1. FUTURE PROSPECTS OF BAST FIBRES

How important is the development of multi-purpose applications of flax, hemp and other bast plants which are known for mankind for ages? What are the future prospects of those fibres and many by-products? Seeds, leaves, woody parts, waxes, oils, listed and characterized in table 1. 2. 3. 4. Their utilization scheme is presented in table 5.
The right answer is not to be found in the present inter fibre position of other than cotton natural cellulosic fibres. This position is rather negligible when compared to cotton and man-made fibres. (Fig. 3)

The FUTURE PROSPECTS of other than cotton natural cellulosic fibres: flax / hemp / jute / ramie / kenaf, also pineapple, sisal and coir are clearly visible when some of the most important factors of the FUTURE are considered such as:

- the growth of population
- social safety: urgent need of economical growth of rural areas
- future clothing and food demand
- raw material resources for polymers
- environment safety: urgent need of forests preservation

The GROWTH of POPULATION, shown in Fig. 4 indicates that population will reach twice today's level in the year 2050, ca 11 milliard.

Social safety in conditions of demographic explosion is critical. The exodus from pure rural areas results in slums around big metropolises world-wide. The problem is recognized but far from being solved.
Bast fibrous plants as a source of raw materials for diversified areas of application

According to F.A.O. and our own experiences THE DEVELOPMENT of all the other than COTTON natural cellulosic fibres CAN RISE THE ECONOMY OF RURAL AREAS AROUND THE WORLD.

All further factors: future clothing and food demands, the situation in the raw-material resources for polymers as well as the urgent need of environment/forest resource protection stress the future potential of natural, cellulosic (other than cotton) fibres.

Clothing/FIBRE DEMAND

The demand for fibres for clothing is expected to rise up to 130 million ton/year in the year 2050. (Fig. 5)

Within that demand the comfort providing fibres are expected at the level of ca 38 mil. ton/year. The main comfort providing fibres (mainly via hydrophilic properties) are at present the cotton and man-made cellulosic fibres. It is well known that cotton cannot be grown at a rate sufficient to satisfy the growing world market due to the following: namely

- it is grown in the geographical zone of highest demographic explosion where the competition of food crops is highest too
- there are limits in the yields even when transgenic cottons are concerned
- the areas of cotton mono-culture have turned into internationally recognized ecological disaster, for example in the area of Aral Sea the fishing industry and biological balance have been destroyed

Thus it is supposed that cotton will reach the level of production between 21-22 mil./ton/year and there are suggestions that:

"It will be easier to find ca 18-19 mil. ton of extra dissolving pulp than 18-19 mil. ton of extra cotton."

But will there be enough pulp?

The demand for pulp is expected to rise up to 480 mil. ton in the year 2010 from current level 270
Bast fibrous plants as a source of raw materials for diversified areas of application

mil. ton/year.

That demand makes the SITUATION OF FORESTS WORLD-WIDE CRITICAL, and stress the importance of other than cotton cellulosic fibres: FLAX, HEMP, JUTE, SISAL, KENAF, even PINEAPPLE and others.

ALL THESE FIBRE PLANTS CAN BOTH:

- COVER THE GAP IN DEMAND FOR COMFORT PROVIDING, HYDROPHILIC FIBRES - mainly thanks to the BRAND-NEW RESEARCH and DEVELOPMENT - much of it being done UNDER F.A.O. AUSPICIES.
- BE the RAW-MATERIAL FOR PULP PRODUCTION - (like jute used at SOUTH INDIA INDUSTRIES for VISCOS) for multi-purpose applications: fibres, papers, currency, tools, toys, furniture, sport-household and other many goods.
ALARM MUST BE RAISED ALL OVER THE WORLD TO STOP THE DEVASTATION OF TIMBER RESOURCES AND TO DEVELOP CELLULOSIC NATURAL FIBRES - other than cotton - AS COMFORT PROVIDING FIBRES and SUBSTITUTES for PULP in ENDLESS END-USES.

NATURAL, CELLULOSIC FIBRES (other than cotton) PRODUCED IN THE MOST ECONOMICAL AND ECOLOGICAL WAY IN THE FIELDS can also:

- RISE the ECONOMY of RURAL AREAS WORLD-WIDE. Even if it would be the only advantage of fibre plants, they SHOULD BE PROMOTED by
  o governments
  o mass media
  o science, social and political authorities in order to provide not only work places but also economical stability - so important for people today.
- STOP the FOOT of non-biodegradable WASTES which are mounting around metropolises or ..., are being shifted "somewhere to the neighbours". (I could tell you stories about what can be found every morning in our woods close to the Western border).
- BE USED in BIOCOMPOSITE MATERIALS PRODUCTION for multi-purpose applications (from tools and toys to aircrafts, buildings, machines and devices constructions).
- STOP the use of some CARCINOGENIC POLYMERIC MATERIALS in furnishing, floor coverings.
- A D D to the FOOD RESOURCES attractive:
  o brand-new antiscerotic and anticarcinogenic food additives - which are also helpful in kidney diseases or heart illnesses
  o antiscerotic and anticarcinogenic unsaturated fatty acids - which are the "MUST" for the "older half of population" to stop degeneration of human organisms
- A D D to the kingdom of COSMETICS and BODY-CARE new natural products on NATURAL OILS, PROTEINS, WAXES, FRAGRANCES BASES.

2. THE NEWEST ACHIEVEMENTS IN HEMP, FLAX AND OTHER BAST FIBRE PLANTS PRODUCTION AND PROCESSING
2.1. IN TEXTILES

the shift in flax/hemp/ramie and pineapple leaves fibre towards apparel sector

Until 1970’s flax/hemp were used mainly in household and technical textiles. The shift towards apparel sector has been made in case of linen in the 1980’s and in case of hemp it started in 1990’s (See Figure 6).

