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Cleaning and Upgrading of Post Consumer Corrugated Containers as a Secondary Fiber Source

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Literature Search

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TABLE OF CONTENTS

Introduction

The use of secondary fiber as a source of raw material in the paper industry is now an important reality ingrained into papermaking. The reasons for using secondary fiber are many and diversified but most point to economy as the primary factor. With wood and virgin pulp becoming more expensive, secondary fiber will undoubtedly maintain its place in the industry and may increase in the future. Total paper production is approaching 88,000,000 tons. Of this total only 23,000,000 is recycled. With nearly 64% of total paper production going to waste either through landfill, incineration or other disposal methods it is obvious that a lot of resources are being lost and wasted.(19) Recovery is mostly motivated by economic incentives however. As virgin pulp and wood costs rise, secondary fiber use becomes more attractive. At times like the present, with virgin pulp prices bottoming out less demand is created for secondary fiber.(16) Recovery can be attractive from several standpoints; capitol costs are generally less than a regular pulp mill, mill space is also less, raw material sources may be closer at hand especially in urban areas, some favorable pulp qualities may also be obtained using secondary fiber. Lower energy requirements are another factor.(16)

Corrugated containers are one of the most popular and effective protective packages available. They are manufactured primarily in areas close to centers of manufacturing and production. These areas also happen to be in proximity to urban areas or trade areas. Corrugated containers are manufactured from two basic components, liner and medium. These two types of board are a large part of paper industries production by weight. Twenty-nine million tons of corrugating stock is produced per year. This makes up almost 32% of the industry's total capacity.(20) Because corrugated containers are a fairly short duration product and are disposed of rapidly, recycling them makes sense. Other factors also contribute to the popularity of recycling. Because optical and aesthetic qualities are unimportant, fiber cleanliness is somewhat less important than with other grades. Also the low amount of inks on the board makes reclaiming easier and more effective. Corrugated containers use almost 26% secondary fiber in their manufacture. This accounts for 33% of all secondary fiber used by weight.(20) As one would surmise, the biggest supplier of secondary fiber is the corrugated industry itself. Eighty-seven percent of corrugated containers secondary fiber stock is corrugated fiber.(20) Within this secondary stock there are two sources: new corrugated and old corrugated. The two are different mainly in the amount of contaminants to be dealt with. New corrugated consists of corrugating mill blanks and cutting, which have not been converted to boxes for the consumer. The old corrugated is post consumer waste boxes.(8) Nearly 75% of the stock consumed is OCC while 25% is new container.(20)

Although the corrugating industry may be the largest consumer of its own waste fiber, other paper grades also make use of both OCC and NCC. With so much of the fiber available it is used in many high tonnage applications to supply strength and bulk requirements where optical properties are unimportant. The boxboard industry utilizes a lot of corrugated container fiber, up to 30% of its total waste paper consumption. The fiber adds strength and bulk to both filler plys and back liners. The tissue industry also utilizes a certain amount of corrugated, up to 300,000 tons.(21) This is a fairly insignificant amount. The tube and core industry gets almost 50% of its fiber from the corrugating industry. As can be seen, recycling of corrugated board is a large source of strong, long fibered waste stock and is consumed in a variety of manufacturing applications.

Economic considerations are putting some pressures on the industry, because virgin pulp and wood prices have dropped dramatically lately the recycling process has often times been made less profitable. Lately, waste stock prices have gone up as much as 110% which makes competition with virgin pulp and imported pulp even more difficult. Old corrugated prices have remained relatively low however, making this source more attractive to the recycled board and other industries using secondary fiber.(16) The problem is that can this source of fiber be cleaned and upgraded sufficiently and feasibly to produce a comparable fiber source. This is the question which will be addressed in this paper and in subsequent experimental work. Although OCC has been used in the liner and medium industry for years its use has been largely limited to filler and low grade applications in other areas. If it can be cleaned and upgraded to a suitable level, a cheaper fiber source will be made openly available for uses where only unbleached kraft or NCC stock had been used in the past. In this paper the problem, properties and characteristics of OCC are examined as well as methods available to clean and upgrade the stock, and finally its performance as a stock.

Corrugated Board

Corrugated containers are three layer constructions designed to protect their contents from damage during shipping, storage and handling. Though box and flute design may vary considerably, the basic structure of the board is similar. The board is made up of a top liner, a fluted medium and a bottom liner. The liners are basically heavy kraft board of from 4-12 pt. The medium is generally a kraft or NSSC sheet of lighter weight but greater stiffness which is fluted by running between two square toothed rolls during corrugation.(18) The fluted medium is sandwiched between the two liner plys and secured with an adhesive, usually starch based. This construction gives the board several desired properties. First, the fluted medium creates a separation between the two liners which gives increased burst and puncture resistance.(18) The fluted medium will also absorb some crush and further protect its contents. The most important aspect is that of compression strength. The fluted medium works on the T-beam concept and provides superior compression stability to the box sides.(18) This allows stacking of containers in the warehouse without them collapsing. To attain these goals each component must have its own specific properties.

The liner of the container imparts two characteristics to the container. It provides the main burst strength in the box and also adds strength by holding the flutes and not letting them collapse.(18) For this reason the liner must be a sheet of high strength, especially burst and tensile as well as a fairly pliable sheet to run well in the corrugator. To attain these characteristics, linerboard is usually a kraft sheet of moderate weight. The long chemical fibers give a strong sheet. Very little fiber cleaning or brightening is done as optical properties are unimportant and tonnage is the objective. Corrugating medium is required to be stiff and somewhat bulky. The stiffness provides the rigidity needed to maintain the structure's shape and compression strength. Much medium is highly secondary fiber and NSSC pulp. These stocks provide shorter stiffer fibers, little refining is done to this pulp. Most virgin medium and liner mills run at high speeds and produce large capacities. Little pulp screening and cleaning is done to the stock. These sheets often contain high speck counts due to bark, shives and knots in the pulp.

Because corrugated board is made up of two components containing chemical fiber, strength is somewhat retained even after recycling. The large tonnages being produced also demand that some of its capacity be recycled.(2) In medium particularly, the shorter, stiffer secondary fiber provides a good characteristic for the board. In times of high virgin pulp prices, use of secondary fiber can be very economical, with today's low pulp prices the recyclers are being put in a squeeze to compete. Linerboard mills usually use a mixture of virgin pulp and secondary fiber. To maintain strength requirements and still have a moderately light sheet. This tradeoff controls the mixture of fiber. As secondary fiber use increases sheet weight must also increase to maintain strength requirements. A balance must be found to economically achieve both. Typically, linerboard is 10-25% secondary fiber. Jute liner is also available using 100% secondary fiber. Strength requirements may not be met however unless weight is increased substantially. Medium is less stringent in strength requirements and may contain up to 100% recycled fiber. The medium must be stiff and somewhat bulky. When recycling one obtains a mixture of these two components.

The next consideration is the contaminants one deals with in recycling corrugated containers. These contaminants vary greatly with the source of the waste stock and whether it is post consumer or new mill blanks and cuttings. The removal of contaminants is of primary importance in the use of old corrugated container stock especially. Again the contaminants encountered will vary with source of the stock and with method of collection.

