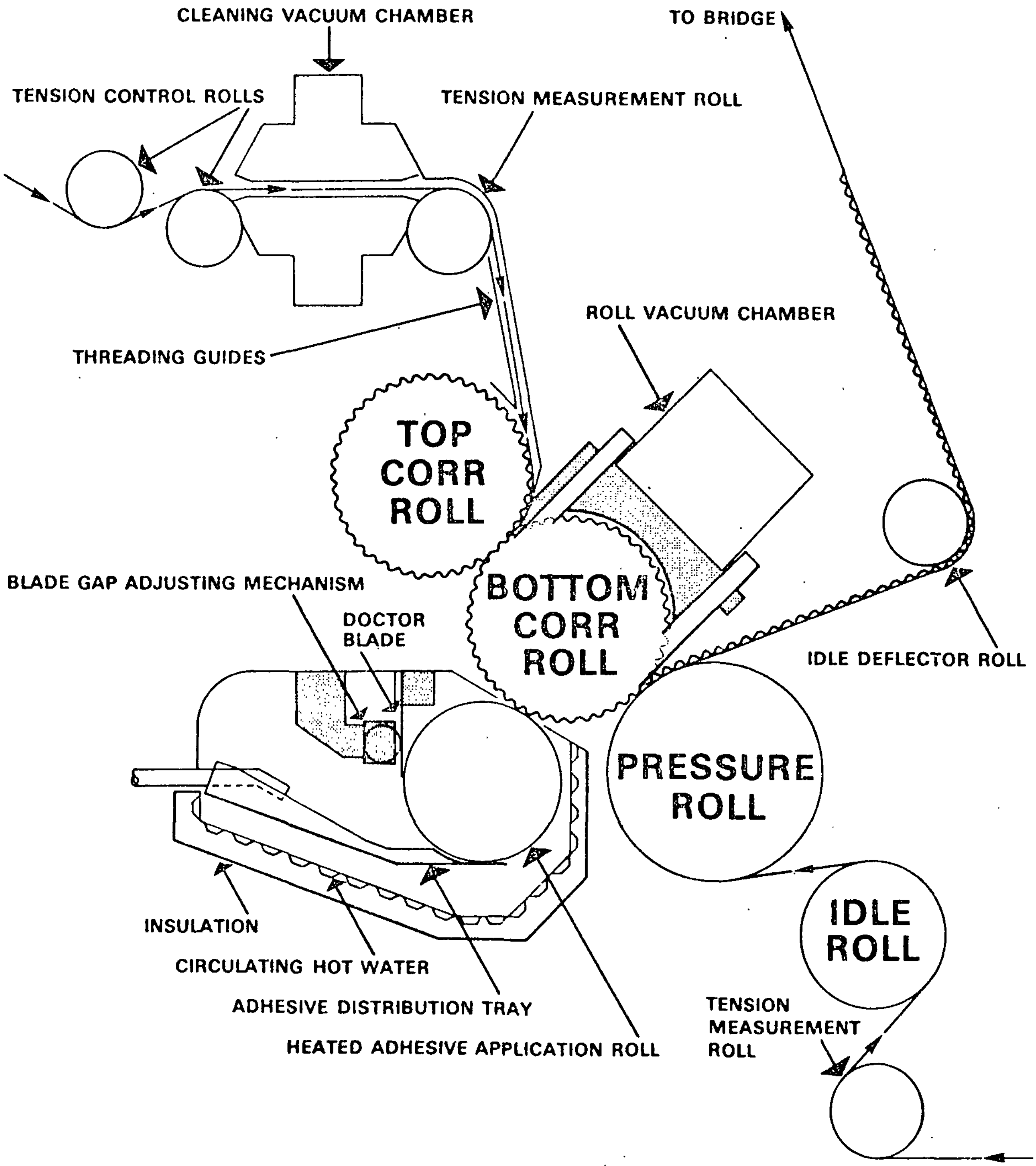


Figure 15. Cold Corrugating Single Facer

General Design

The machine is basically a standard Koppers hot fingerless single facer with modifications only where required for cold corrugating. These standard features are included:

1. Nominal 12" diameter C-flute corrugating rolls, laser hardened and chrome plated.

2. Nominal 13 3/16" diameter case hardened pressure roll with a brass scraper blade.

3. Direct drive to bottom corrugating roll with an air clutch drive for the pressure roll.

4. Roll stack designed for pneumatic loading of 225 lbs per inch for the corrugating roll and 150 lbs per inch for the pressure roll which will operate against stops.

5. All normal steam connections will be retained, although not used.

6. A conventional counter balanced medium treatment applicator utilizing cast bars will be incorporated.

Fingerless Design

A fingerless single facer design was selected for the following reasons:

1. It is the current state-of-the-art and most likely the design of the future and therefore should be the design used for the cold corrugating commercial evaluation.

2. The elimination of fingers permits consideration of several new application concepts, a feature most important to cold corrugating. The design is also mechanically clean to facilitate clean-up.

3. Fingerless designs have been shown to produce board with improved structural properties and there is evidence that they are more tolerant to paper variations.

4. Fingerless designs may show even greater advantages for cold forming.

The Koppers fingerless design utilizes slots 0.080" wide and spaced approximately 2" apart along the lower corrugating roll. A vacuum is applied to the slots by means of a chamber wrapped around the portion of the roll not covered by paper. A vacuum of approximately 25" H_2O, applied between the surface of the roll and the medium, assures intimate contact of the medium to the corrugating roll. The vacuum is generated by a 20 HP blower that produces a flow rate of 700 CFM. Although there are provisions for sealing off unused slots when narrow paper is used, this has been found to be unnecessary.

Web Feeding System

It is very desirable to feed the medium to the corrugator at a constant and controllable tension and to minimize the dragging of the medium on the top corrugating roll. To accomplish this objective, an idler roll is mounted in such a position as to guide the medium into the corrugating nip with minimal contact with the upper roll prior to the nip. This roll is equipped with a load cell to measure the tension in the medium at a point immediately ahead of the corrugating nip. Also mounted on the machine frame prior to the tension measuring roll is a motor-driven tension control unit for fine tension control over the range of 0.5 to 4.0 lbs per lineal inch. Coarse tension control will be accomplished by means of a brake on the roll stand. A dancer roll between the roll stand and the web feeder system will control the roll stand brake and minimize tension spikes.

Another machine-mounted idler roll will be used to measure liner tension for data acquisition purposes. Liner tension will be controlled by a feedback signal from a dancer roll to the brake on the liner roll stand. Control over the range from 0.25 lbs per lineal inch to the capacity of the roll stand will be possible. The dancer roll will also minimize tension spikes.

Web Cleaner

Loose debris on the medium roll surface may be dislodged by the medium treatment applicator and other equipment. To minimize the potential for this debris to collect on the corrugating rolls, a web cleaning system will be supplied. The web cleaner consists of a vacuum hood which is mounted on the top of the single facer between the tension control roll set and the tension measuring idler roll. The blower supplying the vacuum for the corrugating roll will also supply vacuum for the cleaner.

Adhesive System

The adhesive application system is designed to set in the position of the conventional glue pan and applicator system without requiring other machine modifications. For cold corrugating, it is necessary to maintain the temperature of the adhesive at 190°F to 200°F at all times. To do this, the adhesive pan is water jacketed and heated with a constant flow of hot water delivered by the adhesive distribution line water jacket. The water is circulated through the jacket and then returned to the adhesive return line water jacket. Care is taken to insure that any area wetted by the adhesive is heated. All heated surfaces are insulated for operator protection and energy conservation.

The entire application system is shrouded except for the minimal opening needed to apply the adhesive. The opening is automatically closed any time the applicator roll is not in contact with the web. The shrouding serves two purposes. First, it reduces heat and moisture losses and secondly, it prevents vapor from the adhesive system from condensing on the cold corrugating rolls.

Care is taken in the design of the entire adhesive system to prevent stagnation of the adhesive and to provide a steady flow of adhesive from the distribution system, through the applicator system, and back to the adhesive tank via the return line.

Adhesive delivered to a given use station flows through a mass flow meter at the inlet of the glue pan. A proportional level sensor controls the level in the pan by controlling a pump that returns the adhesive to the adhesive storage tank. This returned adhesive flows through a second mass flow meter. Data from these flow meters along with paper width, running speed, and adhesive solids content are used to evaluate application rate in pounds of starch per thousand square feet of board.

For the adhesive application system at the single facer, a gravure roll, with a cell pattern to be determined, will be supplied with a reverse angle doctor blade. The doctor blade is designed with a rigid backing and adjusting screws so that the blade can be accurately paralled to the roll. A combination of blade characteristics, roll characteristics, and roll drive characteristics will be used to control adhesive application rate. Both the gravure roll and the doctor blade support mechanism will be temperature controlled.

A glue pan and dam arrangement consisting of an inclined plate will be mounted under the glue roll with minimum clearance so as to create a small puddle of adhesive in direct contact with the under surface of the glue roll. The wetted width of the glue roll will be controlled by means of adjustable flat dam plates with bent-up lips which will extend around the lower radius of the glue roll. The wetted width will be controlled within 1/4". A handwheel will be used to adjust the dams.

Valving on the adhesive supply and return lines will allow the use of the hot water supply to flush the adhesive application system. Design consideration is focused on allowing for easy access to all parts of the system which will require routine clean-up after use.

Control

Control of the cold corrugator differs little from that of a conventional hot corrugator. The improved medium tension control and the level and temperature control of the adhesive pan have already been discussed. A standard bridge control system will be included.

Instrumentation

All of the instrumentation typically found on a single facer has been retained and additional instrumentation required by the cold corrugating system and useful to an operator has been added. All such variables plus many others will be monitored by the data acquisition system in a parallel fashion. The intent is to provide a data acquisition system for experimental purposes but to also provide independent parallel instrumentation to allow routine operation of the corrugator without the data acquisition package.

The variables to be monitored at the single facer by the data acquisition package (DAP) are as follows:

1. Liner and medium speed.
2. Liner and medium temperature.
3. Liner and medium moisture content.
4. Liner and medium tension.
5. Medium width.
6. Medium treatment applicator (on/off).
7. Adhesive application rate.
8. Corrugating and pressure roll loads.
9. Adhesive and water jacket temperatures.

