Enzymes as natural catalysts reduce the energy and wood fiber required to manufacture high quality paper and paperboard

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Maximyze® enzymes: natural catalysts to reduce energy and decrease the amount of wood fiber needed to manufacture high quality paper and paperboard

Milestone - The most recent milestone is a successful commercial application at a pulp and paper manufacturer in the northwestern USA, completed in 2011. Maximyze technology was added to bleached pulp used in production of paperboard for food containers. Machine speed was increased by 20 feet/minute, which translates into a 2 percent increase in production. At the same time the level of mechanical refining required was reduced about 40 percent, a substantial energy savings for the mill. The most significant benefit is that the basis weight of the paper could be reduced by 3 pounds/1000 square feet while maintaining all quality specifications. This allows a reduction of at least 1 percent in the amount of wood pulp required in this machine, reducing the annual amount of wood needed to produce these food containers by at least 5000 tons.

Eligibility - This technology is not eligible for the small business category or academic category.

Focus area - This technology is in the focus area (3), design of greener chemicals.

U.S. Technology - All the basic research to develop this technology occurred in the United States at the corporate Research & Development laboratories of Buckman International in Memphis, Tennessee. Samples of pulp and paper were obtained from various wood species and pulp types, and testing conducted at this site to determine the most effective enzymes.

ABSTRACT - This nominated Maximyze technology consists of certain new enzymes and combinations of enzymes, not previously available on a commercial basis, which allow for the production of paper and paperboard with improved strength and quality. This innovation provides a completely new way to increase paper strength. Previously, to improve paper strength the papermaker was limited to adding different pulps (costly), or increasing mechanical treatment (requires significant energy expenditure), or using of various chemical additives (many derived from non-renewable resources). The new enzymes are derived from renewable resources and produced by fermentations, not by typical chemical reaction methods.

Sheet strength is an important quality in paper; Maximyze gives improved strength and so the weight of the paper product can be reduced or wood fiber can be replaced with mineral filler. Maximyze allows more efficient production of paper and makes it possible to use more recycled paper. With increased strength, less energy is required in the process, and paper quality can be improved.

The first commercial application on production of fine paper began within the past two years, and since then this technology has been expanded, and is now being applied successfully on many paper mills in the United States and beyond.

We will illustrate real-world application of this technology, and show how it is less toxic than current alternatives, and safer to handle, manufacture, transport, and use than the current chemistries. It replaces products that are more toxic to our environment. These and other benefits are produced by Maximyze -- biotechnology that comes from renewable resources, is safe to use, and is itself completely recyclable.

Background of the New Technology --- The technology that is the subject of this application has the trade name Maximyze®. The name Maximyze refers to group of several products sold by Buckman that are comprised of carefully selected and designed enzymes that are *cellulase* enzymes, derived from natural sources. Maximyze enzymes are now being successfully used in manufacture of fine papers and food packaging to provide many benefits, including:

- a reduction in the amount of wood pulp needed to produce the paper or paperboard
- an improvement in the quality of the paper or paperboard
- an increase in production rates
- a reduction in energy requirements in manufacture
- an increase in the amount of recycled paper that can be used in the product

Cellulases in nature hydrolyze and recycle cellulose, which is the most common organic compound on earth. In natural processes cellulose is completely degraded. Presently this class of enzyme is the subject of intense research in the conversion of biomass to energy. Obviously in paper manufacture the goal is to modify the cellulose fiber, not destroy it. The key is to select and properly apply the specific enzymes from this group to develop the desired results.

The term "cellulase" in fact encompasses a group of enzymes that catalyze the hydrolysis of cellulose. *Endoglucanases* break internal bonds to disrupt the crystalline structure of cellulose, and expose individual cellulose chains. *Exocellulases* separate pieces of two to four sugar monomers from those exposed chains. *Cellobiases* (also called β-glucosidases) hydrolyze those fragments into glucose. Together these completely recycle cellulose.

The discovery of enzymes that act on cellulose is not new. Commercial application of cellulase enzymes is also not novel - these are commonly used in laundry products. Cellulases are used also in the process of converting biomass to ethanol (again a complete destruction of the cellulose molecule, to produce ethanol). The special discovery with Maximyze is (1) learning which cellulase-type enzymes to select and (2) how to carefully implement that technology to improve papermaking. Details on several successful applications will be given below illustrating how the Maximyze technology has been utilized to improve sustainability in the paper industry.

Cellulose fibers are the basic structural material of paper. The properties of a sheet of paper are created by bonding between cellulose fibers. We have determined that using selected cellulase enzymes to modify the surface of the cellulose fiber improves the inter-fiber bonding, increasing the strength of the paper. In the past several years this technology has been commercialized and is used in many paper manufacturing plants.