A) Mill New Corrugated Containers

This type of stock makes up about 25% of the corrugated container waste stock used in the corrugating industry. Even more of it is used in other applications. This stock is made up of unused, pre-consumer corrugated box blanks and cuttings mainly from the corrugating mill. Off-spec corrugator runs, machine trim, misprints, miscuts and converting machine trimmings make up this grade. Paperstock Institute circular describes it as (PS 11) baled corrugated containers having liners of either last liner, jute or kraft. Total outhrows are limited to less than 5%. This stock supply is usually quite clean and is made up of low contaminant board. Contaminants encountered are dirt, shives and possibly wet strength although wet strength often isn't included in this stock grade.

B) Old Corrugated Containers

This grade is comprised of post consumer corrugated containers which may or may not have been treated after manufacturing. This stock varies greatly in contaminants and quality. Cleaning and upgrading of this stock may be difficult, but it is generally much cheaper than NCC. Most of this grade goes into medium or into multi-layer boxboard filler. Contaminants are numerous but some that are dealt with are, wax, asphalt, wet strength agents, dirt, organic material, coatings of various types, plastics and many others. These materials must be removed in order to make a useable paper stock.

Recovery of OCC

Old corrugated containers are a somewhat under utilized waste stock. They are typically used as a filler stock or in lower grade specifications. With proper cleaning and handling OCC can be used in most places that new corrugated is now utilized. OCC stock is much less expensive and varies less in both supply and price than new corrugated. On the negative side, OCC has special problems which must be dealt with. Contaminant levels in OCC are usually significantly higher than in NCC. The quality of OCC can vary a great deal in that no specific grade definition has been established. Quality depends greatly on the source and type of end use the container has had. The circular PS-83 lists two special grades of old corrugated as wet strength containers and waxed cuttings. Post consumer beer boxes is also listed as a special grade. The grade quality obtained is usually either negotiated with the waste paper stock dealer or designated by the mill if direct collection is used. Either way a wide range of contaminants in varying amounts will be present. The cost of cleaning the stock may or may not be offset and made feasible by the reduced stock price. This economic factor will dictate the stock used.

Contaminants in the stock is the primary problem facing the user of old, post consumer corrugated container stock. Knowing what the main contaminants may be is a first step in removing them. Contaminant types and levels will vary greatly with the stock source.

Waxes

Waxes are commonly encountered in corrugated containers which have been waxed for water resistance. The largest contributer of this contaminant is beer boxes, however meat and vegetable packing boxes are also a large source. Waxes may be modified or unmodified. Wax may be removed fairly easily by hydropulping in hot water and skimming off or by pulping at a lower temperature and removing by particle size separation. This may be done by using vibrating screens, pressure screens and to a lesser effect cyclones. Wax will cause holes, clear spots and specks in the final sheet if not removed.

Wet Strength

Wet strength agents are added at the manufacturing site to linerboard for resistance to wet conditions which the box might be exposed to. Again, major sources are beer boxes, freezer boxes and food shipping containers. Wet strength agents may be applied to the stock either at the machine wet end or at the size press (less common). Several types of wet strength agents are used, Urea and Melamine formaldehyde resins have been traditionally used. Phenyl-hydrazine is becoming more popular as a breaking agent. Polyamide is also used as a wet strength agent in some applications. Wet strength paper will not break to a large degree in the hydropulper and may collect in the pulper bottom because it can't be extracted. The unbroken wet strength stock can be removed by screening. Wet strength can be removed by pulping sufficiently with caustic and higher temperature. Many recyclers stay clear of wet strength stock because of increased energy costs to break it.

Tars and Asphalts

These two contaminants are found occasionally in board which has been surface sized for water resistance. Asphalt is applied at a size press at a temperature of 140°F. These contaminants may be removed by pulping above 140° and then skimming off the floating asphalt. It can also be removed by screening and in a centrifugal cleaner. Asphalt not removed may cause pin holes, grease spots and stickies on the paper machine.

Polystyrene and Plastics

Plastics are brought into the stock by quite a few sources. Plastic adhesive tapes, banding and wrapping plastic all contribute to the problem. If not removed, these contaminants can cause serious sticky problems on the paper machine and in the final product. Good removal is obtained only by thorough cleaning of the stock. Centrifugal cleaners will remove plastics as a light component and screening also proves effective. A large amount of plastics can be removed at the cyclone or turbo separator. By using larger hydropulper extraction screens of up to 3/4" to allow plastic through in large enough sizes to be easily removed by screening. Also in this category would be the various adhesives which can also cause stickies problems. Many types of plastic hot melt adhesives are removed by screening in their solidified state like plastic. Some types of cold setting and pressure sensitive adhesives are also removed by screening, although separation may be less successful. The problem with stickies is definitely one of the most difficult problems to be dealt with in the use of post consumer waste stock.

Organics

Post consumer boxes often contain at least some level of organic contamination. Boxes used for shipping and storing food or coming in contact with garbage and food are primary sources of this contaminant. Organics can pose a difficult problem in that they may soak into the fiber and leave oily deposits even after particles are removed. Organics are removed by use of screens and more effectively by centrifugal cleaners. In cases of extreme contamination flotation as is used in deinking may be used to float off light organics and oils. Pulp washing may also be utilized by sidehill screens or drum and decker washing.

Dirt

Inorganic dirt is a large contaminant in old corrugated waste stock. Due to the fact that dirt is much denser than the fiber it is easily removed by centrifugal cleaners or cyclones. Dirt not removed results in high speck counts in the sheet. Lighter dirt of larger particle size may also be removed by screening. The dirt load is high in both OCC and NCC due to its industrial origin.

Other Contaminants

Many other contaminants occur in using post consumer waste stock. Most of these materials may be removed relatively easily either in the hydropulper, in the junk trap or ragger, or else can be removed later by centrifugal cleaners or screening. Some of these contaminants are glass, metal wire, wood, high density plastics.

The very nature of the liner manufacturing process also introduces some problems. Pieces of bark and coarse, unbroken fiber knots are inherently present. These coarse components may lead to lumpy formation and high sheet speck counts. Centrifugal cleaners will remove some of the more dense particles but fine screens will produce the best separation.

Processing of the Pulp (stock)

Waste paper stock is usually obtained through a waste stock dealer. This middleman negotiates stock grades, prices and supply schedules with the processor. The dealer then locates the waste stock supply and schedules its shipment and delivery. The waste is normally collected at a waste stock plant which may grade, sort, and bale the stock, or it may be obtained directly from the generator such as merchandisers, outlets, and corrugating plants. Clean, new corrugated is from box plants which "hog" and bale their rejects, off specs and trimmings to be sold to a waste stock marketer. The price of new corrugated fluctuates with demand for corrugated boxes and also with secondary fiber users. The used corrugated (OCC) stock is post consumer corrugated containers from a variety of sources. Most common sources are food retailers and wholesalers and from merchandisers. This material is generally collected by a waste stock plant. The processor purchases the stock by contract from a waste stock dealer. The stock grade is generally negotiated with the dealer as to what is and isn't acceptable to the processor. OCC is usually much more available, abundant and cheaper than NCC. Price fluctuations aremuch less.

Stock Processing

Pulping

Baled stocks are generally received by the mill as well as some loose stock from local sources. The stock may be hand sorted for gross contaminants on a conveyor or it may be sent to the pulper in whole bales.