10. High-lows (flute height differentials).
11. Bridge stock.

GLUE MACHINE

A Koppers triple deck glue machine has been ordered for the project. The bottom unit will be designed for the cold corrugating process while the top two units will be of conventional design. This will allow Union Camp to maintain hot double-wall production through much of the early cold system evaluation and hence to minimize lost production.

General Design

The glue unit will be driven from the double backer by means of a timing belt drive from the lower tail pulley. The two conventional stations will have a nominal 9 1/2" diameter chrome-plated engraved applicator roll with a chrome-plated metering roll equipped with a reverse angle scraper blade. The hold down roll is air actuated and rides against positive adjustable stops.

As the glue machine and single facer use the same adhesive and the same application rates are desired, most of the design concepts for the glue machine are the same as for the single facer application system.

The adhesive metering and transfer system will consist of a heated gravure roll and adjustable doctor blade as described for the single facer. The gravure pattern will be sized to give a minimum adhesive application rate of 0.5 lb/MSF. The transfer roll will be driven at the same speed as the paper.

All surfaces wetted by the adhesive are heated with hot water circulated from the adhesive distribution system. Shrouding is provided for the entire system except for the minimum opening needed to allow application to the single face web. The opening will close automatically when the single face web is not moving.

Wetted width is controlled by adjustable dams similar to those in the single facer. Adhesive flow and level are also controlled as in the single facer.

The entire system is designed to assure steady adhesive flow with no stagnant areas. External dimensions of the station are such as to fit standard side frames to facilitate retrofit installations.

A conventional air actuated rider woll with positive stops and adjustable gap will be utilized.

The adhesive level control and monitoring system, as well as hot water circulation, will be the same as at the single facer.

Instrumentation

The previous discussion on instrumentation at the single facer applies to the glue machine and double backer as well. Specific variables to be monitored at the glue machine by the DAP are as follows:

1. Single face web and double face liner temperature.
2. Single face web and double face liner moisture content.
3. Single face web and double face liner tension.
4. Adhesive application rate.
5. Adhesive temperature.

6. Adhesive water jacket temperature.

7. Rider roll loading or gap as appropriate.

DOUBLE BACKER

An S & S Model 763 (HE) 97" double backer, modified as required for cold corrugating, has been ordered.

General Design

The machine is 64 feet long with full length Dacron belts both over and beneath the board. The side frames, head pulleys, head pulley stand, tension stand, tail pulleys, and tail pulley stand are all standard or slightly modified components. The side frames, where the hot plates would normally be mounted, are slightly modified to accommodate roller brackets. These brackets will positively constrain support rollers under the lower belt and horizontally constrain weight rollers over the upper belt. These brackets are identical with those normally used in the pulling section.

It is desirable to bring the single face web and double face liner into intimate contact as quickly as possible and under as much pressure as possible. For this reason, the entry throat and weight rollers in the first 6 feet of the double backer were given special attention. A 4" weight roll is located immediately after the tail pulley above the top belt and a corresponding 4" support roll is located under the bottom belt. These serve to close the throat as quickly as possible while still allowing the tail pulleys to be positioned for eventual triple-wall production. Each roller bracket is designed to hold 10 rolls, top and bottom, on 3 1/4" centers. Normally, the rolls are 2 7/16" in diameter. If all 10 top rolls are used, the resultant loading is about 0.4 psi. To provide for loadings in the initial section up to 1.0 psi, the conventional 2 7/16" diameter rolls will be replaced with 3 1/8" diameter rolls loaded by a double acting pneumatic actuator. This combination allows loading over the range from 0 to 1.0 psi. Because of the high loading, 3 1/8" rolls will also be used as support rolls. They will be used the entire length of the machine to maintain a uniform bottom belt height (Fig. 16).

The second 6 feet of the double backer will have an entire complement of 2 7/16" weight rolls while the remainder of the double backer will have 2 7/16" rolls on longer center distances as experience dictates. In total, there will be 96 weight rolls and 124 support rolls.

At present, it is estimated that a 50 HP drive is needed for the two-belt system. However, the specifications require that the drive be sized for possible conversion to hot triple-wall operation. This would require a 150 HP drive and, therefore, that is what will be supplied. The drive is directly coupled to the lower belt. A Reeves variable speed drive is connected to the motor and used to drive the top belt to permit differential speed adjustment to minimize shear on the freshly combined board. Precision speed sensors will be used to monitor the speeds of both belts to facilitate adjustment of the Reeves drive. Manual adjustment of the drive will be used as it is anticipated that the ratio will not need to be adjusted frequently.

The top belt will have a standard pneumatic take-up device for belt tension while the bottom will have a manual take-up. Both belts will be full width with automatic belt tracking.

The glue machine will be driven by a timing belt drive from the lower tail pulley.

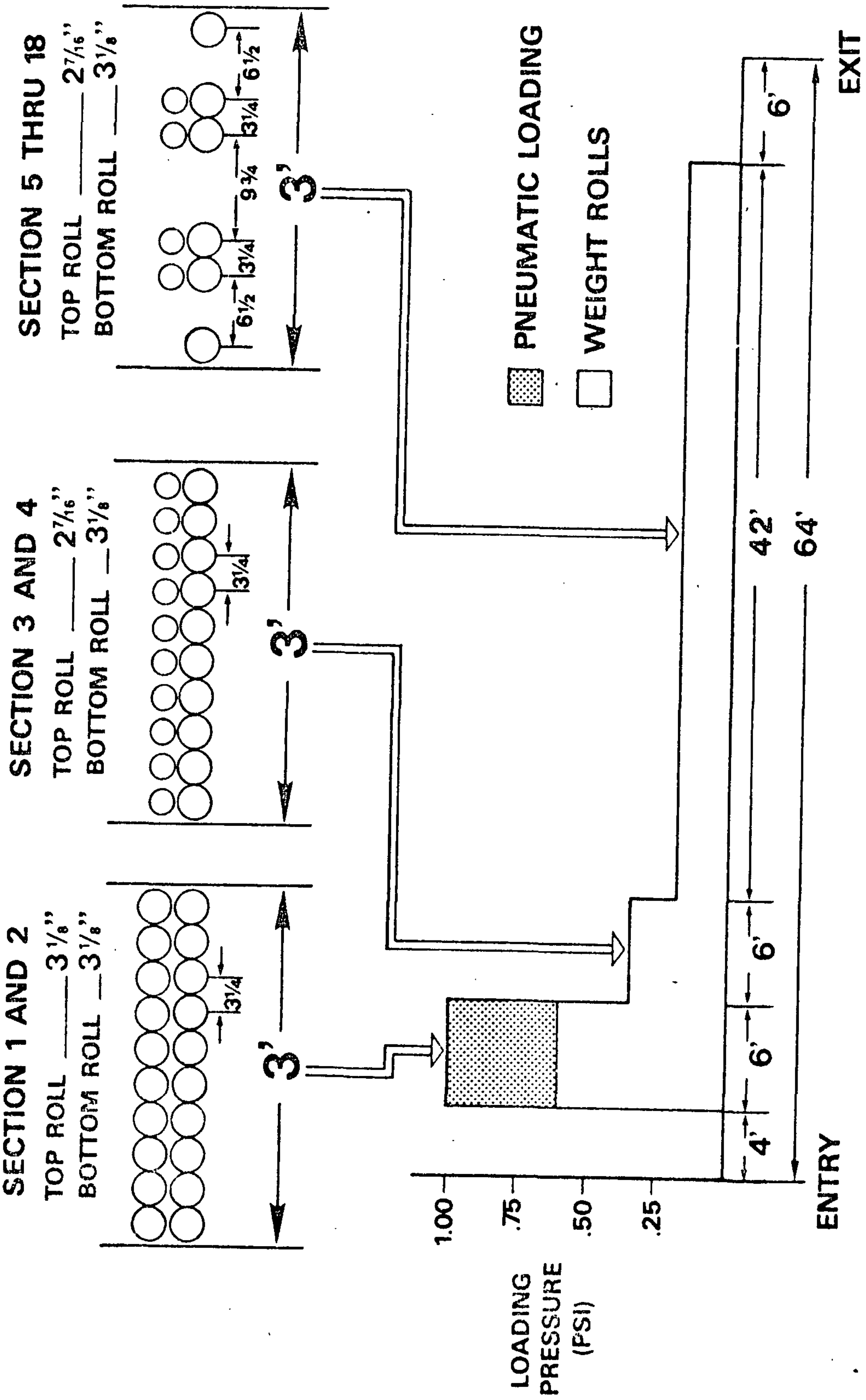


Figure 16. Cold Corrugating Double Backer

As part of the double backer, a closed loop tension control system will be supplied for the single face web and the double face liner. The double face liner will be controlled by a disc brake on the roll stand and the single face web by means of a rotating lagged drum with a disc brake. Both web tensions will be controllable over the range from 0.25 to 4.0 pli.

The double backer that is being replaced is a longer unit than the new one. This resulting gap will be closed with a sheet metal table which will be used to mount the special instrumentation required at the double backer.

Instrumentation

Special instrumentation is to be added to the double backer for monitoring board characteristics. The variables to be monitored by the DAP include the following:

1. Top and bottom surface temperature.
2. Top and bottom moisture.
3. Board caliper.
4. Board speed.
5. IPC-designed moisture scanning system.

ADHESIVE SYSTEM

A new slurry and adhesive preparation and distribution system will be installed as required by the cold process. This will also allow simultaneous running of the cold corrugator with the present hot corrugators at the plant.

General Design

A slurry make-down tank is located near the present starch storage area and a slurry storage tank is located near the thermal conversion unit which, in turn, will be located on the drive side of the glue machine. The slurry will be prepared from bagged starch and a vented hood will be provided to minimize dust in the area.

The slurry from the make-down tank will be pumped to the storage tank. Both the storage tank and the thermo-chemical conversion system will be located near the glue machine. At the adhesive preparation area, ammonium persulfate will be added to the slurry by a metering pump. The modified slurry is then cooked in a hydroheater cooking unit. A coil is provided to hold the starch for 4 minutes under proper cooking conditions after which caustic is metered in to achieve a proper adhesive pH. After the caustic addition, the adhesive is passed through a flash tank and to a heated adhesive storage tank. The adhesive is delivered to the use stations via a hot water jacketed distribution line. Excess adhesive is returned to the storage tank via another jacketed line. Hot water for heating the use station glue pans is drawn from the jackets of this jacketed line.