Among the brand new comfort clothing assortments are the following:

- **100% knitted dresses for women, children wear and polo-shirts**, ideal for all the occasions, specially in hot climate conditions
- **blended linen/hemp knitted apparel** for women, men and children for all seasons of the year and all kind of activities be that special occasions or everyday wear, sport, outdoor or active wear. All these knitted apparel do not crease during wearing and can be worn after washing without or with only little ironing. Comfort properties of knitted blended clothing are presented in the transparency
- **linen terry dry robes for babies and adults** developed lately on the basis of 100% and blended linen yarns are presented in the following transparencies. The water absorbency of these assortments is extremely high (Photos) and provides perfect comfort to the wearer
- **men’s and ladies, underwear** - made of linen and linen blends
- **linen and linen blended socks** which we consider the healthiest socks in the world due to the lowest known amount of water condensed in them when worn - what COPPELIUS test has shown (See Figure 7).
- **linen/hemp shoes**
- **new collections of woven apparel** made of linen/hemp and their blends, which provide special comfort, hygiene and UV-protection with no electrostatic load on them. The last two properties are very important as we are approaching the UV-illuminated world of 21st century, which will surround us with more and more automatic production lines, electronic devices, computers.
To be competitive in the markets the wash-and-wear properties of woven LINEN apparels must improve. Disadvantages inherent in natural cellulose fibres like creasing after wearing and shrinkage/stiffening after washing must be diminished.

The technological trials in using the liquid ammonia process for linen show the possibility of significant improvement of linen fabric performance in wearing.

During bleaching and liquid ammonia finishing the cellulose I in linen fabric changes into cellulose III.

The linen yarn structure changes during bleaching and the liquid ammonia process from a thin, smooth, and relatively dense yarn, typical of a wet spun product to that of a dry spun yarn with a higher specific volume.

The great disadvantages of linen: creasing while wearing, shrinkage and stiffening after washing can be significantly diminished by the use of liquid ammonia treatment. The wash and wear value 3.5-4.0 can be obtained, which shows the improved performance of linen fabric and clothing (See Figure 8).
2.2. TEXTILE COMPOSITES

Textile composites combine various layers of different desired properties in a fabric. The use of renewable cellulosic natural fibres as reinforcing fillers in fibre composites or adding a fibre blend in technical textile products is appealing because of the properties of the resultant composites and because of the environment viewpoint. The advantages of bio-fibres are low cost and a possibility of using renewable biodegradable raw materials in some technical textile products to a much greater extent than it is being done today.

For textile composites comprise many products of different type:

- fabrics coated with rubber, PVC, polyurethane.
- flocked - fibers are forced into a fabric substrate and held by an adhesive or electric bonding to make a pile figure or overall pile on fabric, used in apparel, upholstery and automotive fabrics.
- bonded fabric - two or more fabrics are made to adhere together by an adhesive or flame-foam process.
- laminated fabric used in apparel, shoes and industrial products,
- quilted - one or two fabrics and wadding, batting or foam are stitched together by sonic vibration (used in ski jackets, robes, comforters, quilts and upholstery),
- foam and fiber - fibres and polyurethane solutions are mixed together, cast on a drum, or forced through a slit to make fabric.

All above mentioned products could be produced on the base of lignocellulosic fibres.

NON-WOVENS

The problem of changes in traditional methods of textile product manufacture is an old one as it results from the 19th century patents taking into consideration a possibility of making textile products by using gluing agents without spinning, weaving or knitting.

The term non-woven has been in general use since 1955. Jute and other bast fibers are used to produce cheap blankets. Now needle looms produce blankets and floor coverings, filtration, horticultural and geotextile products.

Nowadays the most frequent raw material to manufacture non-woven textiles are viscose and natural lignocellulosic fibres.

SPUN BONDING

The idea of forming fabrics directly from spinneret (omitting cutting the tow), carding and bonding is fairly obvious in principle, but difficult in practice (commercial product was started by Du Pont in 1960). Now it is the fastest growing of all non-woven systems with end uses: carpet backing, furniture, roofing, nappy linings, protective clothing, packaging, and geotextiles.

This process is used to form fibres on a conveyor by blowing hot, low viscosity polymer from spinnerets or by dies, the air blast drafting the filaments in a somewhat irregular manner, often
producing very fine fibres.

2.3. FOOD AND FODDERS

Flax and hempseed are the next important products in flax/hemp cultivation. Both are perfect raw-
materials for agriculture-rooted industries such as:

- food industry
- natural pharmaceutical and cosmetics products
- paints and varnishes production.

Newly developed by the Institute of Natural Fibres are the following:

Food additives on linseed basis with high contents of lignans and unsaturated fatty acids (mainly
linolenic and linolic acids interconnecting 18 carbon atoms). The original length of these acids,
assisted by additional reaction in the liver, allow them to develop chemically more double bounded
carbons. The result is that each of us has a personnel communication system of about 13,000,000,000
interconnecting brain cells with extension to fingers, toes and all between.

About 50% of our brain, spinal cord and its branches are made up of essential fatty acids, particularly
linolenic acid. We literally think with these acids - they are the brain.

It is even supposed that if a pregnant mother has digested a proper amount of these fatty acids, she
probably (according to Larkin) has the best chance of delivering an intelligent child. As a result of the
newest research in this field, the school systems in the USA are encouraged to add linolenic
acid/linseed to the school lunch menus.