Many companies make hydropulpers of various types but almost all work on a similar principle. The pulper is a large cylindrical vat containing a rotor plate with pitched blades circumfirentially around it. This rotor is either mounted at the vat's bottom or on the sides. The rotor generally covers an extraction plate beneath it which is a perforated plate containing predetermined hole sizes. The hole size is determined by the size of the pulp which one wants to pass out of the pulper. The spinning rotor breaks up the stock both by hydraulic and mechanical shear without too much fiber cutting or damaging. The most common type rotor is the Voke's rotor by Black Clawson. Voith Morden and others make similar rotors. The rotor blade pitch force the stock out perpendicularly to the rotor axis. Heavy contaminants sink to the bottom along the pulper vat sides and are removed in a junk trap. Much of the heavy gross contaminants are removed here. A ragger is a wire or chain which hangs in the pulper's vortex and collects textiles, wires and other long stringy contaminants. When the pulper is dumped, oversize material remains in the pulper, (that which won't pass the extraction holes). Though pulpers vary in operation, 4-6% is a normal pulping consistency. Corrugated is usually pulped with 2-5% N_aOH added to the pulper to help defiberize. Wet strength paper is the hardest to break and may require more caustic and pulping time. Some plastic in the pulper helps to collect ink, though ink removal is not of prime importance in corrugated. Pulping may be done hot (140°-180°F) to break wax and some adhesives or it may use the low attrition method of cold pulping to preserve contaminant solidity to make removal by screening more effective. Extraction holes are typically 3/8" up to 3/4". Larger holes allow contaminants to pass through larger for easier removal in the screens and cyclone. Both vertical and horizontal pulper models are available. The hydropulper performs several basic tasks: it defiberizes the waste stock, it removes gross contaminants, and it may also break up other contaminants and disperse them so they may be removed later either by size or density methods. Following the hydropulper, a secondary pulper or deflaker may be used. The pieces of equipment most commonly used resemble large plate clearance disk refiners. The purpose of the deflaker is to further defiberize and break up larger fiber bundles passed from the hydropulper. It has been found that pulping to a larger deflake percentage and then completing the job in a secondary pulper may be more economical energy speaking.

Coarse Cleaning

After being defiberized the pulp still contains large amounts of now size reduced and thoroughly disperse contaminants. However, with many of today's hydropulpers and deflakers, emphasis is placed in not breaking the contaminant particles to a too small size. These larger, coarse contaminant particles are now removed. A liquid cyclone is first used by many mills to remove large, dense particles as well as some lights. The ruffclone and hydraclone by Esher-wyss are two centrifugal liquid cyclones which remove dense contaminants from the tangentially accelerated stock by settling them to a bottom water-filled trap. The Beloit Belcor and Voith Morden turbo separator work similarly with heavies being thrown to the outside and removed targentially while some light material is removed from the cyclone's vortex by periodically operated extraction valves. In this coarse cleaning, large contaminants such as metal, glass, high density plastics and wood are removed. Some plastics may be removed from the vortex extraction. The stock is still at 4-6% consistency when going through the system although this may be varied depending on how much material is removed by the cyclones.

Further coarse screening is accompanied by use of a vibrating screen system. Vibrating flat screens such as the Johnson screen slowly move stock down its length while being showered. The accepts pass through the screen while the large sized rejects are extracted in an almost solid form at the flat screens end collector. The rejects may be rescreened or sewered. Large size contaminants are removed such as unbroken plastics, wet strength paper, and large wax pieces if cold pulped. Wire and large dirt particles also may be removed. These screens are often a mill's bottleneck due to slowness and tendency to break down. Because they are usually open, they can be messy. Most often the vibrating screens are used to re-sort the turbo separator rejects to reclaim rejected fiber. This is a more popular use because of lower volume handling. The vibrating screens do get a very sharp separation and reject very little fiber. The accepts are usually returned to the pulper. The vibrating screen is used for both applications with reject screening using screen hole sizes to 7mm. An on line stock screen would use finer perforations, around 2mm.

Fine Cleaning

After the large contaminants have been removed the stock still contains finely dispersed and broken-down particles of dirt, glass, organics, plastics, and waxes and adhesives. Coarse fiber bundles, shives and pieces of bark may also be present. These must now be removed through fine cleaning before a papermaking material is realized. Before feeding to the fine system, the stock is usually pumped through a deflaker to deflake and create a smooth and uniform stock. This deflaker also helps to further disperse contaminants within the stock.

Centrifugal Cleaners. After diluting the stock to about 1% or lower consistency the stock is fed to a bank of primary centrifugal cleaners. Many types of cleaners are available but the Bird triclean is quite popular. The stock is accelerated tangentially into the cleaner cone and accelerates as it reaches the narrower bottom. The accept fiber then travels back up out the cleaner top to the next stage. Heavier particles cannot travel back upward and settle out of the cleaner bottom. The triclean utilizes a core bleed system where lightweights are removed from the cyclone's vortex. These lightweights are then sent to a secondary system. The heavy rejects go to a secondary system for further fiber recovery, each having core bleed light removal. All lights go to vibrating screens which in turn recycle their accepts back to the first stage. This lightweight removal at all stages is a key to reducing latter sticky problems. In OCC stock especially hot melt, cold set and other solidified adhesives make up a large portion of the light fraction along with plastics. These are the culprits in sticky problems on the machine. Feed consistencies are kept at around 1%

while reject consistencies are three to four times higher and core bleeds around 0.5-0.7%. At the PCA Filer City corrugating liner mill where 75% secondary post consumer stock is used the heavy rejects are cleaned through three consecutive stages to recover as much fiber as possible. Several factors effect cleaner efficiency, inlet consistency and through put pressure drop. A low consistency, high pressure drop cleaner will get better separation efficiency.

Whereas centrifugal cleaners separate by specific density, screens obtain separation by particle size. The screens either use slotted or round holes for their perforations. The screens used for fine screening of corrugated are usually pressure screens. The screens are either inflow or outflow type. In the inflow type, the pressure drop across the screen forces stock into the screen basket with rotating pressure pulse foils either inside or outside the basket. Accepts pass through the basket circumference and is drawn off in the center. Rejects leave from the outside. Outflow screens are more common with stock introduced inside the screen basket and forced outward. The selectifier pressure screen introduces the stock to the center of a rotating device which throws the stock outward against a cylindrical screen "basket." The centrifugal force supplies the screening pressure. The screens are usually used as the last step in fiber cleaning. By sizing the screen holes, accept size will be controlled. Coarse unpulped fibers, shives, plastic pieces from adhesives which are solidified, and any other oversize particle. By cooling the stock or by pulping at a low temperature (80-100°F) wax and hot melt adhesive particles may be removed. Screen perforations generally run around 0.070-0.080 inch. Consistency to the screens is usually quite low due to being fed from the cleaner accepts, consistencies range around 1%. Secondary screening may be used to further recover fiber from the primary screen rejects. The screening process also may be used to separate fiber types. Fiber fractienation of corrugated waste stock is done to separate the long fibered chemical liner board fibers from the shorter, weaker medium fibers. By drawing off both accepts and rejects from screens and processing them separately this fiber fractionation may occur. The screening may be done in two stages with coarser screens first and following up with finer screens to remove fines and short fibers by reverse screening. Reverse screening involves using the former rejected oversize fibers as accepts.