The hot water system for supplying the jacketed pipe and adhesive storage tank jacket is a closed loop system with a hot water storage tank. Temperature of the system is maintained by a hydroheater.

<u>Slurry System</u>

The system will utilize bag starch and is designed with a starch dust collection system which feeds the dust directly into the slurry tank. Fig. 17 is a schematic of the slurry system.

The slurry make-up is a manual operation which requires that the operator meter a predetermined quantity of water into the tank following which a prescribed number of bags of starch are added through the bag dumping system.

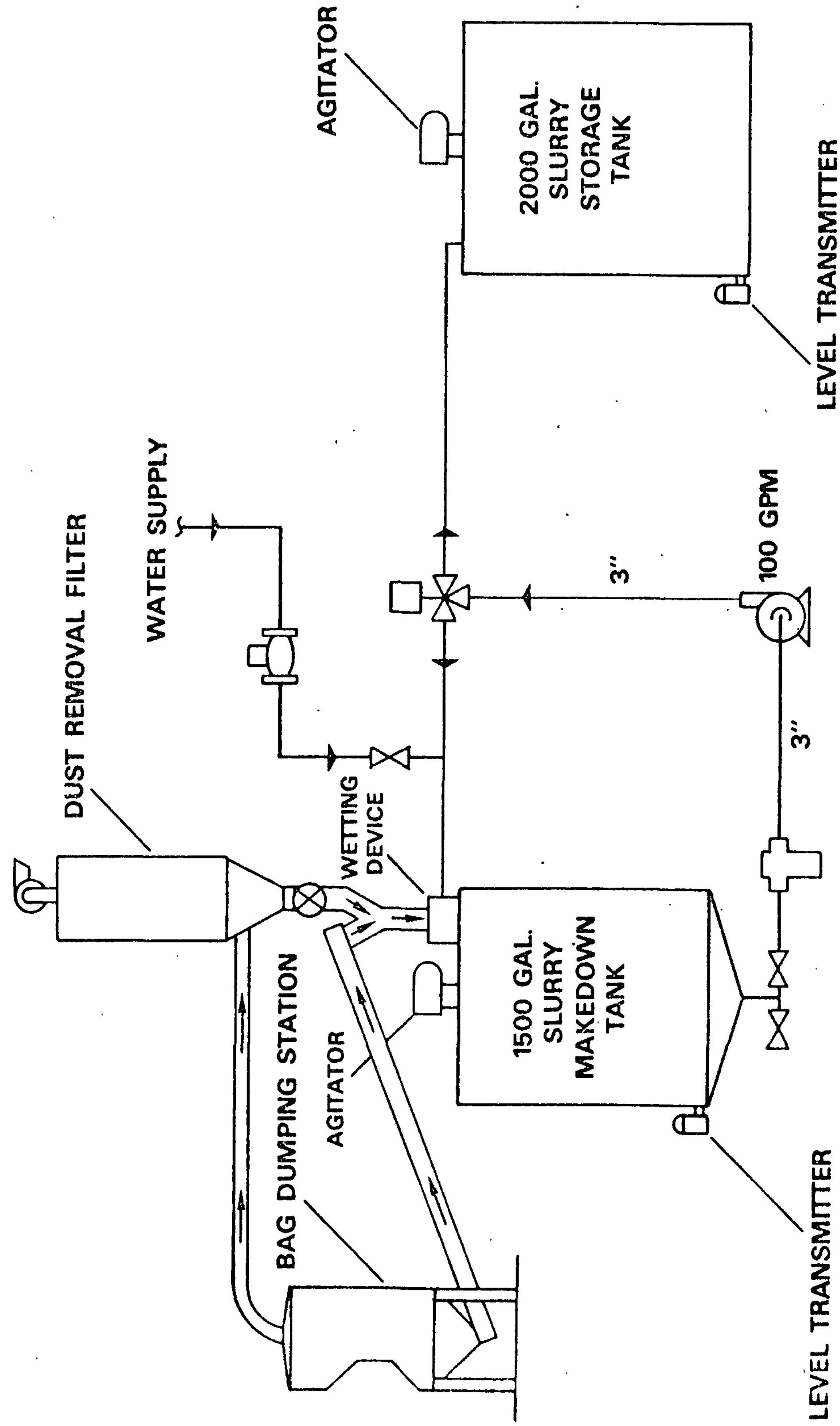


Figure 17. Slurry Make-Up System

The system is designed with interlocks so the dry starch conveyor will not convey starch into the slurry tank unless there is a minimum level of water in the tank, as sensed by the tank level transmitter, and the agitator and the pump are both operating.

The dry starch entry to the slurry tank is fitted with a wetting device which eliminates the dusting of starch as it drops into the tank. A trough-like deflector is located below the wetting device which deflects the slurry against the tank wall, thereby providing additional mixing for dispersing the starch, and also minimizes the entrainment of air.

The make-down water is metered into the tank with a Neptune volumetric meter which is manually set for the desired batch size.

The slurry make-down tank automatically transfers to the slurry storage tank on receiving a low level signal from the slurry storage tank level transmitter.

As soon as the slurry make-down tank goes empty, an alarm signal notifies the operator the tank is empty so he can make arrangements to make up another batch.

The slurry tank is sized at 2,000 gallons to provide sufficient slurry for two productions shifts with a normal triple-wall machine product mixer. The make-down tank volume is 1,500 gallons so that a batch can be made up and dumped to the storage tank before the storage tank is completely emptied. Both tanks are of 304 stainless steel and continuously agitated. Slurry is transferred from the make-down tank to the storage tank at the rate of 100 gpm by a centrifugal pump. Levels for both tanks are monitored by differential pressure cells.

Thermal Conversion System

The adhesive preparation system is designed to cook the slurry at 10 gpm. The slurry is delivered at this rate to the cooker by a Moyno pump. Prior to entry to the pump, ammonium persulfate is metered into the slurry by an ECO pump. The control system insures that AP is pumped only to slurry entering the cooker and not to slurry being recirculated. The AP flow rate is controlled by an orifice-type flow-meter. AP is stored in an agitated 10-gallon tank located at the cooker. A type J, size 600, hydroheater is used for cooking the slurry. Cooking temperature is automatically controllable over the range from 270°F to 330°F by a steam control valve on the cooker steam supply.

A Foxboro control valve automatically maintains the cooker back pressure at a level which can be set between 10 and 100 psig. The slurry is passed through an insulated coil at the high pressure and temperature to provide a holding time of 4 minutes to insure complete conversion of the starch. The coil consists of 4" stainless steel pipe wound in a helical coil approximately 4'6" in diameter by 5' high. It is jacketed with 1" of insulation.

After exiting from the holding coil, NaOH is metered into the adhesive to attain a pH of 6-10. A Foxboro pH controller and Milton Roy metering pump are used to control the NaOH addition at the desired set point. The sodium hydroxide is stored in a 100-gallon tank located near the cooker. The adhesive then flows through a static mixer to assure proper mixing of the caustic and then to a flash tank. Adhesive flows out of the flash tank by gravity to the adhesive storage tank. This is a 500-gallon hot water jacketed, insulated, and agitated tank. Hot water flowing in the jacket maintains the storage tank at approximately 200°F. Fig. 18 is a schematic of the thermal conversion system.