Hemp seed oil - its properties

Hemp seed's nutritional values are already well-documented as being an excellent source of balanced
Essential Fatty Acids, particularly omega-3, which is responsible for the proper growth and
functioning of the body. Hemp seed oil is one of the best delivery oils healing properties and
moisturizing.

Linseed-based food additives contain also lignans which seem to be capable of slowing the cell
division of some tumours. They are said to diminish or delay the onset of colon and breast cancer.
Lignans increase also the urine transport across the interface between the capillary and rental tubule.
This entity called the anti-platelet agglutinating characteristic of the lignans in flax seed is important
when progression and chronic nephritis and glomerulonephritis are to be stopped or delayed.

Dietary studies have also shown that four weeks on flax seed enriched bread can lower the
cholesterol levels between 7-9%, depending on the particular cholesterol fraction tested.

As arteriosclerosis is the nightmare of the older half of the population and the danger of cancer is
rising - there is no wonder that linseed-based food additives are real bestsellers.

The production of those developed by the INF (for example Bioflax®) is a significant part of the
income of my Institute and has a real potential to add to the value of flax crop and profits of farmers.

**Linseed proteins and mucilages** are used in such food products as ice creams, powdered sauces and soups, where they give the "smooth test" and viscosity.

Similar market potential have the linseed and hempseed based products in pharmaceutical and cosmetics area, where flax/hemp oils, waxes are applied and where the brand of "natural product" has become the keyword in the marketing success.

**Hemp leaves and seeds based fodder.** About 16% of biomass of the hemp crop are leaves and unripe seeds, treated as waste products in the deseeding process It has been found that:

- after simple operations like grinding and sifting of the above mentioned waste products, protein and vitamin rich fodder can be obtained (See Table 6).
- the aminoacids and carotenoids content of new fodder is similar to that of traditional fodders like alfa-alfa and clover green meal with lower level of cellulose in the case of hemp fodder (See Figure 9).

**Table 6 – The main compounds in different green fodders**

<table>
<thead>
<tr>
<th>Compound</th>
<th>alfalfa (acc. Domina)</th>
<th>alfalfa (acc. Magyari Deck)</th>
<th>white clover (acc. Domina)</th>
<th>hemp leaves (acc. Manys)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw - Protein (% of dry mass)</td>
<td>25.4</td>
<td>16.6</td>
<td>24.0</td>
<td>22.5</td>
</tr>
<tr>
<td>Caroten (mg/kg)</td>
<td>211.0</td>
<td>x</td>
<td>195.0</td>
<td>312.0</td>
</tr>
<tr>
<td>Cellulose (% of dry mass)</td>
<td>22.1</td>
<td>18.8</td>
<td>21.1</td>
<td>14.2</td>
</tr>
<tr>
<td>Fatty acids (% of dry mass)</td>
<td>x</td>
<td>2.8</td>
<td>x</td>
<td>17.2</td>
</tr>
<tr>
<td>Ash (% of dry mass)</td>
<td>9.0</td>
<td>12.3</td>
<td>7.1</td>
<td>4.6</td>
</tr>
</tbody>
</table>

X - not determined

**The content of aminoacids in hemp leaves and alfa-alfa dried green fodder**
(in g/16 g N)

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Dietary test on chickens and hens have shown that new hemp fodder can be used instead of alfalfa meal. It provides the same rates of growth of chickens and the same or even better rates of laying. Due to high carotenoids content the egg yolks of hens "on a hemp diet" are intensely yellow, which is considered a special benefit of the new fodder.

The above presented new-uses of flax and hemp-based products and the expected demand for these natural new products have raised the potential of both crops to a significant degree.

Thanks to the result of that para-research, flax/hemp fibre became associate products which can compete in the markets more easily, leaving part of their production costs to the new by-products of high value and in demand.

### 2.4. HEMP AS RAW MATERIAL FOR PULP PRODUCTION

The productivity of hemp biomass is very very high - 2-2.5-fold higher than can be produced from the same area of forest. The concentration of a-cellulose in the raw fibre (bast), reaches the level of 90% while the concentration of cellulose in softwood and hardwood ranges from 50-54%. This makes the hemp very attractive as a raw material for pulp and paper production. Recently, in the common research project coordinated by the INP, the environmentally safe technology for production of bleached hemp pulp, grown on the soil polluted by metallurgical industry form hemp, has been developed by the Pulp and Paper Institute in Łódz. The process has been developed and optimized in laboratory and part-technical scale and verified in commercial scale in continuous and non-continuous production flow. The pulps had target whiteness of 75-85% and their other parameters are presented in tables below. Their mechanical parameters meet requirements for long fiber pulps used for production of special printing paper. The heavy metal content in this paper meets requirements specified for wrapping paper for food.

#### Table 7 – Results of hemp fiber pulping

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Trial No</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount of added alkali</td>
<td>%</td>
<td></td>
<td>11.2</td>
<td>15.4</td>
<td>25.0</td>
<td>11.9</td>
<td>10.0</td>
</tr>
<tr>
<td>Alkali concentration in pulping liquor</td>
<td>g/dm³</td>
<td></td>
<td>18.7</td>
<td>26.7</td>
<td>41.4</td>
<td>19.8</td>
<td>16.7</td>
</tr>
<tr>
<td>Pulping temperature</td>
<td>°C</td>
<td></td>
<td>165</td>
<td>165</td>
<td>165</td>
<td>165</td>
<td>165</td>
</tr>
<tr>
<td>Pulping time</td>
<td>min</td>
<td></td>
<td>210</td>
<td>210</td>
<td>180</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Remains of alkali in liquor</td>
<td>g/dm³</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>8.1</td>
</tr>
<tr>
<td>Pulping efficiency</td>
<td>%</td>
<td></td>
<td>71.3</td>
<td>68.4</td>
<td>60.4</td>
<td>69.4</td>
<td>69.8</td>
</tr>
<tr>
<td>Kappa No</td>
<td></td>
<td></td>
<td>11.6</td>
<td>5.0</td>
<td>9.8</td>
<td>7.8</td>
<td>9.8</td>
</tr>
</tbody>
</table>
Table 8 – Some mechanical parameters of hemp bleached pulp beaten up to 50°SR