Other Treatments. After final screening the stock is usually thickened on a decker or disc saveall. After thickening to about 30% consistency it may be either stored in a high density stock chest or thickened to 4% to be sent to the machine room. Some other treatments have been tried to remove particular contaminants such as asphalt and plastics.

Asphalt, if encountered in the stock, usually comes from specialty waste grades, asphalt treated tapes or mill wraps in the stock. It can cause severe sticky problems if not dealt with. Mainly the asphalt is degraded by heat and mechanical action until it is dispersed in small enough particle size to be unnoticeable in the sheet. Sprout Waldron uses a system of shredding dry waste stock, then wetting it to 30% consistency. This stock is then steamed at 175-212°F for several minutes. A high consistency refiner using large plate clearances to produce little fiber degradation disperses the asphalt to particle sizes of 20mm or less. Normal pulping and treatment is then used.

A treatment for removing plastics and waxes uses extraction in three stages with trichoethylene. The plastics and waxes are dissolved out and the residual solvent is extracted with steam from the fiber. The process is dry so little fiber alteration occurs.

Another treatment which is used to clean heavily organically contaminated stock is washing with either sidehill or flotation pulp washers. Especially flotation washing is able to disperse light organics, oils and fats and float them off. All these methods are possibilities, but in reality they are rarely put into actual operation. The asphalt dispersion system is utilized by Ohio Box Company to recover heavily contaminated KD (asphalt laminated board) but few other installations are used. The economics of these specialty treatments make them impractical. The major treatment of old corrugated is the basic thorough pulping and cleaning previously described. Many mills, like the Filer City mill stay clear of wet strength stock and heavily coated or plastic contaminated OCC.

Conclusions

The waste stock grade of old-post consumer corrugated containers is a cheap and potentially high quality fiber source. Though the supply varies greatly in contaminant load and types, the user can generally control the type of stock he will accept. By cleaning methods described previously an upgraded stock comparable to new corrugated container grades can be obtained. With available equipment the cost of cleaning this grade can be economically feasible to offset the cost difference between the two grades. OCC can be used as a high grade, unbleached fiber source in many grades due to its content of long fibers in the liner board portion of the corrugated. Specialized screening and even use of centrifugal cleaners can be used to separate the long fiber (liner) and the short fibers (medium) for separate uses, but as of now economics hinder this use.

Experimental Plan

This experimental work will focus on the specific cleaning and upgrading of old corrugated container stocks to a higher value grade of new corrugated cuttings. In the past OCC has been used as cheap filler material for folding boxboard and as filler for corrugating medium manufacture. The possibility of utilizing the long chemical fibers in old corrugated as a high quality, unbleached fiber source is one that has only recently begun to be fully exploited. OCC is much cheaper and available than new corrugated cuttings from box mills. By checking the stock for contaminants the types and levels of the incoming stock can be qualitatively observed. This will be done by making representative handsheets of untreated stock samples. These same samples will be pulped with caustic and screened in the lab and handsheets made from these. Rejected contaminants will be kept for comparison. The main experimental work will be done in the pilot plant using a system somewhat similar to the Hartsville Secondary fiber system. This system is a variation of the OCC recovery system used at the PCA, Filer City mill. The emphasis of the cleaning is in sticky removal and dirt removal. The Filer mill uses a cold pulping method to retain wax particles for removal, they don't pulp much wet strength paper. I plan to pulp hot with caustic to break wet strength but then cool the stock to below 100°F before cleaning. The contaminants removed at each stage are to be sampled and classified as are the accepts. Emphasis is on optimum contaminant removal at each stage. A portion of the stock will be flotation washed to see if oils and organic removal is improved.

If time permits a laboratory fractionation of the stock may be attempted to obtain the longer fiber portion for higher quality use. The cleaned, treated pulps will be compared to a pulp made from clean, new mill corrugated cuttings obtained from Aruco Container Corporation. Comparison will be in areas of strength, speck counts, and fiber classification (Tappi).

<u>Pilot Plant Flow</u>

1) Hydropulper: 3/8" or 3/4" extraction plates
   - -4% caustic (N_aOH) on paper
   - -175°F
   - -45 minutes (?)
   - -Let cool to @ 100°F or less
   - -Consistency: 4-6%
2) Belcor 4mm (0.157") extraction holes
   - -lightweight separation from vortex (sample)
   - -heavyweight separation from tangentially (sample)

3) To chest

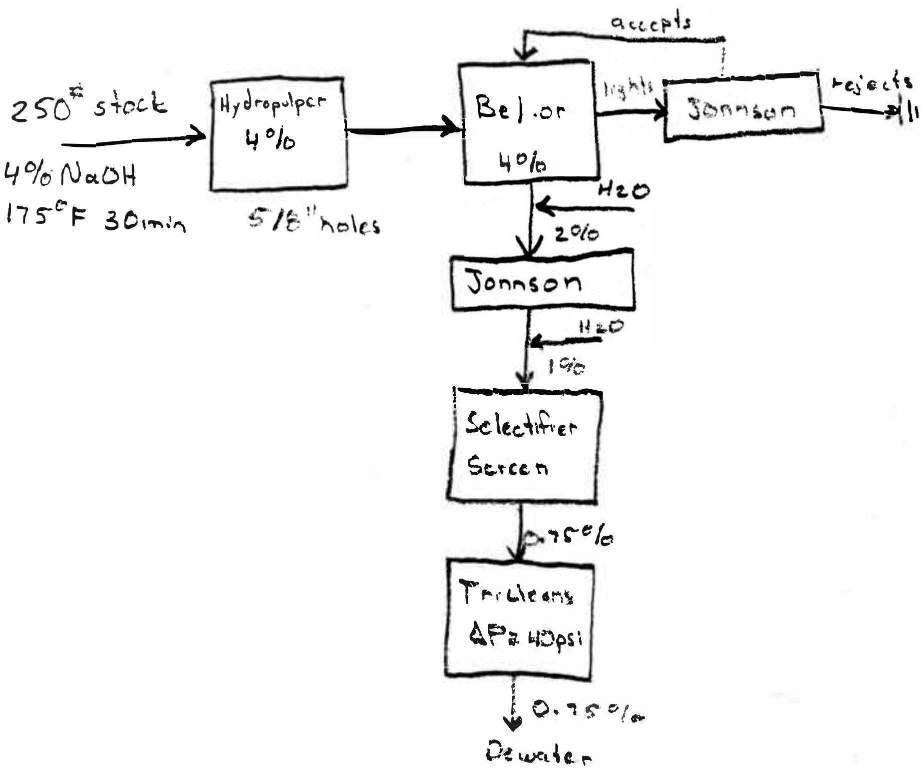
4) Pump through deflaker @ 3 1/2% (Refiner w/wide plate clearance)

5) Dilute to 0.86% (range)

6) Feed to Tri cleaners

7) Accepts to selectifier (0.66%) pressure screens 0.78" holes

8) Rejects to pressure screen of 0.071" round holes Accepts back to first cleaners



OCC Stock 250#

150# post consumer packing containers (no wax or wetstrength)

50# beer boxes

25# vegetable & fruit packing boxes (wet strength, organics)

10# pizza rounds

Also: may add some mill tapes & dirt.