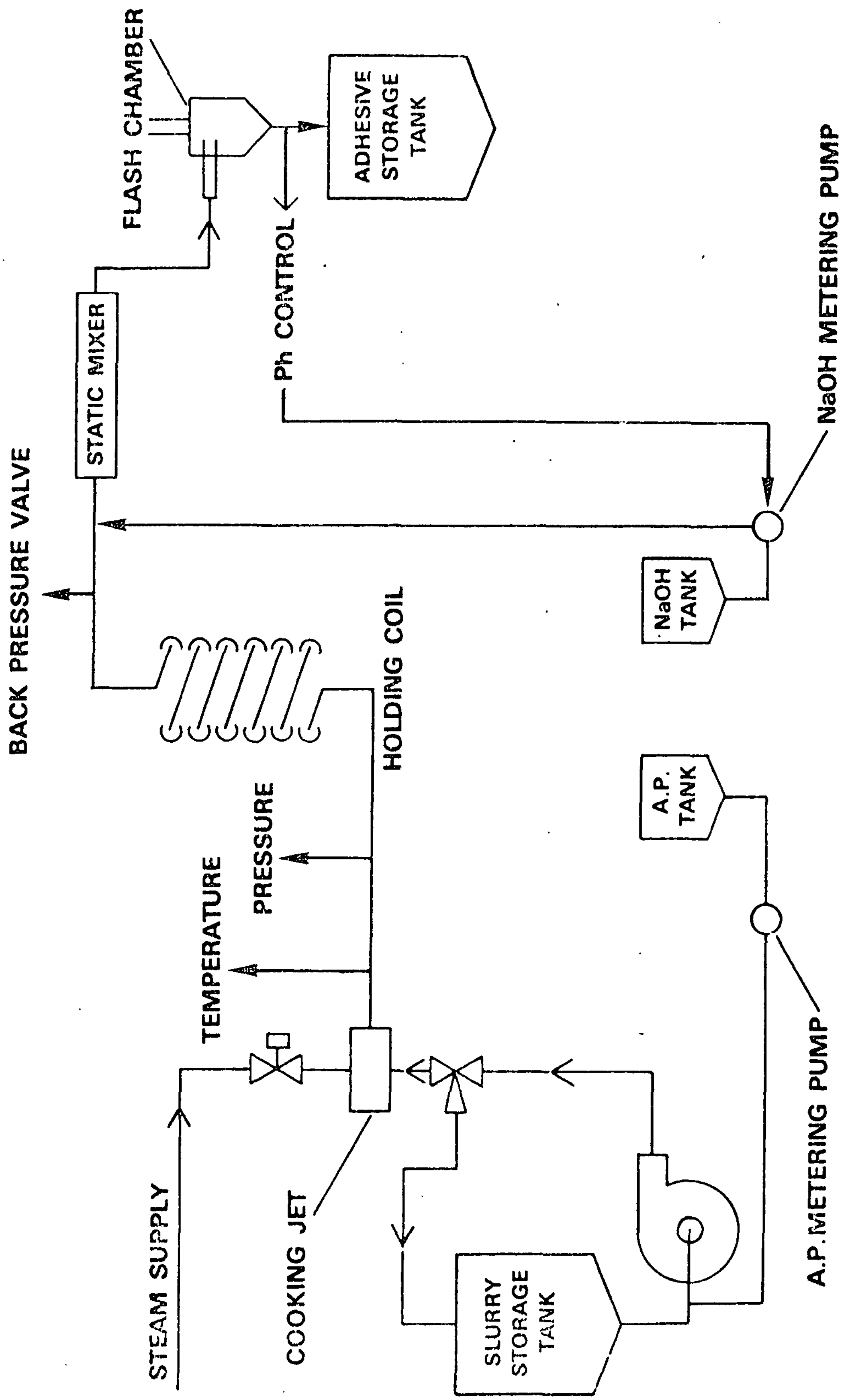


Figure 18. Thermal Conversion System

Adhesive Distribution System

The adhesive in the storage tank is circulated through a loop to the glue machine and single facer. The recirculating loops are water jacketed with 205^{o}F water flowing in the jackets. The line is fabricated with 2" 304 stainless steel pipe jacketed with 4" carbon steel pipe to the glue machine and then 1 1/4" stainless and 3" carbon pipe to the single facer. The line is covered with 1" of insulation. The pipe is assembled in flanged sections to allow for cleaning in the event of a plug-up. Flushing connections, drains, air vents, and expansion joints are designed in where necessary.

Adhesive is pumped at a rate up to 40 gpm through the recirculating loop with valved tees at the use stations. Excess adhesive from the use stations is returned to the recirculating loop and flows back to the storage tank. A dual filter unit with 30 mesh screen is located in the return line to remove any foreign material from the adhesive.

Connections are provided for purging the adhesive lines with hot water when a use station is shut down. This same water would also help clean the use station. In the event of a prolonged power outage, an auxiliary generator will provide power for purging and clean-up.

Hot water from the jacket is drawn off at each use station to circulate through the glue pan water jackets. This water is circulated through the use station and then back to the water jacket. Fig. 19 illustrates the adhesive and hot water distribution system.

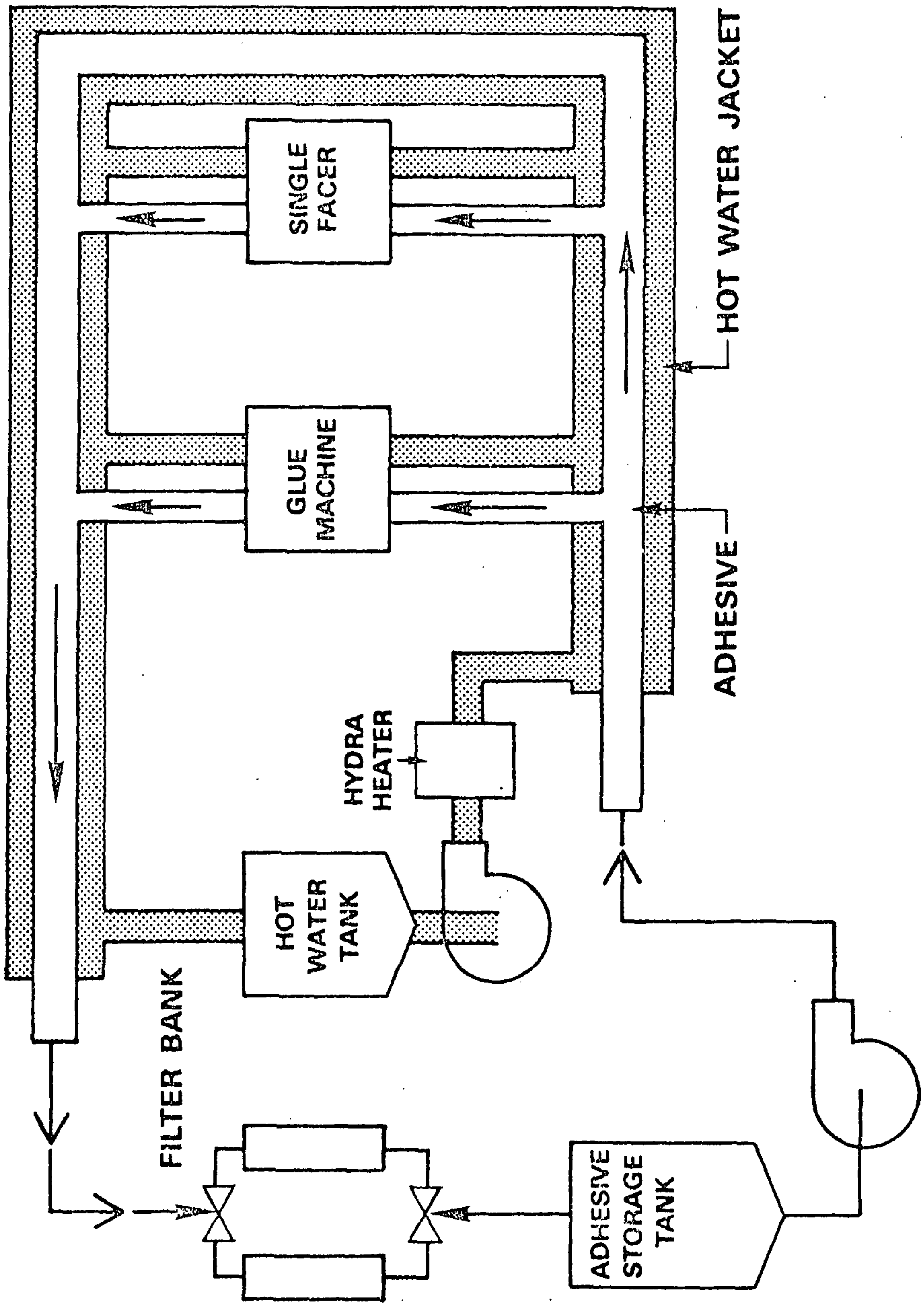


Figure 19. Adhesive and Hot Water Distribution System

Hot Water System

A 500-gallon insulated storage tank acts as a surge tank for the hot water system. This is a carbon steel tank which is insulated to minimize heat loss and for operator protection. It is a closed loop system so the hot water is continuously recirculated from the surge tank through a hydroheater equipped with automatic temperature control to maintain the hot water at the preset temperature.

The total volume of water in the jacketing of the adhesive storage tank, the adhesive piping, and the use stations is about 250 gallons. The hot water is circulated at a rate of 100 gpm; therefore, there is a turnover of water in the system every 2 1/2 minutes. This should allow for a warm-up time of less than 25 minutes.

Since this is a closed loop system, it should not be necessary to provide water treatment. An initial fill of boiler feed water or condensate would put the system in operation. Condensate from the steam jet heater will gradually add more water to the system.

The excess water will overflow into a separate 150-gallon tank to be used for the purging of lines when it is necessary.

Instrumentation

In addition to the instrumentation mentioned for control, which will be monitored by the data acquisition system, additional instrumentation will be supplied to monitor other variables. These include the following:

1. Slurry storage tank temperature.
2. Slurry pH after the AP addition.
3. Steam pressure into cooker.

4. Cooker back pressure.
5. Slurry flow rate.
6. Adhesive storage tank level.
7. Adhesive pH after the caustic addition.
8. Rate of caustic addition.

DATA ACQUISITION SYSTEM

An important task in the commercial evaluation of the cold process is a thorough mapping of the equipment design and the cold corrugating process. Data from trial runs are necessary to provide a definitive assessment of cold corrugation performance and advantages and information for second generation equipment design.

To assist in this evaluation, a data acquisition system capable of on-line monitoring of all of the variables which can affect equipment performance and board quality is to be incorporated. Sensors for monitoring these variables are mounted on all of the equipment. Three remote conditioning stations are used to collect the information from the sensors, convert the signals to digital form, and send them to the central computer. The central computer serves two major functions: it processes and stores the data for later analysis and updates three operator display stations. The operator display stations are located at the single facer, the glue machine-adhesive system area, and the slitter-scorer. These stations display to the operator the current values of the variables being monitored. Fig. 20 illustrates the data acquisition system.

It should be noted that the computer is being used strictly in a data acquisition mode and not for corrugator control. In fact, all variables needed for