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
<th>Standard requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity</td>
<td>0.387</td>
<td>g/ccm</td>
<td>not standardized</td>
</tr>
<tr>
<td>Selfbreaking</td>
<td>3610</td>
<td>m</td>
<td>&gt;3500</td>
</tr>
<tr>
<td>Tenacity</td>
<td>2.0</td>
<td>%</td>
<td>not standardized</td>
</tr>
<tr>
<td>Tearing strength</td>
<td>2029</td>
<td>mN</td>
<td>667</td>
</tr>
</tbody>
</table>

Table 9 – Some mechanical parameters of hemp bleached pulp up to 80°SR

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
<th>Standard requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity</td>
<td>0.560</td>
<td>g/ccm</td>
<td>not standardized</td>
</tr>
<tr>
<td>Selfbreaking</td>
<td>3380</td>
<td>m</td>
<td>&gt;3500</td>
</tr>
<tr>
<td>Tenacity</td>
<td>2.0</td>
<td>%</td>
<td>not standardized</td>
</tr>
<tr>
<td>Tearing strength</td>
<td>1262</td>
<td>mN</td>
<td>667</td>
</tr>
</tbody>
</table>

In addition to cellulose, the main components of lignocellulosics are lignin, hemicelluloses, pentosans. The role of isolated lignin in the chemical industry grows incessantly. This by-product obtained during the manufacture of cellulose found its application, among others, as:

- a substitute for phenol-formaldehyde resins in composites,
- a natural polymer which can be modified to higher reactivity, and applied as follows:
  o agrochemicals,
  o for packaging, laminates, moisture barrier coatings, stiffening agent (boxboard),
  o friction materials (brakes, pads),
  o wood adhesives (plywood, waferboards, particleboards, fiberboards),
  o plastic moulding (automotive)
  o foundry mould binders
  o antioxidants.

A bright future in the cellulose industry opens before the new technology of pulping - the Alcell® process developed by Repap Enterprises Inc., Montréal, Canada. Experimentation using organic solvents to dissolve and separate wood components was first documented in the early 1990's. It was not until the early 1970's that the commercial use of organic solvents for wood pulping was seriously considered. The new method consisting in the treatment with ethanol at 195°C under the pressure of 29 bars appeared in 1990. In 1994 the production started in the first commercial Alcell® Mill in Miramichi, New Brunswick, Canada, of capacity of 144 thousand tons of pulp. The most important
advantages of the Alcell® process are its high yield of high-purity products and the absence of water (ethanol is recovered). Table 10 shows yields of different products depending on lignocellulosic raw material used.

<table>
<thead>
<tr>
<th>Product</th>
<th>Lignocellulosic Raw Materials</th>
<th>Bagasse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulp</td>
<td>47%</td>
<td>47%</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>Furfural</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Alcell® lignin</td>
<td>19%</td>
<td>14%</td>
</tr>
<tr>
<td>Xylose / Xylitol</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td>74%</td>
<td>71%</td>
</tr>
</tbody>
</table>

*Source: Anonymous, 1997*

In the cellulose industry the interest is growing in production of pulp and paper from agro-based lignocellulosic raw materials such as bagassa, bamboo, reeds, e.g., hemp, flax, abaca, sisal, grass, etc. The amount of pulp made of non-wood resources is still growing. In 1995 the capacity of non-wood pulp production was 6.8% in total, and the forecast for 1998 is about 11%. Figure 4 shows the world production of pulp and paper and the growing contribution of cellulose of agro-plant origin to the above production. Cellulose of the latter origin is of very high quality due to the fiber length and it is used mainly for manufacturing high quality paper (cigarette paper, securities, etc.). Further increase in the contribution of agro-plant cellulose is foreseen and it should reach about 15% in 2010 (the total production in the mentioned year is estimated to be about 480 million tons).

### 3. BIOCOMPOSITES BASED ON LIGNOCELLULOSICS AND MAN-MADE OR NATURAL POLYMERS

Biocomposites included a wide range of products of different applications, from construction or insulation panels made of wood pieces, particles and fibres, through special textiles (geotextiles and non-woven textiles) to plastic products based on polymers filled with lignocellulosic particles.

Lignocellulosic polymer composites are made mainly for the following purposes:

- to bond lignocellulosic particles with polymer glue (lignocellulosic boards based on the organic and inorganic binding materials);
- to reinforce polymeric material with lignocellulosic particles or fibers;
- to modify polymeric material, e.g. make it biodegradable;
- to modify lignocellulosic materials with polymers which results in the material improvement, e.g. limited permeability and better dimensional stability (wood, textiles), and higher resistance to biodegradation.
In Table 11 the most important lignocellulose-polymer biocomposites are listed. In many areas of application lignocellulosic raw materials should be modified to improve properties of a composite (e.g., adhesion, bio-resistance) and to enable successful production. Major lignocellulose - polymer composites were described below with a special emphasis on composites based on non-wood lignocellulosic materials.