Cleaned Stock

1) Yield

2) Tests on hand sheets

   -burst

   -tear

   -tensile

   -visual speck counts

   -fiber classification on pulp

3) Reject samples: consistencies, qualitative analysis, ash, fiber

4) Accept samples: consistencies, hand sheet evaluation, speck counts

Preliminary Work

Samples of each type of stock to be used will be chosen to represent basic contaminant categories. Stock samples will be tested by pulping in the laboratory pulper at 2% consistency with 2% N_aOH for 15 minutes. Hand sheets will be made on a Noble-Wood to observe for contaminants.

Procedure put forth by the BRDA will be used for repulpability.

1) Equipment: Waring blender
hot plate
large Buchner funnel
2) Take 3" x 3" sample from container, tear into small pieces and dilute in blender
3) Fill blender 3/4" full of hot tap water. Pulp for 30 seconds
4) Make sheet on Buchner
5) Place pad between blotters and press.

Testing of sheet:

1) Inspect for wet strength lumps (if lumps found, use indicator)
2) Place sheet on hot plate filter paper down. (Setting 4 @ 355°F). When pad is dry, inspect filter side for indications of transfer of color, wax, discoloration, etc.
    a) Ink--discolors filter paper
    b) Adhesives--hand sheet may stick to filter paper, may see pieces of adhesive
    c) Wax--hand sheet blotchy, greasy. May smell burning wax
    d) Examine sheet for other visible contaminants

Comparison Testing

NCC

Pulp clean, untreated mill blanks in laboratory pulper for 10 minutes at 30°C, with 2% N_aOH. Screen pulp on coarse laboratory vibrating flat screen. Make Noble Wood hand sheets (4gm).

OCC

Take cleaned pulp and dewater. Make Noble Wood hand sheets (4gm).

Testing

1) Visual: speck count/square inch
2) Visual formation check
3) Burst (mullen)
4) Tensile
5) Tear
6) Repulpability
7) Possible fiber classification to separate liner from medium fiber by using laboratory screens.

Materials Needed

A) Wet strength testing kit

WS1 phenylhydrazine hydrochloride
sulfuric acid

WS2 anhydrous ferric chloride or ($FeCl_3 6H_2 0$)

B) Filter paper and hand sheet fabric

Buchner funnel and evacuator

Noble & Wood machine

c) Pilot plant Run

1) Caustic (N_aOH)

2) Sample bottles (16)

3) Stopwatch

Estimate of Lab Time

		Hours
1)	Procurement of Corrugated Samples	6
2)	Testing of OCC for Contaminants	20
3)	Preliminary Pulping and Testing	25
4)	Pilot Plant Run	15
5)	Procurement and Testing of Samples	30
6)	Final Comparison	5
	Total Lab Hours:	101

Pilot Plant Run

On Monday, June 6, 1983 the secondary fiber facilities at the WMU pilot plant were used to clean and process old corrugated container stock from a local supermarket. The pilot plant run was part of the senior thesis project. The objective of the run was to observe the cleaning effects of a system to upgrade waste corrugated. All accept and reject flows were sampled, and handsheet made of each so they could be compared qualitatively. The system design used to clean the stock was fundamentally based on the corrugated stock cleaning system. An emphasis was put on removal of stickies causing materials which were present in large quantity in the dirty stock furnish. As was discussed in the background information, the idea was to pulp at a fairly hot temperature of over 175^{o}F and to attempt to melt the wax and soften the plastic contaminants in the waste stock. By diluting with cold water after pulping, the wax particles are resolidified and thereby removed more easily by cleaning methods. In the end the cleaning system worked quite well and much of the stickies contaminants were removed.

The experimental work which was actually carried out was somewhat different than the original experimental plan. For this reason, it will be described in detail.

Procurement of OCC

The feed stock to be cleaned in the system was a typical waste corrugated stock generated by most large supermarkets. The stock used was obtained randomly from the box bales at Hardings Supermarket on West Main. The samples drawn contained a good cross section of the material generated by the supermarket. The store produces 5-8 700# bales of mixed OCC per week. The waste is baled on metal skids and picked up twice weekly by the Spartan Food Corp. in Grand Rapids. Each bale is generally worth $6-8 to the company. Though the waste is mixed and generally heterogenious, it can generally be categorized into four main groups, each with its attending problems and properties.

1) Lightly to Moderately Printed Corrugated:

Regular corrugated containers with levels of printing ranging from almost none to moderate amounts of two or three color printing. This group made up the bulk of the waste stock. This material was comparatively free of major contaminants and was of generally high quality. These cartons are used for casing sub-packaged products and therefore contain little organic contamination. The main contaminants found here were general dirt, hot melt adhesives used to seal the boxes and some metal staples. This category is probably the most useful as far as stock goes and makes up the majority of waste stock generated by dry goods vendors and other "hard-goods" stores. The ink coverage presented little problem since it was comparatively light and was applied as flexographic printing. Due to the dark color of the finished pulp, ink removal is not important.

2) Waxed and Wet-Strength Corrugated:

This category made up the second largest category in the waste stock. In large supermarkets this material may be considerable. This category includes meat packaging containers and produce boxes. The meat containers generally were waxed on the outside and contained wet-strength plys inside as well as plastic inner linings (some of which were removed manually). These containers were heavy often double flute walled containers which were heavily contaminated with grease and organics. Also in this group were produce containers for packing fruit and vegetables. These containers were often heavily waxed and contained some wet strength. These containers also contained organic contaminants. Both types of containers contained special wet resistant adhesives and metal staples. Although this category made up to 20% of the total waste stock by weight, it would probably best be avoided. Much of this material ends up being rejected anyhow. Still it definitely does contain a lot of fiber. Though difficult to recover, these types of OCC must be dealt with.

3) Coated Printed Boxboard and Bleached Kraft:

This category is mostly made up of coated and printed beer cartons and six-pack containers. Though not corrugated they made up a substantial amount of the waste stock. These containers generally contain some good long fibers but also contain wet-strength material and large amounts of ink. Most of this wet strength can be effectively pulped by using high temperatures and fairly large amounts of caustic. This category is a good source of comparatively bright and clean fiber and is in ample supply in almost all stock samples of mixed waste.

4) Miscellaneous Kraft Bags and Printed Paper:

The last category includes kraft grocery bags and heavily printed coated paper. This catch-all category made up less than 5% of the waste stock by weight but contained comparatively clean, strong fibers which enhance the furnish. Main contaminants here are dirt and ink. Both are readily removed in a stock cleaning system and pose no real problems. If anything, this category is an asset.

The four categories named obviously are not hard-set categories and some stock may overlap. They do, however, allow one to get an idea of the nature of the mixed supermarket waste used. The waste contained a lot of gross contaminants which were removed manually before pulping. These included plastic bags, glass bottles and large pieces of foil and metal. These contaminants could be removed in the hydropulper, however. The waste stock used was dry and was weighed out to a total weight (air dry) of 201#. 168# was the supermarket waste stock and 32# was corrugator trim from Menasha Corporation. The trim was added to the stock to pad out the weight and also to dilute the contaminant concentrations. This facilitated better system equilibrium and a higher quality final stock. Even the corrugator trim contained significant amounts of dirt, as it was taken from a 500# bale.