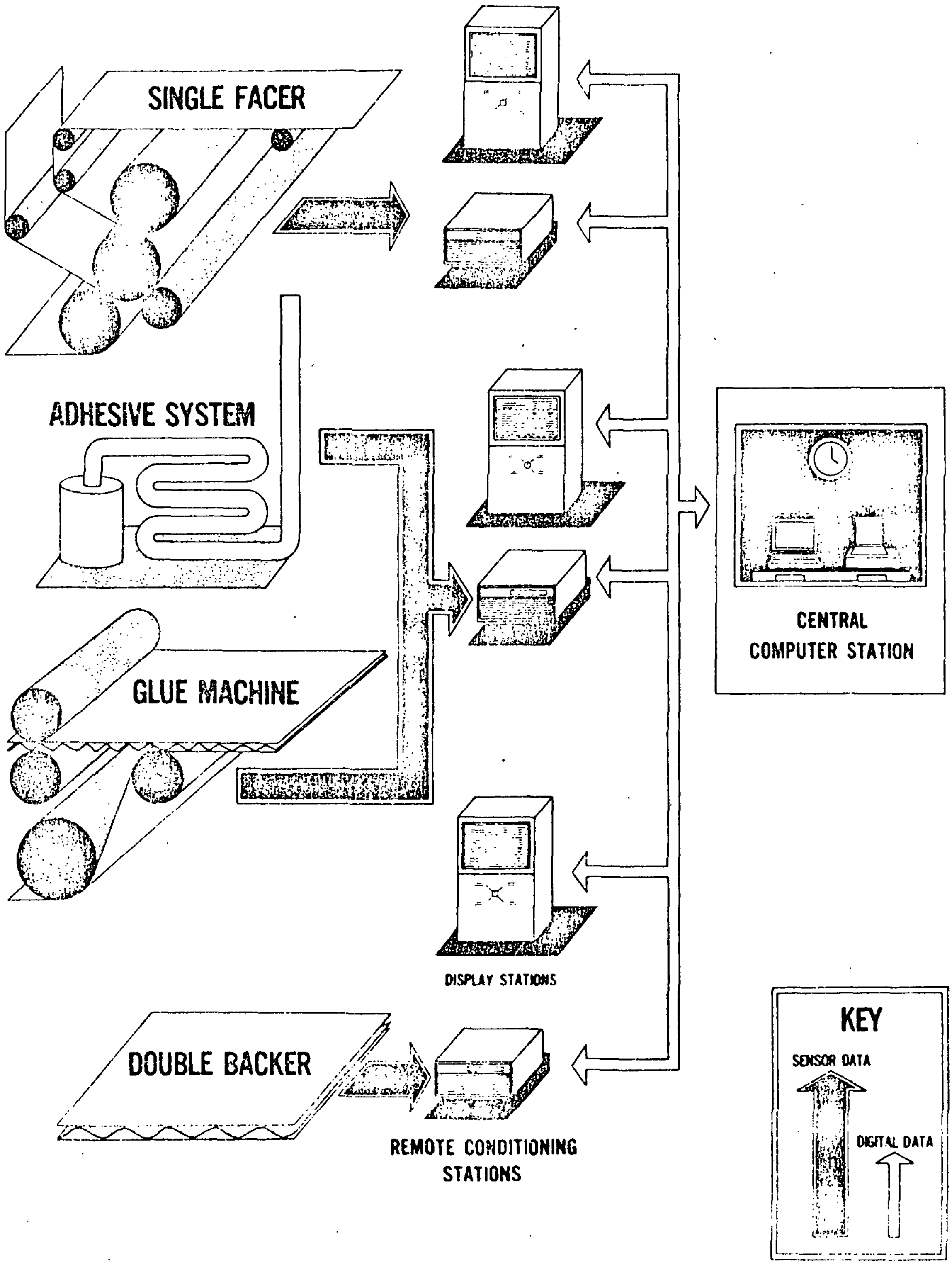


Figure 20. Data Acquisition System

corrugator operation are also displayed independent of the computer system so the system can be operated without the computer.

The initial intent was to purchase the data acquisition system on a turnkey basis. Further analysis of the situation revealed a very real problem with coordinating the computer hardware, software development, sensor selection, and corrugating equipment suppliers. Further problems were anticipated with system responsibility after the equipment was installed. For this reason, it was decided to purchase all of the computer hardware from a single vendor and have IPC personnel develop the software and select the sensors unique to the project.

Sensors

Four classes of sensors have been identified for the cold corrugating system. These are defined below and listed on subsequent pages.

1. Class 1 -- Those sensors to be utilized only by the data acquisition system, e.g., liner and medium moistures. These sensors will be furnished by IPC and mounted and wired to a suitable junction box for connection to the data acquisition system by the equipment supplier.

2. Class 2 -- Those sensors which will be utilized by both the data acquisition system and the equipment manufacturer's control system, e.g., liner and medium tensions. These sensors will be furnished, mounted, and wired to a suitable junction box for connection to the data acquisition system by the equipment supplier.

3. Class 3 -- Those sensors necessary for machine operation should the data acquisition system not be functioning or as a supplement to it. This class would include all variables which are normally used in the operation of the corrugating equipment, e.g., a pressure gauge monitor of the corrugating roll load. These sensors will be furnished and installed by the equipment supplier.

4. Class 4 -- Those sensors to be installed for the measurement of energy consumption. These sensors will be furnished by IPC and installed by Union Camp.

Class 1 Sensors

Sensor Number	Sensor	Location
1	Medium speed, 50 - 1,000 fpm, ±0.1%	Single Facer
2	Medium temperature, 50-150^{o}F, ±2^{o}F	Single Facer
3 & 4	Medium moisture, 2-12%, ±0.5% moisture	Single Facer
5	Liner speed, typical	Single Facer
6	Liner temperature, typical	Single Facer
7 & 8	Liner moisture, typical	Single Facer
9 & 10	Adhesive application rate*, instantaneous application rate, lb starch/MSF, ±10%	Single Facer
11 & 12	Top corrugating roll load, 0-300 psi, ±5% (2, drive and operator's side)	Single Facer
13 & 14	Pressure roll load, typical (2, drive and operator's side)	Single Facer
15	Adhesive temperature at delivery to transfer roll, 100^{o}F to 200^{o}F, ±2^{o}F	Single Facer
16	Adhesive system water jacket temperature, 70^{o}F to 200^{o}F, ±2^{o}F	Single Facer
17	High-low monitor*	Single Facer
18 & 19	Single face moisture before adhesive application	Glue Machine
20	Single face temperature before adhesive application	Glue Machine
21	Double face liner temperature before double backer	Glue Machine
22 & 23	Double face liner moisture before double backer	Glue Machine
24 & 25	Adhesive application rate*, typical	Glue Machine
26	Adhesive temperature, typical	Glue Machine
27	Adhesive water jacket temperature, typical	Glue Machine
28	Top surface temperature, typical	Double Backer
29 & 30	Top moisture content, typical	Double Backer
31	Bottom surface temperature, typical	Double Backer
32 & 33	Bottom moisture content, typical	Double Backer
34 & 35	Moisture scanning gauges (2 sensors, one top and bottom)	Double Backer
36	Slurry temperature, 40^{o}F to 150^{o}F, ±2 psi	Adhesive System
37	Slurry pH, 4-9, ±1	Adhesive System
38	Steam pressure into cooker, 50-150 psi, ±2 psi	Adhesive System

*Under development at The Institute of Paper Chemistry.

Class 2 Sensors

Sensor Number	Sensor	Location
	Medium tension, 0.25-4.0 pli	Single Facer
	Liner tension, typical	Single Facer
	Bridge stock (located at bridge but wired to either single facer or glue machine terminal box)	Single Facer
	Medium treatment application, off/on	Single Facer
	Medium width, 45-96", ±1"	Single Facer
	Single face tension, typical	Glue Machine
	Double face tension, typical	Glue Machine
	Rider roll gap or loading	Glue Machine
	Combined board caliper	Double Backer
	Combined board speed	Double Backer
	Adhesive pH after caustic addition, 7-11, ±1	Adhesive System
	Rate of caustic addition, 50-500 ml/min	Adhesive System
	Cooker back pressure, 50-100 psi, ±2 psi	Adhesive System
	Slurry flow rate, 50-150 lb/min, ±5 lb/min	Adhesive System
	Adhesive storage tank level	Adhesive System

Class 3 Sensors

Sensor Number	Sensor	Location
	Adhesive system water jacket temperature, $70^{\circ}F$ to $200^{\circ}F$, $\pm 2^{\circ}F$	Single Facer
	Adhesive temperature, $100^{\circ}F$ to $200^{\circ}F$, $\pm 2^{\circ}F$	Single Facer
	Adhesive system water jacket temperature, typical	Glue Machine
	Adhesive temperature, typical	Glue Machine
	Slurry storage tank temperature, $50^{\circ}F$ to $100^{\circ}F$, $\pm 3^{\circ}F$	Slurry Area
	Slurry make-up tank level, full/empty	Slurry Area
	Slurry storage tank level, full/empty	Slurry Area
	Steam pressure, 50-150 psi, ±5 psi	Adhesive System
	Cooker back pressure, 50-100 psi, ±5 psi	Adhesive System
	Level in adhesive storage tank (proportional)	Adhesive System

Also to be included with Class 3 sensors are all those which would be furnished with a conventional corrugating system.

Class 4 Sensors

Sensor Number	Sensor	Location
	Steam consumption, cooker (total consumption and rate)	Adhesive System
	Steam consumption, water heater, typical	Adhesive System
	Electrical consumption, single facer, typical	Single Facer
	Electrical consumption, double backer, typical	Double Backer
	Electrical consumption, dry end equipment, typical	Double Backer
	Electrical consumption, remainder of system, typical	Glue Machine

For almost all of the sensors, a manufacturer has been selected, most have been ordered, and many have been delivered.

The web speeds will be sensed by means of a Madison Electric digital tachometer mounted on an idler roll.

A Conax roller tip temperature probe will be used for sensing temperatures of moving webs. This is a thermocouple-based sensor.

Moisture is being monitored by a Delmhorst finger-type probe. Moisture percentage is determined by the change in resistance with the change in moisture content. The probe being used measures surface resistance and therefore is not greatly affected by varying basis weights. Initial tests indicate that different paper grades do not have a great affect either. Over a wide range of paper grades, moisture contents, and basis weights, there was a correlation coefficient of 0.89 between the probe readings and moisture contents determined by weighing and oven drying the samples.

Most of the sensors will be mounted on a manual scanning bar so that the sensors can be positioned at any desired position in the cross-machine direction.

On the table at the exit of the double backer, there will be an automatic scanning system interfaced to the computer. There will be a moisture sensor for both the top and bottom of the combined board. At preselected intervals, the computer will initiate a cross-machine scan. The information obtained in this scan can then be graphically presented to yield a moisture profile of the board as well as stored with other data.

Adhesive application rates are measured by a pair of Micro-Motion Mass flow meters. These meters sense the flow in and out of the adhesive use stations.

The computer will use these two readings as well as the liner speed, web width, and percent solids of the adhesive to calculate the application rate in lbs/MSF.

For monitoring the pressure loading of the corrugating, pressure, and rider roll, Robinson-Halpern potentiometric pressure transducers will be used.

Omega type J industrial thermocouples will be used for monitoring adhesive, slurry, and water temperatures.

A Selcom Optocator, a laser-based height sensor, along with IPC developed electronics, will be used for detecting high-lows of the single face web.

Proportional sensing of the glue pan adhesive level will be accomplished with Drexelbrook level sensors. These sensors work on an admittance principle and are unaffected by build-up on the probe. In the range from 2" to 5", they have an accuracy of ±1/64".

The steam flows will be monitored by Engineering Measurements turbine-type flow meters.

Electrical usage rates will be monitored by an Ohio Semitronics hall effect transducer.