**Table 11 – Biocomposites based on lignocellulosic raw materials and polymers**

<table>
<thead>
<tr>
<th>Type of Biocomposite</th>
<th>Raw Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lignocellulosic and other</td>
</tr>
<tr>
<td><strong>Structural composites:</strong></td>
<td></td>
</tr>
<tr>
<td>Glulam beams</td>
<td>wood boards and veneer, bamboo, bast fibres as tensile and compressive members</td>
</tr>
<tr>
<td>Laminated veneer lumber (LVL)</td>
<td>urea, melamine, phenol, isocyanate, resorcinol, vinyl polyacetalte</td>
</tr>
<tr>
<td>Parallel strand lumber (PSL)</td>
<td></td>
</tr>
<tr>
<td>Oriented strand lumber (OSL)</td>
<td></td>
</tr>
<tr>
<td><strong>Panels:</strong></td>
<td></td>
</tr>
<tr>
<td>Plywood</td>
<td>wood veneer, bamboo</td>
</tr>
<tr>
<td>COM-PLY*</td>
<td>wood veneer and lignocellulosic particles</td>
</tr>
<tr>
<td>Particleboards</td>
<td>urea, melamine, phenol, isocyanate, resorcinol.</td>
</tr>
<tr>
<td></td>
<td>vinyl polyacetalte.</td>
</tr>
<tr>
<td>Protein: casein, soybeans based; lignin and enzyme decomposing lignin</td>
<td></td>
</tr>
<tr>
<td>Medium density fiberboards (MDF)</td>
<td>lignocellulosic fibres</td>
</tr>
<tr>
<td>Oriented strand boards (OSB)</td>
<td>lignocellulosic strands</td>
</tr>
<tr>
<td>Insulating (thermal, acoustic, radiation)</td>
<td>vegetable stalks, lignocellulosic particles, wood veneer, paper</td>
</tr>
<tr>
<td>Lignocellulosic-mineral</td>
<td>wood wool, paper, lignocellulosic particles including waste paper pulp, mineral particles, e.g., vermiculite, microspheres, mineral wool, asbestos, glass fibers</td>
</tr>
<tr>
<td>Special functional (water-, fire-, bio-resistant)</td>
<td>+ fire retardants, fungicides, etc.</td>
</tr>
<tr>
<td><strong>Polymers filled or reinforced with lignocellulosics:</strong></td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Thermosetting polymers</th>
<th>lignocellulosic fibres including waste paper, saw dust, flour</th>
<th>urea, phenol, resorcin, isocyanate, epoxy resins, pure melamine,</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermoplastic polymers</td>
<td>wood saw dust, flour; short fibres, waste paper</td>
<td>PP, PE, PVC, PS, PA, LDPE</td>
</tr>
<tr>
<td>Natural polymer</td>
<td>lignocellulosic fibres including waste paper, saw dust, flour</td>
<td>natural rubber, casein, modified starch,</td>
</tr>
</tbody>
</table>

**Textiles:**

<table>
<thead>
<tr>
<th>Lignocellulosic and man-made fibers blends</th>
<th>cotton, flax, hemp, kenaf, roselia, ramie, jute, kapok, coir, pineapple, abaca, sisal, henequen</th>
<th>wool, silk, polyesters, polyamides, polyaramide, acryl, modacrylic, olefin lycra, man-made cellulose fibres: viscose, rayon</th>
</tr>
</thead>
<tbody>
<tr>
<td>textiles improved with polymers</td>
<td></td>
<td>starch, gelatin, urea, melamine resins (sizing), urea, melamine resins (wringling), condensation products of formaldehyde with urea, thiourea, guanidine, melamine, e.g. DMU, DMEU, DMDHEU (abrasion), reactive dyestuffs: triazine or pyrimidine or vinyl sulfonate derivatives (dyeing), metal (metallization),</td>
</tr>
<tr>
<td>textiles coated with polymers</td>
<td></td>
<td>PVC, polyurethane</td>
</tr>
<tr>
<td>Non-woven textiles including geotextiles</td>
<td>as above and wood wool, straw, bentonite, active carbon, vermiculite, silica</td>
<td>soya oil, rape oil</td>
</tr>
<tr>
<td>absorption chemotextiles including filters and sorbents</td>
<td></td>
<td>urea, phenol, resorcin, isocyanate, epoxy resins, ure melamine</td>
</tr>
<tr>
<td>Packaging</td>
<td>wood, wood wool, bamboo, paper including wastes</td>
<td>starch, silicates, urea resin, polyvinyl alcohol, lignin</td>
</tr>
</tbody>
</table>


### 3.1. PARTICLEBOARDS

The composition boards, including particleboards (extruded and platen pressed) and fiberboards, especially medium-density fiberboards (MDF) belong to the most abundant materials for construction, furniture, and interior decoration (wall and ceiling paneling). They are, however, very young materials produced and used by man. No one has been able to coin a good, descriptive term
acceptable to everyone for this relatively new branch of forest product industry.

The main lignocellulosic raw material used for particle and fiberboard industry is wood, but in many countries other agro-based residues, mentioned in above chapter, are successfully utilized. Annual plant wastes: flax and hemp shives, jute stalks, bagasse, reed stalks, cotton stalks, grass-like Miscanthus, vetiver roots, rape straw, oil flax straw, small grain straw, peanut husks, rice husks, grapevine stalks and palm stalks are cheap and valuable raw materials for lignocellulose board production. It is worth to add an important fact that production technology is similar to the lignocellulose board production from wood particles.

The specificity of board production from annual plant waste consists in raw material preparation, including purification and sorting of the material. Lignocellulose boards from annual plant wastes are characterized by a wide range of densities 300-750 kg/m³.