Secondary Fiber System Set-Up

As was stated earlier, the system was modeled after the Hartsville Secondary Fiber system as is used at the PCA Filer City Mill in Manistee, Michigan. Due to the small amount of stock used, no equilibrium could be maintained for secondary cleaning. For this reason all reject streams were sampled and sewered. The system was piped up Monday morning and stock dilution was obtained by estimating water requirements and then adding the amount in holding chests between stages. Generally, 2 quarts of stock was obtained from the reject and accept lines at each stage. The final cleaned stock was dewatered (20 gallons) in a filter back and stored for hand-sheeting.

1) Hydropulper

The hydropulper used was a black clawson pulper using a Vokes rotor and 5/8" extraction plate. The pulper was filled with 201# of furnish as described in the previous section. 540 gallons of water was added and steam was added to bring the temperature to about 178^{o}F. This heating took 38 minutes, at which time 8 lbs. of dry caustic (NaOH) was added to make

4% NaOH on furnish. This slurry was pulped for 34 minutes at which time agitation was ceased. The stock slurry was then extracted through the 5/8" extraction holes and pumped directly to the Belcor at approximately 4.5% consistency.

2) Belcor

The Belcor turbo-separator was donated to WMU in 1968 by the Beloit Machine Company. This piece of equipment had not been used in several years. The Belcor used 0.157" (4mm) extraction holes on its periphery to remove heavy contaminants, and light weights are removed from the turbo separator's vortex center. The stock was still hot, above 170^{O}F, when it was introduced to the Belcor at 4.5% consistency. The two reject streams were sampled and sewered. Normally, these two streams (particularly the light fraction) would be recycled through a secondary cleaning stage to reclaim useable fiber. The accepted fiber is pumped into a holding tank where it is diluted with cold water to 0.75% consistency. This dilution also acts to cool the stock to below 130^{O}F. This cooling allows much of the wax to resolidify in order to facilitate wax particle removal at the screens.

3) Jonnson Screen

The Jonnson screen is used as a coarse vibrating screen to remove rough contaminants that may damage the selectifier screen basket or the Bird cleaners. The Jonnson screen uses 1/8" holes. The screen is fed at a consistency of 0.75%. The rejects are discharged at a very high consistency and are almost dry when sewered.

4) <u>Selectifier Screen</u>

The accepts from the Jonnson screen are fed at exit consistency to the Selectifier pressure screens. The screen uses tangential force to force the stock through a cylindrical basket screen. The basket used had 0.062" holes. Rejects were sampled and then sewered. Accepts were diluted to 0.68% consistency and fed to the Bird Tricleans. The Selectifier was an important stage in stickies removal. It was hoped that the screens would remove solidified wax and hot-melt particles as well as grease-soaked fibers and oversize dirt and plastic particles.

5) <u>Bird Tricleans</u>

The accepts from the Selectifier screens were fed to the Bird Triclean centrifugal cleaners. The cleaners were set up to extract both a light and a heavy fraction. The four cleaners were fed at 0.68% consistency, a pressure drop of 44 psi was used to obtain optimum efficiency. Due to the small amount of stock used, equilibrium could not be established long enough to allow a secondary stage to be instituted. For this reason fiber reject rate was very high. It was hoped that the Bird cleaners would act as a final separation, removing dirt particles and plastic and small wax particles. Both reject streams were sampled and the accepts were dewatered as the final cleaned pulp product.

The system was designed to remove contaminants in a step-wise fashion. At each stage a different separation was obtained, either by size or density. The emphasis on wax and stickies removal was obtained by several steps. First the wax was melted by pulping at high temperatures, this allowed wax coatings to float free of the fibers, grease separation also is obtained in this way. Hot melt adhesives may also be softened and loosened by the heat and agitation. Secondly, the stock was cooled by diluting it with cold water, this cooling allowed emulsified wax and grease to resolidify into separable particles. Hot melts and plastics were further stabilized into pelletized particles which facilitates screening. Thirdly, the stock was pressure screened, using smaller than conventional screen orifices. Although more fiber was lost, stickies particles were removed to a greater extent than usual. Finally, low density wax and plastics were removed by the light stream on the Bird cleaners.

Wet-strength handling was also a major concern due to large amounts of wet-strength board in the furnish. Wet strength was handled primarily in the hydropulper. By pulping at high temperatures and using 4% caustic (on paper) we hoped to break the majority of the wet strength. Unbroken wet strength was to be removed at the pulpers extraction plate, the Belcor and at the Jonnson screen. Dirt removal occurred at all stages but particularly in the Belcor, Selectifier screen and at the Bird Tricleans. The entire run took about 2 hours once the hydropulper reached temperature.

The results of the run are discussed in the next section.

Pilot Plant Run Results

The pilot plant run was observed in a largely qualitative manner with more emphasis on what was removed and how the pulp quality was improved than how much was removed. Overall the system operated better than expected. Some quantitative estimates of separation are offered on a purely observed basis. As each cleaning step is discussed one may refer to handsheet samples in the Appendix of each accept and reject line. Vast improvement is clearly obvious between Belcor accepts and final pulp produced.

1) Hydropulper

After 34 minutes of pulping at 178^{o}F and with 4% caustic (on stock), the slurry was quite dark with significant foam present on the surface. When pulper was dropped almost all of the stock was removed. All that remained was large pieces of plastic sheeting and some strapping. Very little unbroken wet strength was observed. This was unexpected, it did show that the high temperature and caustic is effective in breaking down wet strength.

2) Belcor

The Belcor was our most unexpected find. It was expected that the Belcor was going to remove only the large, coarse contaminants. We found that the Belcor was effective in removing up to 60% of the total contaminant load without excessive loss of good fiber. The Belcor's heavy rejects outlet was inadvertantly plugged so that most rejects were forced out of the vortex reject port. This did not seem to effect performance, however. One can see from the light reject handsheets that large amounts of unpulped, hard fibers, pieces of material (textile) and hot melt particles were removed at this cleaner. The heavies port, when unplugged, contained staples, wood and high density plastic particles. The use of the Belcor virtually made the use of the Jonnson screen unnecessary. Another advantage is that the Belcor is able to be directly fed from the pulper at the same consistency (4-5%). The 4mm extraction holes allowed large particles to be removed.

3) Jonnson Screen

After diluting the Belcor accepts in chest 3 with 2400 gallons of cold water, the stock was pumped through the Jonnson. Due to the Belcor's effectiveness, very little material was removed as rejects at the Jonnson. The rejects removed were almost insignificant and consisted of staples, plastic and some unbroken stock. By looking at the Jonnson accept samples and at the Belcor accept samples, little improvement is noticed. It is concluded that use of the Belcor should allow the bypass of the vibratory screen in most cases.

4) Selectifier Screen

By examining the Selectifier rejects sample one can see the large amount of wax and hot melt spots. This indicates that the strategy proposed earlier for wax and sticky removal was to some extent successful. The resolidified wax particles and the hot melt adhesive pellets were effectively removed by the small (0.064") holes in the screen. Also removed is dirt particles and some coarse fibers. The accepts show considerably less grease, wax and stick spots as the Jonnson accepts but speck count is still high due to small dirt particles and some stickies still to be removed. Reject rate was fairly high (30%) due to small holes used but stick removal warranted it. I believe use of slots would attain even better separation. Most of the reformed stickies particles were round and slots would facilitate better removal.