Remote Conditioning Stations

There are three remote conditioning stations in the data acquisition system. They are located at the single facer, glue machine/adhesive system, and at the end of the double backer. The function of the stations is to collect the low level signals of various forms from the sensors, condition and convert them to digital form, and transmit the digital values to the central computer. As an additional function, the station will store the digital values from the sensors until the central computer is ready to receive the data and then transmit the values in a burst.

A Macsym 20 remote measurement and control system from Analog Devices was selected for use as the remote conditioning unit. There are provisions for 16 input conditioning modules each capable of accepting 16 or more sensors. These modules provide the conditioning necessary to accommodate various signal forms such as voltage, current, thermocouple, frequency, or strain gauge signals. The unit has an internal 12-bit analog to digital converter with programmable gain up to 2,048.

The unit is equipped with a Z80A microprocessor and 16K bytes of RAM memory. The microprocessor is programmed in a BASIC-like program. This programmability will allow the unit to scan the sensors, convert the inputs, and store the results in memory without any intervention from the central computer. Upon request from the central computer, the stored data will be transmitted over an RS 232C interface in a burst fashion. The fact that the station is programmable will greatly free the central computer for other tasks.

The Macsym 20 would normally be hard programmed with EPROM memory, but because of the interface to the central computer, programs can be down loaded from the central computer and stored in the RAM memory. This will allow for easy change of programs as necessary.

At this time, it is anticipated that the remote monitoring station at the double backer will also control the moisture scanning gauge located there.

Central Computer

The central computer collects the data from the three remote conditioning stations, converts it to engineering units, checks for out of limit variables, sends present values to the Operator Display Stations, and stores the values for later use. As background tasks, the computer can analyze current or past data, provide reports to be used in conjunction with laboratory test results, and prepare either graphical or numerical reports.

Present plans call for the central computer to be located in an office elevated above the double backer. This position allows the operator and test personnel to view the entire corrugator while monitoring the computer. It also avoids use of floor space which might add congestion to the corrugator line.

A Macsym 2 from Analog Devices was selected for the central computer. This is a 64K minicomputer with an interactive BASIC disk operating system. Peripherals included with the system are a dual floppy disk drive, cartridge tape system, Tektronix 4006 CRT graphic display with keyboard, Tektronix 4662 digital X-Y plotter, and a Data Royal 80 column printer. All of the equipment was purchased as a system from Analog Devices to simplify interface and maintenance requirements. The CRT display with a keyboard will serve as the principle input/output device for programming and operator interaction.

It is intended that the disk system will be the main storage medium for the process variables. A new disk will be used for each day's running and the old disks retained so that the data can be retrieved for analysis as needed. The disk will also serve as a system and program stroage unit.

The graphic CRT terminal can be used for viewing data in either an alphanumeric or graphical mode. This would allow a rapid screening of the stored information.

Hard copy reports of any of the information could be obtained on the printer for alphanumeric data or from the X-Y recorder for graphical presentation. A printed output of corrugator conditions for each test would be available including blank areas for the recording of laboratory test data.

Because of the dual disk capacity, it will be possible to analyze historic data, i.e., previously collected data, while the system is collecting current data.

Operator Display Stations

The three operator display stations are located at the single facer, glue machine/adhesive system, and the slitter scorer. Perkin-Elmer Model 550 CRT terminals supplied by Analog Devices were selected for this purpose. The function of the stations is to keep the operator informed of conditions on the corrugator line. Current values of the monitored variables will be displayed and constantly updated. Variable values which exceed present limits will be highlighted to attract the operator's attention.

The CRT terminal at the central computer will function as a fourth station when it is not being used for other purposes. This will allow personnel in the central computer office to monitor the corrugator operation also.

RETROFIT

Part II of this report outlines the design of the equipment to be installed for the cold corrugating commercial evaluation project. In specifying and selecting this equipment, every effort was made to include all features that might prove helpful in achieving success. Hence, it is likely that some of the features incorporated for this project will not be required in future systems. The mapping portion of this project should establish much more clearly the minimum requirements for retrofit of existing equipment. It is therefore premature to discuss retrofitting of existing corrugators beyond the brief outline below.

Single Facer

1. New glue application system.
2. Medium infeed to nip and tension.
3. Medium treatment applicator.
4. Web cleaner.
5. Fingerless → highly preferred if not necessary.

Glue Machine

1. New glue applicator system.

Double Backer

1. Take out hot plates and move bottom tail pulley to entry.
2. Install full length belt and support rollers.
3. Increase entry loading.
4. Probably split drive from top to bottom belts.

Adhesive System

1. All new except slurry system.

PART III - ECONOMICS OF COLD CORRUGATING

The cold corrugation process is being developed as a replacement for the hot corrugating process currently in use. The new process offers major advantages including the potential for a 95% reduction in process heat consumption, a 45% reduction in electrical drive energy requirements, a 20% reduction in waste, and a reduction in new equipment costs. In addition, advantages in medium and starch usage now seem likely. Reductions in corrugator maintenance costs and increases in product quality and in productivity are also expected but have not been quantified. It is expected that all of these advantages can be realized by utilizing machinery designs based on todays machinery technology. Capital and operating cost reductions and energy consumption analyses are presented in this section.

CAPITAL COSTS

The cold corrugation process does not require any of the usual process heating equipment. Thus, all such equipment may be deleted from the system, the boiler may be deleted or reduced to a small unit, and the hot plate section may be replaced by a simple press and pulling section that is less costly. Collectively, these equipment changes make the cost of a new cold corrugator approximately $300,000 less than the cost of a new hot corrugator.

Retrofit of a hot corrugator operation requires installation of a new starch handling system and some modification of the double backer, the single facer, and the glue machine. The cost of these changes will vary dramatically depending on the condition of the existing system and the approach taken. However, operating cost savings should pay for the retrofit in 1 to 2 years depending on plant productivity.

ENERGY CONSUMPTION ANALYSIS

In cold corrugation, forming of the corrugating medium is accomplished without the use of either heat or steam. Bonding of the medium and liners is accomplished with a starch-based adhesive that sets upon cooling and drying. Thus, the only heat energy used in the process is that required to prepare the adhesive and to keep it warm until used. This amounts to less than 5% of the process heat required for the hot process.

Electrical drive energy consumption will also be substantially lower for a cold corrugator. This stems from elimination of several pieces of driven equipment and the utilization of a "carrying" rather than a "dragging" double backer. This reduction is estimated to be 45%.

Corrugator waste currently averages about 13% or about 2.3 million tons per year. About 39 x 10^{12} Btu/year are required to repulp this broke and manufacture linerboard or medium from it. Included in the waste are edge trim, splices, and warped sheets that can not be converted. At the present time, it is estimated that the cold corrugating process should reduce this waste figure by 20%, primarily by the reduction in waste due to warp.

Process trials have indicated that the caliper of cold corrugated board is greater than that of hot corrugated board. This allows a reduction of approximately 2% in the amount of medium used while still producing board of the required caliper. In addition to the cost savings to the corrugator, this represents an energy savings in terms of energy needed to produce the medium.

Optimization of the cold corrugating process requires adhesive application rates on the order of 1.50 lbs/MSF of board as compared to present hot corrugating application rates of 2.25 to 2.50 lbs/MSF. Again, this represents a cost savings to the corrugator and an energy savings in the conversion of corn to starch.

Table V summarizes the energy saving potential of the cold corrugating process. Energy sources include gas, oil, and coal, thus making cost assessment difficult. Although it is unrealistic, an average energy cost figure of $3/MM Btu's has been used.

Table V

Energy and Cost Saving Potential of Cold Corrugating

Energy Savings Source	Per Corrugator 10^3 \$/Yr	Per Corrugator 10^9 Btu/Yr	Total Industry 10^6 \$/Yr	Total Industry 10^{12} Btu/Yr
1. Process Heat: Hot	78.7	26.3	59.9	19.95
Cold	3.9	1.3	2.96	.99
2. Electrical Drive: Hot	21.6	7.2	16.4	5.47
Cold	12.12	4.04	9.21	3.07
3. Medium Usage	8.21	2.74	6.25	2.08
4. Waste Reduction	30.9	10.3	23.5	7.82
5. Starch Conversion Energy	4.89	1.63	3.72	1.24
Total Cold Corrugator Advantage	128.28	42.83	97.6	32.50

Details of this energy analysis are presented in Appendix II.

The data in Table V reflect all known energy saving potentials from cold corrugating. Items 1 and 2 represent energy savings in converting paperboard materials in the box plant. Items 3 and 4 reflect energy use reductions in the paperboard mill due to reductions in the total amount of paperboard required. Item 5 is a reduction in starch mill energy consumption that will result from reduction of the amount of starch required per ton of paperboard. Collectively, these items represent the energy savings to all parties involved.

COST ANALYSIS

Energy cost savings to the box plant are accounted by Items 1 and 2 in Table V. Additional box plant cost savings accrue from reduced paperboard costs from Items 3 and 4 and reduced starch costs from Item 5. Total estimated operating cost savings to the box plant from all sources other than labor are summarized in Table VI.

Table VI
Box Plant Cost Reduction Potential - Cold Corrugating

Cost Savings Source	(M$) Per Corrugator/Yr	(MM$) Industry (760 Corrugators)
Process Heat	75.0	57.0
Electricity	9.5	7.2
Medium Usage[1]	32.5	24.7
Waste Reduction[2]	124.0	94.2
Starch Reduction[3]	25.3	19.2
	266.3	202.3

[1] 2% reduction in medium use at $260/ton.
[2] 20% reduction in waste at $205/ton (paperboard price - waste price).
[3] 0.75 lb/MSF reduction in starch consumption at $200/ton of starch.

APPENDIX I

DOUBLE BACKER SIMULATOR

The double backer simulator was designed to provide a controlled, easily repeatable test for the relative evaluation of cold corrugating adhesives. It was decided to model the full-scale double backing process as closely as possible in order to assign some meaning to the test variables and test results. Time was chosen as the primary test variable since it is the time for bond setup that is the most critical parameter in a successful corrugating adhesive. A 2" wide by 12" long strip of single face board is bonded to a double face liner in the simulator and the bonds are then broken one at a time to create a measure of bond strength vs. time of bond existence.