### Table 12 – Density Range of Particleboards from Different Annual Plant Residue

<table>
<thead>
<tr>
<th>Density (kg/m³)</th>
<th>Low Density</th>
<th>Medium Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>300</td>
<td>400</td>
</tr>
<tr>
<td>FLAX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HEMP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>JUTE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAGASSE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLAX + SAW DUST</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RAPE (canola)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*SOURCE: Kozlowski, Mieleniak and Przepiera 1994*

Physical and mechanical properties of particleboards from annual plant residues, manufactured according to the INP technology, are shown in Table 13. The table contains results obtained for 19 mm boards.
### Table 13 – Physical and mechanical properties of particleboards made of annual plant waste, produced according to the INF technology

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Flax Shives</th>
<th>Hemp Shives</th>
<th>Flax Shives + Saw Dust</th>
<th>Vetiver Roots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Particle-board</td>
<td>Three-Layer Particle-board</td>
<td>Three-Layer Particle-board</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td>600</td>
<td>600</td>
<td>600</td>
<td>650</td>
</tr>
<tr>
<td>Modulus of Rupture</td>
<td>MPa</td>
<td>16-18</td>
<td>15-16</td>
<td>17-18</td>
<td>17-18</td>
</tr>
<tr>
<td>Internal Bond</td>
<td>MPa</td>
<td>0.3-0.4</td>
<td>0.4-0.5</td>
<td>0.5-0.6</td>
<td>0.5-0.6</td>
</tr>
<tr>
<td>Swelling Thickness</td>
<td>%</td>
<td>15-20</td>
<td>16-18</td>
<td>20-25</td>
<td>8-10</td>
</tr>
<tr>
<td>after 24 h</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12-13</td>
</tr>
</tbody>
</table>

*Source: Kozlowski and Piotrowski 1987*

### 3.2. MEDIUM DENSITY FIBERBOARDS

Among modern materials are medium density fiberboards (MDF). They consist of wood fibers or annual plant fibers (82%), gluing amino resin (9%), paraffin (1%) and water (8%). The production of MDF from fibers of annual plants started in 1985, when the Sunds Defibrator company in Thailand developed the process of MDF manufacture from bagasse. Next factories based on bagasse were built in Pakistan, China and India. The production of straw-derived board materials is intended or has already begun in Great Britain and Canada. This fact points to a growing interest in the utilization of annual plants to make board materials for a variety of purposes. Annual renewability of plant raw materials and considerable annual cellulose increment, which is three times as high as annual ring of trees, give the reasons for this growing interest.

Crumbled hemp, flax and kenaf straw and shives also belong to excellent raw materials for the MDF production. The manufacture of MDF requires appropriate defibering of raw materials and preparation of fibrous mass of stable quality parameters. Modern thermodefibrators offered by leading companies in this field (particularly by Sunds Defibrator) enable to produce fibrous mass from any sort of wood and many annual plants. Quality of these fibers allows to make excellent MDF without a necessity of additional crumbling and classification of fibrous mass.

Medium density fiberboards compared to particleboards offer the following advantages:

- higher structural homogeneity,
- small roughness and closed surface,
- dimensional stability which is considerably higher than that of solid (uniform) wood and
Bast fibrous plants as a source of raw materials for diversified areas of application

Currently known wood-derived materials.
- capability of easy and uniform dyeing.
- bending strength and tensile strength which are higher than those of particleboards of the same density.

MDF can be also compared with solid wood. In the latter case, the advantages of MDF are seen in the following facts:
- drying and seasoning are unnecessary.
- fiber orientation is of no importance to frontal processing.
- varnishing of MDF can be done with equally good effect as in the case of wood.
- yield related to raw material is incomparably higher.

The above advantages have established MDF’s prominent position in the furniture making industry, where the application of medium density fiberboards is regularly growing. They are used particularly for purposes, where particleboards cannot be employed, e.g. for moulding of edges, varnishing of surfaces and edges, veneering of surfaces and edges with thin foil, etc. In Europe, the high rate of MDF production increase occurred in the late eighties and since then it regularly goes up. Properties of MDF based on flax, hemp and kenaf are shown in Table 14.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Flax</th>
<th>Hemp</th>
<th>Kenaf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td>785</td>
<td>880</td>
<td>817</td>
</tr>
<tr>
<td>Internal Bond</td>
<td>MPa</td>
<td>0.55</td>
<td>0.21-0.59</td>
<td>0.75</td>
</tr>
<tr>
<td>Modulus of Rupture</td>
<td>MPa</td>
<td>29.0-35.4</td>
<td>7.8-20.8</td>
<td>19.3</td>
</tr>
</tbody>
</table>


The use of whole stalks of bast materials can be necessary to provide sufficiently high performance characteristics for bast materials. The advantage of using the whole stalks is further strengthened by the fact that many countries have minimized the use of only flax shives as a furnish material. The whole stalks make a more promising option for furnish in the light of their improved performance characteristics. Such an approach must be competitive in terms of raw material cost, however, some cost may well be saved by removing the decortication step from the processing of the whole stalks.

3.3. INSULATING BOARDS

Annual plants residues such as rape straw, oil flax straw, small grain straw, reed and reed wastes are useful for the insulating board production, for instance according to the "Stramit" method.