5) <u>Bird Tricleans</u>

This last cleaner also had the highest reject rate (x 50-60%) due to lack of a secondary cleaner system. It can be noticed from the heavy reject sample that a large amount of coarse fiber has been removed. A very high speck count also shows that large amounts of dirt particles have also been removed. The lights consist mainly of wax and stickies particles plus overpulped fibers. A lot of good fiber was rejected in both streams. The accepts show a remarkably clean stock considering the furnish used. Speck count is greatly reduced and may be as low as 3-5 counts/in^2.

Contaminants remaining consist mainly of some stick spots as well as coarse fiber particles. Sheet color is considerably lighter.

As one can see from the samples, the accepts become increasingly cleaner with each step. Most dramatic improvement occurs with the Selectifier screen and the Belcor. Sticky removal was largely at the Selectifier screen with additional removal at the Bird cleaners. Dirt removal was greatest at the Selectifier also. Most of the coarse, woody fibers came out at the Bird cleaners. Gross contaminant removal including organics occurred largely at the Belcor.

Handsheets

Handsheets were made on a standard Noble & Wood machine using 120 mesh screens and dryer temperatures of $240^{\circ}F$. This dryer temperature caused hot melt and sticky particles to melt producing the characteristic dark spots. Some of the sheets actually stuck to the screens, indicative of problems which may arise if sticky removal is not emphasized. The sheets were made to a target weight of 2.5 grams/sheet. 80% of the sample sheets were ±0.5 grams of the target weight. Some reject samples were made heavier for better exhibitive properties. Handsheets were not possible of the Jonnson rejects, Belcor heavies or Hydropulper rejects.

NCC Comparison Samples

For comparison purposes, several clean corrugated mill blanks were pulped in the laboratory pulper in the pilot plant.

These blanks were free of any added contaminants and were simply free blank sheets off of the corrugator. The sheets used were obtained from Aruco Container Corporation and were roughly 32" x 14" in dimension. The sheets were simply pulped for 20 minutes at 140^{o}F. The pulp was then made into handsheets of 2.5 grams for comparison to the OCC samples. As one can see the NCC sheets are clean and relatively free of specks. Coarse fibers appear to be the only contaminants. The comparisons were made on the basis of visual formation and cleanliness and by speck count. Some physical strength tests were also performed. The NCC standards were also made on the Noble & Wood machine in as close a manner as possible to the OCC samples.

In comparison, the OCC pulp produced suffered in several areas. Speck count and visual contamination in the OCC samples was noticeably higher, but this was to be expected. No matter how thorough the cleaning system used, some contaminants were bound to remain. Speck counts were in the order of 150-300% higher in the OCC than in the standards. Typical counts ranged from 4-8 counts/in^2 in the OCC to 1-3.5 counts/in^2 in the NCC. Specks of noticeable prominance were counted and didn't include coarse or dark fibers.

Strength testing was only marginally successful due to the incongruities in the two pulps' methods of processing, direct comparison is only slightly beneficial. Most interesting was burst and tear tests. Burst strength was generally

20% greater in the NCC samples. This was probably due to better sheet formation and less fiber degredation caused by harsh pulping conditions in the pilot plant pulper. Though the wet strength and other tough stocks were pulped, there was a price to pay. Tear was comparable with the NCC holding only a marginal edge. The greater OCC sheet density and inclusion of some long fibered stock made this comparable. Other tests were less conclusive. Tensile is of little consequence in corrugated container manufacture (to an extent) and this test produced clear-cut NCC advantage of almost 30%. Visual inspection of sheet cleanliness and formation was probably most important.

The NCC standard samples exhibited a smooth formation but screenable shives and coarse fibers were visible. Dirt content was obviously low. The OCC, due to finer fiber sizes, exhibited a uniform formation as well as a smooth surface. When observed over background light, however, interior dirt specks and coarse fibers become evident.

Conclusions

Before conclusions are drawn from this work, it may be beneficial to recap the question being studied, the reason for the investigation which was undertaken. The use of OCC stock, mixed waste in particular, has long been relegated to use as three main materials. First, as a fuel source with all but the best stock being dried and incinerated for energy recovery. Secondly, as a cheap, low-grade fiber source for grades such as roofing felts, building materials and as cheap fillers in boxboard and laminated boards. Thirdly, some mills have undertaken cleaning and processing programs to upgrade the stock to a useable furnish for use in manufacture of medium, boxboard and in a few cases liner (jute). With virgin stock now inexpensive, the emphasis has left secondary fiber for the time being. However, as business picks up and NCC becomes more in demand or more costly, recycling of OCC will become more attractive. Is upgrading possible, and what is required to process this mixed waste effectively? These are questions addressed.

It was found that mixed corrugated waste contains many types of material, not all desirable. Large amounts of wax, wet strength and stickies must be dealt with. Also in the stock were found printed boxboard and bleached kraft board. I believe cleaning is possible, stickies must be a major focus of the program, however. Due to large quantities of wax, organics and hot melt adhesives, stickies could be a real stock problem if not addressed in the cleaning program. Sticky removal, though not complete, was achieved by pulping at high temperatures to melt and soften the materials. Cooling stock with dilution water (cold) prior to screening with smaller (less than 0.071 in.) holes or slots than conventionally used removed most of the stickies. This melt, separate, reform and screen technique is effective and should be further investigated.

Wet-strength paper, which was in evidence heavily in the mixed waste used, was effectively broken by using high temperatures (above 175^{o}F) and 4% NaOH on stock. Screening and turbo separation is an additional way to remove residual unbroken wet strength. Given ample conditions, even the most stubborn wet-strength stock can be broken. The large amounts of coarse contaminants and organics which are typical in this type of mixed waste were handled very effectively by a combination of Vokes rotor 5/8" extraction plate holes in the hydropulper followed by 1/4" extraction holes in the Belcor turbo separator. The Belcor was found to be a very effective piece of equipment for obtaining a coarse separation. The use of the Belcor was able to eliminate the need for a coarse vibrating screen and possibly reduced the load on the pressure screens. Remarkably little good fiber was lost at the Belcor and it may be fed at hydropulper discharge consistencies. The Belcor turbo separator is an underused piece of equipment which warrants more attention.

Dirt and coarse fiber was removed by the pressure screens and by the Bird cleaners, while removal was effective more dirt could be removed. By instituting more centrifugal cleaners and possibly some fine screening, even better stock would be obtained. I practice most reject flows need to be run through a secondary separation to minimize good fiber loss for economic reasons.