For proper simulation, the total time interval for the double backing process was divided into three segments: open time, or the time between glue application to the flute tips and the point where single face board and double face liner are joined; time under pressure, where the finished board is under the double backer belt; and the total bond time from formulation until the finished board reaches the slitter-scorer. Since a running speed of 600 fpm could not easily be achieved in a laboratory instrument, the simulation of these three time segments had to be accomplished by proper scaling of the machine size to its own operating speed and by providing additional time controls.

The macine was designed to be modular in nature. The major elements can be seen in the overall view of Fig. 21. The machine frame houses a hot water system for temperature control (lower left), liner sample roll (lower center), and air control system (lower right). The top of the frame supports a jacketed adhesive pan and applicator system (left center), an air loaded combining section (center), and liner

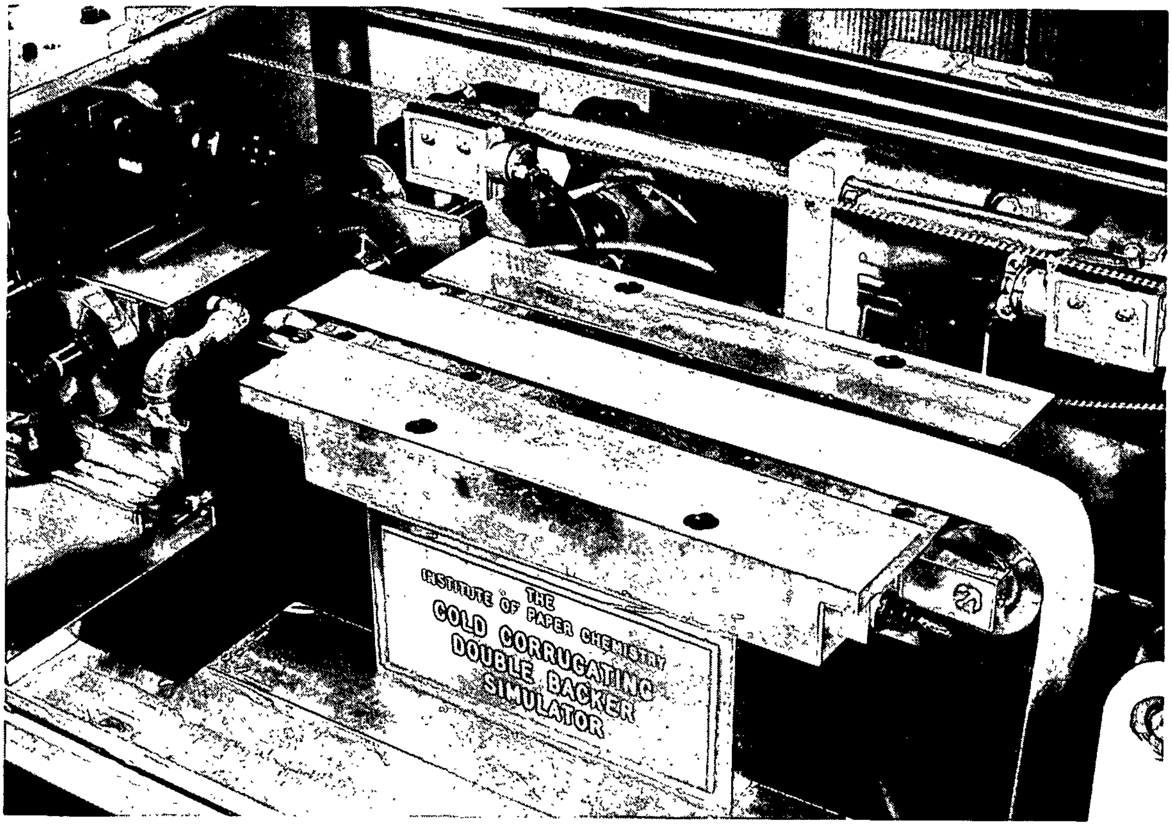


Figure 21. Overall View of Double Backer Simulator

pull rolls (right center). Immediately below the liner pull rolls is a load cell system for measuring the bond strength. The single face sample rides in a carriage (upper left) supported by horizontal rods across the top of the machine. Also seen in Fig. 21 is the electrical control panel (above the machine) and the bond force recorder (extreme right).

The machine was designed to be portable. It rolls on casters and is compact enough to be transported in a van. Only air and electrical connections are required for operation.

For a test determination, the 2" by 12" single face samples are cut with the 12" dimension in the machine direction. This provides about 39 flutes for individual bond strength determinations. The single face liner of the sample is bonded to a metal holder with two-sided tape. The holder with sample is slipped into the end of the sample carriage with the flute tips down and clamped in place with compression springs. The adhesive pan is prewarmed to the desired temperature by the hot water system and filled with adhesive. The desired adhesive film thickness is set on the adhesive pan applicator roll by adjusting the position of a single doctor blade. The applicator roll turns continuously at an idle speed. The double face liner is threaded from its supply roll over the air table combining section, down and under the roll on the load cell, and then up to the pull roll and through the pull roll nip. A weighted roll supported in a liner loop near the supply roll provides a controlled amount of liner tension.

At the start of a test cycle, the sample carriage begins to move across the top of the machine (left to right in Fig. 21) at a preset speed and the flute tips contact the glue roll to pick up adhesive. This speed determines the open time between point of glue application and contact with the double face liner. The positional relationship between adhesive pan and liner can be seen in Fig. 22. At the start of the test, a set of clutches disengages the glue applicator roll from the idle motor and engages it to be driven synchronously at the carriage speed. The double face liner also moves synchronously with the sample carriage.

As the first flute of the single face sample contacts the double face liner, two control timers are activated and air pressure is supplied to the air loaded combining section. The first 3" of the combining section are under the control of one pressure

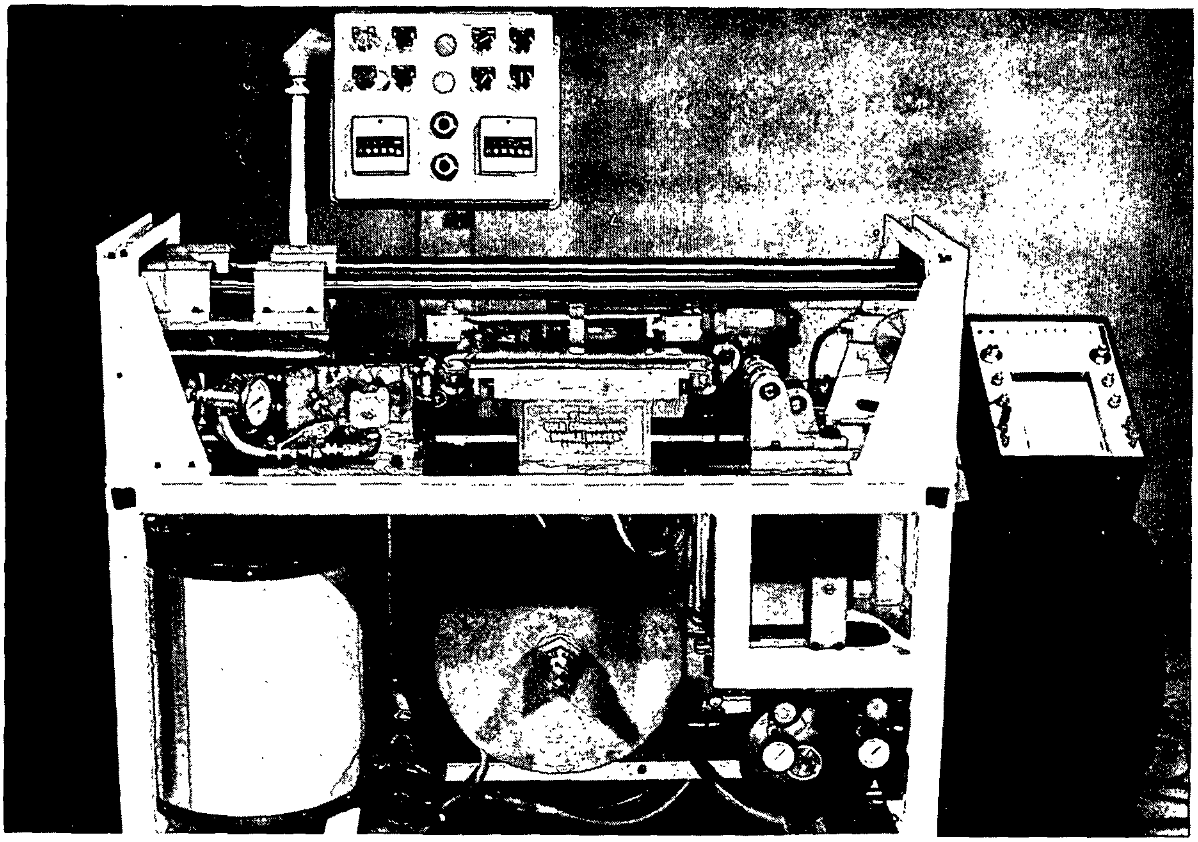


Figure 22. Adhesive Application Section and Air Table Combining Section of Double Backer Simulator

regulator, while the last 12" are controlled by a separate regulator. This provides for an initial segment that can be set for one combining pressure while the remainder of the combining section is set to another combining pressure. A Teflon-coated belt is used between the air supply ports and the bottom of the double face liner to more evenly distribute the air pressure and reduce drag. The sample carriage continues until the first flute reaches the end of the air table, at which time the carriage stops.

One of the two control timers determines the length of time that the air pressure is applied to the combined board to simulate the actual time under the top belt of the double backer. The second timer controls the time from bond formation until the start of bond breakage. When this timer deactivates, the sample carriage moves forward at a predetermined slow speed (typically, one flute per second) to initiate bond breakage. As the carriage moves forward, the double face liner is moved along at the same speed by the liner pull rolls. However, the liner is pulled down over the end roll of the combining section and away from the single face sample (see Fig. 22) end roll and causes it to fail. The tension in the liner increases until it is sufficient to cause bond failure. After bond failure, liner tension drops back to zero until the next flute is reached, at which point the process is repeated. The load cell system measures this liner tension. The recorder plots a graph of liner tension and, hence, bond strength as a function of time. The test cycle continues until all of the bonds have been broken and then automatically stops.