The production makes a continuous process proceeding in the device which includes six machines. The production is a programmed, multifunctional cycle with an automatic temperature. The press is uniformly fed with raw materials, firmly compacted and pressed. At the same time the compacting mechanism moves gradually pressed material which is subsequently blended in a continuous way. The cardboard is fed from rolled bales which are placed over and under a board formed. Then the board is placed in a tunnel where it is dried and the glue bond is hardened.
Table 15 – Physical and mechanical properties of insulating boards depending on raw material used

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Rape Straw</th>
<th>Oil Flax Straw</th>
<th>Small Grains Straw</th>
<th>Unclassified Straw</th>
<th>Rees and Reed Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>mm</td>
<td>50 +/- 1.5</td>
<td>50 +/- 1.5</td>
<td>50 +/- 1.5</td>
<td>50 +/- 1.5</td>
<td>50 +/- 1.5</td>
</tr>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td>270</td>
<td>490</td>
<td>420</td>
<td>490</td>
<td>270</td>
</tr>
<tr>
<td>Moisture content</td>
<td>%</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Water absorption</td>
<td>%</td>
<td>220</td>
<td>190</td>
<td>210</td>
<td>195</td>
<td>200</td>
</tr>
<tr>
<td>Compression strength</td>
<td>MPa</td>
<td>0.80</td>
<td>1.15</td>
<td>1.00</td>
<td>1.15</td>
<td>0.08</td>
</tr>
<tr>
<td>Bending strength</td>
<td>MPa</td>
<td>1.20</td>
<td>1.60</td>
<td>1.35</td>
<td>1.60</td>
<td>1.20</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>W/mK</td>
<td>0.071</td>
<td>0.069</td>
<td>0.073</td>
<td>0.069</td>
<td>0.071</td>
</tr>
<tr>
<td>Acoustic insulation at frequencies:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 - 3200 Hz</td>
<td></td>
<td>-</td>
<td>20</td>
<td>19</td>
<td>20</td>
<td>-</td>
</tr>
<tr>
<td>3200 - 12800 Hz</td>
<td></td>
<td>-</td>
<td>22</td>
<td>21</td>
<td>22</td>
<td>-</td>
</tr>
</tbody>
</table>


Another type of lignocellulosic insulating boards are hemp insulating boards. Technology of manufacturing is very simple and equipment is cheap and not complicated. The raw material is hemp straw.

Studies carried out at the INF have shown that straw collected from the final stage of vegetation is the best. At this stage hemp stalks are sufficiently lignified and fully developed with empty pith hollow which contributes to a low value of thermal conductivity. The presence of nodes in the stalks results in the lack of free circulation of air in the stalks. At that time hemp is also the lightest. Bulk density of loose hemp straw with the moisture content of 15% is about 120 kg/m³.

From technological and economical point of view, long slender hemp of 6-12 mm in thickness and short, poorly ramified panicle is the best for the manufacture of insulating boards. Hemp with such parameters can be obtained by appropriate sowing time and control of sowing density. It was estimated that in the case of Polish varieties of monoecious hemp intended for board production, the density of sowing should be about 60 kg/ha at the drill spacing from 15 to 20 cm. The yield of unthreshed straw is about 10 t/ha.

An improvement in these type of boards from the point of view of water sorption as well as fire resistance can be performed by introducing silicates or the INF-developed fire retardant Fobos M-2L, which is a product of polycondensation of urea polyborate and polyphosphate with silicate.
The most important parameters of insulating materials are density, thermal conductivity and absorbability. In table 16 the properties of insulating boards made of plant materials were contrasted with those made of polymer foam.

Table 16 – Selected properties of insulating boards of plant origin in comparison with boards of polymer origin

<table>
<thead>
<tr>
<th>Type of Insulating Board</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Density kg/m³</td>
</tr>
<tr>
<td>Hemp</td>
<td>200</td>
</tr>
<tr>
<td>Reed</td>
<td>250</td>
</tr>
<tr>
<td>Hemp particleboard</td>
<td>400</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>15</td>
</tr>
<tr>
<td>Polyurethane</td>
<td>40</td>
</tr>
</tbody>
</table>

3.4. POLYMERS FILLED WITH LIGNOCELLULOSIC MATERIALS

It is a growing interest in composites prepared on the basis bast fibres and other agro-fibres as a filler and/or reinforcement of thermoplastic matrix. This problem was paid a lot of attention.

One of the limitations of lignocellulosic particles as board material is the necessity of processing at a relatively low temperature (up to about 200°C) in order to avoid lignocellulosic material decomposition and prevent from the evolution of volatile matter, because the latter results in a deterioration of composite properties kompozytu.

In some cases there is a possibility of a short-time heating at elevated temperatures. It results from the above that polymers which can be employed to manufacture such composites are limited to thermoplastics such as polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), and polystyrene (PS).

Lignocellulosic materials are added to polymers in the form of small particles, short fibres or flour. The main problem is to obtain good adhesion between the polar lignocellulosic particles or fibres and thermoplastic matrix. As it was in the case of reinforced fibres based on glass, carbon, aramid, etc., which are widely used nowadays, the commercial scale success was achieved when problems with interface layer were solved. In the case of bast fibres we took into consideration their high higrosopicity and very low adhesion to polymer, i.e. the fact that there is no good adhesion between hydrophobic matrix and hydrophilic cellulose fiber (e.g. adhesion between PP matrix and flax fiber). This difficulty was overcome by special finishing of bast fibers. Examples of such finishing are given below:
4. CONCLUSIONS

If I ever might have any objections that I too eagerly promoted natural bast fibres - being my beloved subject and passion - these objections vanished thanks to opinions of world recognized authorities in man-made fibres:

Prof. J. McIntyre - opening the International Symposium on Fibre Science and Technology - Yokohama - 1994 - and looking for future polymer resources for textile and non-textile applications, said:

"THE PREFERED LONG-TERM SOLUTION MAY BE TO SUPPLEMENT PLANT SOURCES by the use of AUTOTROPHIC BACTERIA or ALGAE which CAN USE CARBON DIOXIDE DIRECTLY TO SYNTHESISE POLYMERS."