The final pulp was found to be quite good if one considers the waste stock used. Good uniform formation was obtained and the stock was satisfactorily free of major contaminants and coarse fibers. Some stickies remain but content was dramatically reduced (@ 70%-80%). More fine dirt removal could be used, however. While as a furnish solely in itself this stock was not comparable to pure, clean NCC stock, it may be used to supplement NCC stock grades. Several reasons arise for OCC stocks physical inferiority. First, the harsh pulping conditions required tend to degrade the fiber somewhat. The stock will inherently have shorter fiber and will not be nearly as homogeneous as the NCC which is all corrugated fiber. Secondly, residual contamination with dirt, stickies and coarse fibers do inhibit good formation to some extent. Even though cosmetically inferior to a 100% NCC stock, the economics dictate OCC's consideration, especially when purchased as a mixed waste grade. With NCC stock grades costing from $150-$220/ton and sure to be increasing, the use of $18-$35/ton mixed corrugated waste is bound to be attractive. Though cheaper in material cost, the grade is costly to process. High rejection rates, cleaning system capital and operating costs as well as a lower selling price all must be considered. In the near future, more attention must be given to mixed old corrugated grades.

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Appendix I

Pilot Plant System

A. Furnish (201#)

Corrugator Trim - 32#

Mixed Supermarket Waste - 169#

Corrugated Container ("clean")	-	65%
Waxed & Wet-Strength Boxes	-	20%
Boxboard (some wet strength)	-	8%
Kraft Bags	-	3%
Miscellaneous printed paper	-	4%

NaOH (dry)	-	8 lbs.
H_2O & steam	-	520 gal.

B. System

1. Hydropulper (4.5% consistency)
   - Vokes rotor (5/8" holes)
   - 178°F
   - 30-40 minutes
2. Belcor (turbo separator)
   - 5% consistency
   - 178°F
   - 1/4" extraction holes
3. Jonnson Screen (vibratory)
   - need not be used

4. Selectifier (pressure screens)

   - feed at less than 150°F (138°F)
   - 0.78% consistency
   - 0.066" holes or slots (better)

5. Bird Tricleans (centrifugal cleaners)

   - operate both modes
   - 0.68% consistency feed

Appendix II

Contaminant Handling

A. Wet Strength (20% of stock)

- Pulp at + 170°F
- 4% NaOH on stock
- Pulp 30-40 minutes
- Use 3/8" extraction plate in pulper
- Removal at Belcor and Selectifier

B. Stickies (wax, plastic, grease)

- Pulp hot (below 170°F)
- Cool stock with dilution water (above 140°F)
- Selectifier screen (0.066" holes or slots)
- Residual removal at Bird cleaners

C. Dirt

- Belcor Heavy extraction (coarse dirt)
- Selectifier screen
- Bird Heavy extraction (most)

D. Organics

- Pulp hot (175°F)
- Belcor (most)
- Selectifier
- Bird (lights)

E. Gross Contaminants (wood, glass, metal, plastic)

- Hydropulper extraction plates (plastic)

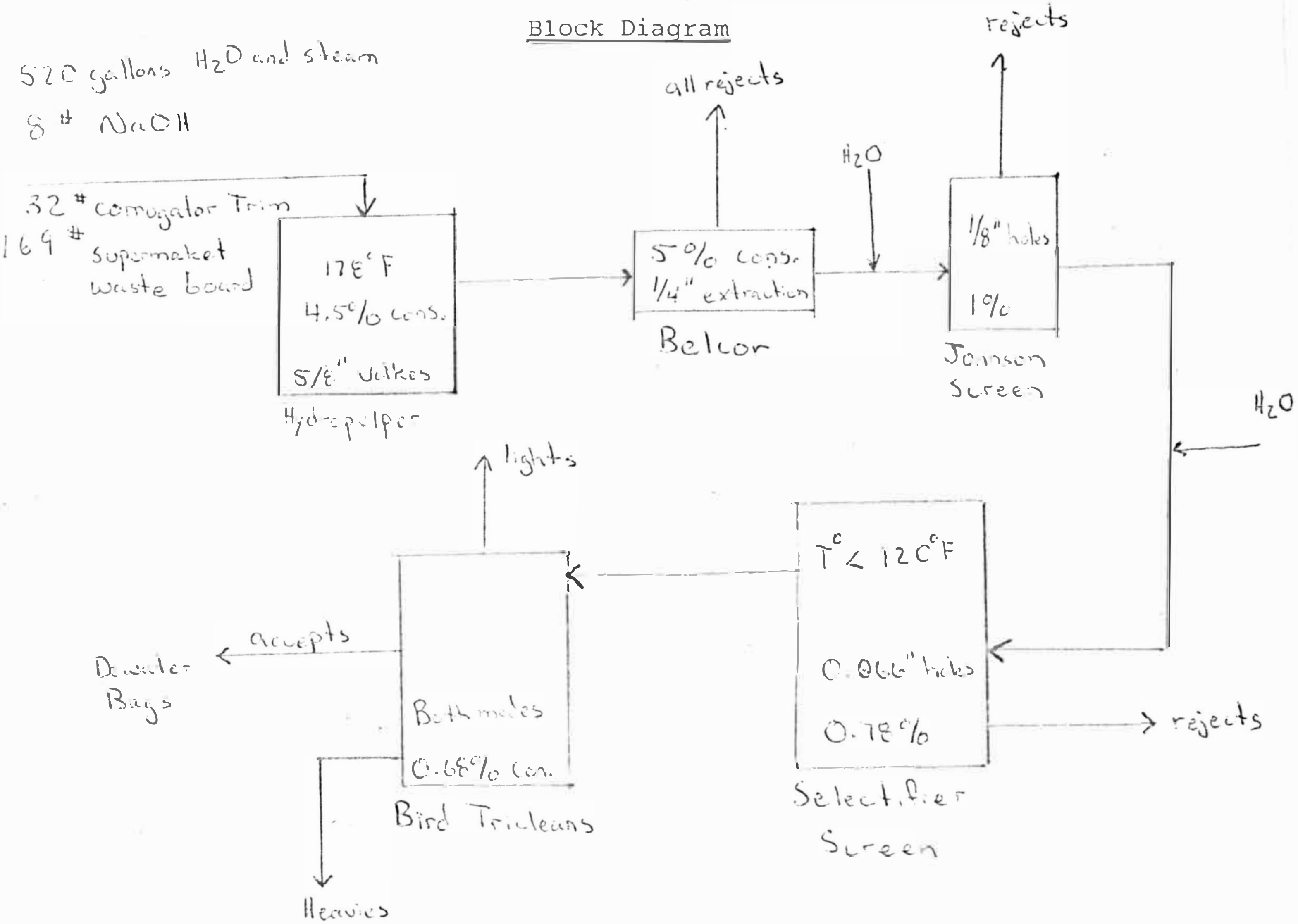
- Belcor (heavy)
- Jonnson (insignificant)

F. Coarse Fibers

- Selectifier
- Bird (heavies)

Appendix III

Block Diagram



APPENDIX 4

Physical Test Data (Comparison)

A) Speck Count (counts/in.^{2})

OCC	NCC
4	2
4	2
6	3
5	4
4	1
8	3
8	2
5	0
7	3
5	1
$\bar{5}.6$	$\bar{2}.1$

B) Burst (Mullen)

OCC	NCC
11	17
14	18.5
13.5	14
11.5	16
13	16.5
13	15
12	18
16	17.5
13	17
21	16
--	--
12.9	16.5

C) Tear Factor

OCC	NCC
70	71
72	77
76	72
80	73
71	77
77	74
77	81
82	80
73	76
76	70
--	--
75.4	75.1

D) Tensile

This test was very eradic and was not used for any evaluative purposes.