A typical graph for a test cycle appears as Fig. 23. Bond strength appears on the vertical scale and bond age appears on the horizontal scale, increasing from left to right. At the top of the graph is an event line which drops slightly as the first flute contacts the double face liner. At this point, the air combining pressure is applied. Counting to the right from this point to any bond break at one second per major graph division determines the age of that particular bond. The event line returns to its normal position when the air pressure control timer deactivates. For each test, this identifies the amount of time that the combined board was under pressure. In the example of Fig. 23, the board was under pressure for 5 1/2 seconds.

Looking at the main curve in Fig. 23, it can be seen that prior to the start of the trial, the recorder pen is at midscale on the graph. As the test cycle

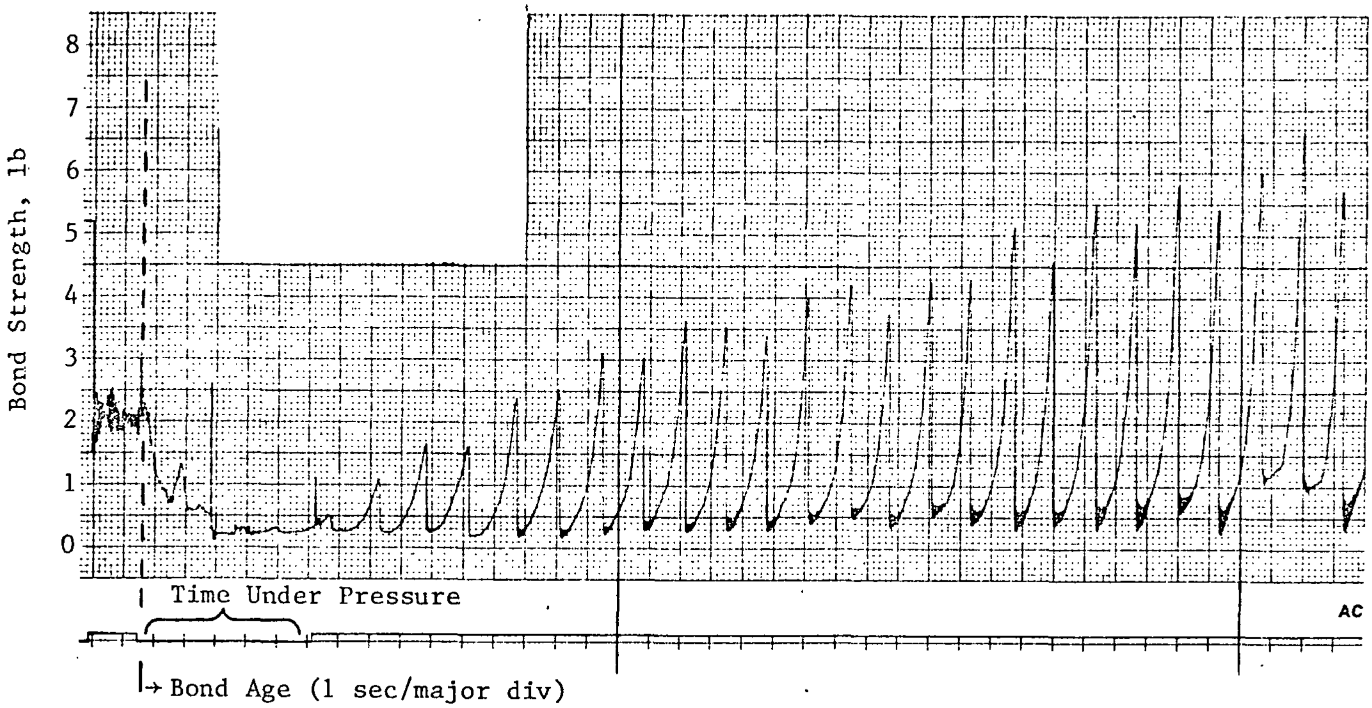


Figure 23. Typical Bond Strength-Bond Age Recording from Double Backer Simulator

begins, the recorder first shows the liner tension induced by the weight attached to the liner, about 2.0 pounds. As the cycle continues and the single face flute tips contact the glue roll and then the double face liner, the load cell output becomes irregular as the sample moves through the combining section. Notice that the liner tension decreases as bonds are formed and the sample carriage provides some of the driving force for the liner. When all of the flutes have contacted the liner, the liner tension reaches its lowest point and the irregularities disappear.

In the bond breaking portion of the test cycle, the first few bonds exhibit low strength. As the cycle continues, however, the bond age and hence the bond strength increase as the adhesive continues the curing process. The presence of flute-to-flute irregularities, due in part to the high-lows, is evident. For this reason, five trial runs are averaged to give statistically reliable results.

Adhesives can be effectively compared with respect to rate of bond strength development and final bond strengths by plotting bond strength as determined from the peaks of the graph as a function of bond age. Control adjustments on the simulator permit these comparisons to be made for any simulated speed of production, double backer length, combining pressure, glue application rate, component combination, etc. Thus, the double backer simulator provides an extremely efficient and versatile tool for the evaluation of adhesives. An example of the kinds of data obtained from the simulator and of the comparisons that can be made is given in Part I as Fig. 11.

APPENDIX II

ENERGY SAVINGS ANALYSIS

Process Heat Analysis

Hot Process

1.	1978 production[1]	17.5×10^6 tons or 256 x 10 MSF
2.	Energy consumption rate[2]	1.14×10^6 Btu/ton
3.	Total energy consumption	19.95×10^{12} Btu/year
4.	Energy consumption/corrugator[1]	26.3×10^9 Btu/year/corrugator
5.	Energy cost/corrugator[3]	$78,750/year/corrugator
6.	Total cost (760 corrugators)	$59.9 million/year

Cold Process

1.	Adhesive preparation[4]	0.5×10^9 Btu/year/corrugator
2.	Adhesive temperature maintenance[4]	0.8×10^9 Btu/year/corrugator
3.	Energy consumption/corrugator	1.3×10^9 Btu/year/corrugator
4.	Energy cost/corrugator	$3,900/year/corrugator
5.	Total energy (760 corrugators)[1]	0.99×10^{12} Btu/year
6.	Total energy cost (760 corrugators)[1]	$2.96 million/year

Electrical Drive Energy Analysis

Horsepower Distribution	Hot	Cold	Operating Time %	Operating Time Hrs/Yr
Single Facer[1]	60	60	25	625
Single Facer[2]	60	60	100	2,500
Double Backer	150	50	100	2,500
Miscellaneous	70	40	100	2,500

Hot Process[5,6]

340 HP → 317 kWh → 3.3×10^6 Btu/hour → 2.062×10^9 Btu/year
280 HP → 261 kWh → 2.74×10^6 Btu/hour → 5.137×10^9 Btu/year

7.2×10^9 Btu/year/corrugator

1. Electrical energy consumption	7.2×10^9 Btu/year/corrugator
2. Electrical energy cost[3]	$21,600/year/corrugator
3. Total electrical energy consumption (760 corrugators)[1]	5.472×10^{12} Btu/year
4. Total electrical energy cost (760 corrugators)[1]	$16.4 million/year

Cold Process[5,6]

$$\begin{array}{l} 210\ \text{HP} \rightarrow 196\ \text{kWh} \rightarrow 2.06 \times 10^6\ \text{Btu/hour} \rightarrow 1.28 \times 10^9\ \text{Btu/year} \\ 150\ \text{HP} \rightarrow 140\ \text{kWh} \rightarrow 1.47 \times 10^6\ \text{Btu/hour} \rightarrow \underline{2.76 \times 10^9\ \text{Btu/year}} \\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad 4.04 \times 10^9\ \text{Btu/year/corrugator} \end{array}$$

1. Electrical energy consumption	4.04×10^9 Btu/year/corrugator
2. Electrical energy cost[3]	$12,120/year/corrugator
3. Total electrical energy consumption (760 corrugators)	3.07×10^{12} Btu/year
4. Total electrical energy cost (760 corrugators)[1]	$9.21 million/year

Medium Savings Analysis

1. Tons of medium used[1]	6.125×10^6 tons/year
2. Medium saved (2%)	0.125×10^6 tons/year
3. Energy/ton of medium	17×10^6 Btu/ton
4. Total energy saved	2.08×10^{12} Btu/year
5. Total energy cost savings[3]	\$$6.25 \times 10^6$/year
6. Energy saved/corrugator	2.74×10^9 Btu/corrugator
7. Energy cost savings/corrugator[1]	\$$8.21 \times 10^3$ Btu/corrugator

Waste Reduction Analysis

1. 1978 waste (%)[1]	13%
2. 1978 waste (tons)[1]	2.3×10^6 tons/year
3. Waste reduction (estimated %)	20%
4. Waste reduction (tons)	0.46×10^6 tons/year
5. Energy/ton of waste	17×10^6 Btu/ton
6. Total energy savings	7.82×10^{12} Btu/year
7. Total cost savings	\$$23.46 \times 10^6$/year
8. Energy savings/corrugator	10.3×10^9 Btu/year/corrugator
9. Energy cost savings/corrugator	\$$30.9 \times 10^3$/year/corrugator

Starch Savings Analysis

1.	Energy used for refining corn[7]	12.94×10^6 Btu/ton starch
2.	Hot process usage	2.25 lbs starch/MSF
3.	Cold process usage	1.70 lbs starch/MSF
4.	Cold process savings	0.75 lb starch/MSF
5.	Board production[1]	256×10^6 MSF/year
6.	Tons starch saved/year	96×10^3 tons/year
7.	Energy saved/year	1.24×10^{12} Btu/year
8.	Energy cost saved/year	\$3.72 $\times 10^6$/year
9.	Energy saved/corrugator	1.63×10^9 Btu/year/corrugator
10.	Energy cost saved/corrugator	\$4.89 $\times 10^3$/year/corrugator

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[1] Boxboard Containers
[2] Koppers communication
[3] $3/million Btu energy cost
[4] SAECO communication
[5] 10,500 Btu/kWh
[6] 746 watts/HP - 80% efficiency
[7] Corn Refiners Association communication

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