Sir Julian Hill - (The real inventor of Nylon and the nearest coworker of Carother) in an interview in 1988 regretting the industrial choice of nylon and other non-biodegradable plastics instead of CELLULOSE BASED PRODUCTS, said that he thought that

"MANKIND WILL PERISH by BEING SMOTHERED in PLASTICS"

Prof. T.F.N. Johnson - in his perfect study pointed out the BIG WORLD DEMAND for COMFORT FIBRES and the gap between that demand and cotton production potential - shown in previous transparencies

Having as a background the above mentioned opinion of authorities in thermoplastic materials area, I would like to conclude:

1. The role of natural cellulosic fibres (other than cotton) is growing not only in science but also in economy. It is of special importance today for social and environmental questions.
2. The diversified BRAND-NEW uses for bast and allied fibres are growing simultaneously. These, mainly developed under the FAO auspices, are listened in the transparencies. The long list of new products based on bast and allied fibres and their by-products shows that these achievements meet the most important needs of mankind like o CLOTHING
3. In almost all above mentioned markets NEW PRODUCTS on bast fibre plants base bring the brands:

NATURAL-ECO-HEALTHY

which are the key to market success.

4. In textiles other than cotton cellulotic fibres will be in demand up to 18-19 mil./ton/year in the year 2050. It is expected that (excluding the high segments of market) they will be used in clothing in blends, mainly with polyester fibre.

5. Fibres like flax, hemp, jute, kenaf, ramie (also sisal, coir and the allied) should be used in fast growing quantities for pulps for multi-purpose uses:
   - paper
   - currency
   - packaging
   - medicine/hygiene products

TO STOP the FORESTS DEVASTATION AROUND the WORLD.

6. Bast and allied fibres will be used in wide spectrum of BIO-COMPOSITES MATERIALS to STOP the FLOOD of NON-BIODEGRADABLE WASTES.

7. The lignocellulosic raw materials can be combined with man-made or natural polymers giving a wide range of useful composites applied in textiles, particle- and other boards, pulp and related products, composite non-wovens, geotextiles, chemo- and thermosetting polymer-containing goods, filters, transportation, building industry and agriculture. In the future all lignocellulosic biocomposites have to be recyclable or biodegradable.

8. NEW PRODUCTS on BAST and ALLIED FIBRE PLANTS BASE for diversified uses will be developed to provide work places and raise the living standards of rural areas WORLD-WIDE promoting the growth of agriculture rooted industries. THESE should result in more sustainable development in social and environmental safety.

9. In developed countries flax and hemp cultivation can solve the problem of the extraction of heavy metals from polluted soils. Using this approach even heavy polluted areas can be recultivated.

5. REFERENCES

Environment and Development. Natural Fibres - Włókna Naturalne, Special Edition: Flax and
other Bast Plants Symposium, Poznan, Poland, pp. 85-91.
USG Process. Proceedings of the 4th International Inorganic-Bonded Wood and Fiber
Composite Materials Conference, Spokane, USA (A.A. Moslemi, Inorganic-Bonded Wood and
from Agro-Based Resources (R.M. Rowell, R.A. Young, J.K. Rowell ed.) chapter 8, pp. 269-
00.
Fibres in Automotive Components). Non-Textile Applications of Flax, Natural Fibres, special
edition, pp. 22-23.
9. Haber Z., 1995: Kenaf, a Promising New Material for Textile Industry. Natural Fibres -
Włókna Naturalne, Poznan, Poland, pp. 161-168.
4th International Inorganic-Bonded Wood and Fiber Composite Materials Conference,
Spokane, USA (A.A. Moslemi, Inorganic-Bonded Wood and Fiber Composite Materials), vol.
4, 1995, pp. 113-118.
11. Herrmann A.S., Hanselka K., 1995: Bio-Composite a New Material Based on Renewable Raw
Design. Natural Fibres - Włókna Naturalne, Special Edition: Flax and other Bast Plants
Symposium, Poznan, Poland, pp. 67-74.
Company, New York, USA.
15. Kołodziejczyk P., Koziowska J., "Recent Progress in Linseed Utilization in Health Food for
Human Nutrition", (1996)
Proceedings of the Congress on Academic and Technological Interchange on Textiles, Mexico
City.
Status Report. Proceedings of the Conference Bioresource Hemp '97, Frankfurt am Main,
Germany (in the press).
Particleboards Based on By-Products of Fibrous Plants and Other Materials. Proceedings of
Pacific Rim Bio-Based Composites Symposium, Rotorua, New Zealand, FRI Bulletin No. 177
pp. 320-325
European Regional Workshop on Flax. Rouen, France. pp. 409-418.
Fourth International Conference on Frontiers of Polymers and Advanced Materials, Cairo.

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9/26/02
54. Niedermaier F.P.: Technology, Engineering and Machinery for Manufacturing of Panel Board
BAST FIBROUS PLANTS AS A SOURCE OF RAW MATERIALS FOR DIVERSIFIED AREAS OF APPLICATION

Prof. Dr. Ryszard Kozlowski

ABSTRACT
Flax, hemp and other fibrous plants, which have been used for more than 6,000 years, are and will be future of raw materials not only for the textile industry but for modern environmentally friendly composites used in different areas of application, building materials, particle board, isolation board, food, feed and nourishment, friendly cosmetics, medicine and source of raw materials for other biopolymers and biomaterials.

They do not cause any disturbing effect on the ecosystem, they can grow in different climate zones and they recycle the carbon dioxide in our Earth.

Rejuvenation that plants for Europe is very important, because they give better agricultural balance in this region, they grow up their own natural areas and they will reduce a deficit of cellulose raw materials for next millennium when the population will be multiplied up to about 11.6 billion people. In this presentation all aspects of these plants' future development are being discussed.