Paper products are essential components of modern life, important for many things like communication and packaging. The paper and packaging industry is an important part of the U.S. economy, with product sales of $115 billion a year and employment of about 400,000 people. More than 95 percent of all products in the United States are shipped in corrugated boxes. One major advantage of paper is that its basic raw material (trees) is renewable; the paper industry has a strong commitment to sustainability in maintaining forest lands. Yet there is also a major commitment to recycling: 63.5 percent of paper consumed in the U.S. is recovered (2010 statistics) and recycled to be reused back in the manufacture of paper and paperboard.

Commitment to stewardship and sustainability demands continuous improvement. It requires dedication to more efficient use of resources like energy and raw materials, and to increasing use of materials that minimize the use of non-renewable resources, and also to maximize safety and preserving our environment. The Maximyze technology promotes these benefits.

Maximyze has already provided a number of examples of such returns to the paper industry. This technology fits into Focus Area (3), the design of greener chemicals. Enzymes are the ideal green substance, manufactured from renewable resources by microorganisms, and – as proteins – easily broken down to non-toxic materials. Enzymes improve the use of natural resources by substituting substances made from renewable resources for chemicals coming primarily from petrochemical feedstock. Enzymes catalyze limited specific reactions and therefore are unlikely to have unexpected effects in industrial uses or in health or environmental issues.

Only in the past decade has there been a substantial effort to utilize enzymes in papermaking. A recent example is the use of an enzyme-based product to facilitate the use of recovered paper products. (See "A New Enzyme Technology To Improve Paper Recycling," awarded a Presidential Green Chemistry Challenge Award in 2004.)

Benefits - Here is a summary of benefits of this technology in real-world applications (details follow in specific case studies given later in this document).

- First, improving the strength of a paper product allows reducing the amount of cellulose fiber required to attain the required specifications. The *basis weight* of the paper can be reduced, so less fiber (i.e. fewer trees) is required to create the same product. In addition to the environmental benefit, the primary cost for manufacture of a paper product is the fiber raw material; so this provides a significant economic benefit to the manufacturer.

- Another economic and environmental benefit relates to transport of the end paper product: a lighter weight paper or board translates into reduced resources required for shipping.

- One problem with recycled paper is that there is a loss of strength when paper is made from recycled fiber. The enzymatic action of Maximyze products improves the strength of paper made from recycled fibers, and allows a papermaker to use more recovered paper.

- Next, less refining is required. *Refining* is a mechanical treatment unique to paper making. This is an energy-intensive process that collapses the fiber and modifies its surface to improve inter-fiber bonding. In Maximyze applications, modifying fibers by enzymatic treatment allows significant reduction in energy requirements for refining, up to complete elimination.

- The combination of enzyme action and reduced refining results in fewer fiber fragments and fines, which improves water removal in the papermaking process so less steam is required to dry the paper on the paper machine.

- Often addition of softwood fiber is required to maintain the strength needed in paper. Maximyze allows an increase in the proportion of hardwood fiber. To the papermaker this reduces cost (softwood fibers have a higher cost). We can regard the use of hardwoods for pulp to have fewer deleterious environmental effects. For example, *Eucalyptus* plantations supply cellulose fiber much more quickly, requiring less forest land compared to softwoods.

- Most paper is recycled, but the use of lighter-weight paper might have an effect of reducing volumes in landfills.

- This focus area involves designing and implementing chemical products that are less hazardous than the products or technologies they replace. Maximyze can replace or reduce the use of current chemical products used for improving paper strength. These include synthetic chemicals like glyoxalated polyacrylamides (g-PAM) and polyacrylamide copolymers which require the use of more toxic materials sourced at least in part from petroleum-based raw materials. Related to this is the incredible efficiency of enzymes. One enzyme can catalyze as many as 40 million conversions in a second, so a very small amount of Maximyze is required. Table 1 compares the enzymatic technology with conventional g-PAM chemistry, showing that the amount of additive required with the enzyme is a small fraction of the g-PAM required.

Table 1 – Maximyze compared to a conventional product for paper strength

	Use rate (actives basis)	Daily required amount on 500 ton/day machine	Source	Aquatic toxicity (96-hr LD50 freshwater fish)
g-PAM	2 pounds/ton	1000 pounds	Petroleum feedstock	20 ppm
Maximyze	0.02 pounds/ton	10 pounds	Fermentation - renewable materials	700 ppm

Note: we are replacing *more toxic* materials which are derived from *non-renewable* resources with *biodegradable* products made from *renewable* sources and used at much *lower addition* rates.

Enzymes are made using renewable raw materials in a fermentation process. This is a non-hazardous process, much safer than vinyl addition polymerizations used to make the conventional materials. For the conventional product, reactive monomers (one a carcinogen) are blended at 85°C and initiators added to start the chemical reaction. Care must be taken to make certain the reaction is controlled. In the fermentation, however, an organism (yeast or bacteria) is developed which secretes the desired enzyme. To manufacture the industrial enzyme, the vessel is sterilized with steam, and the water is added along with the correct substrate for the organism to create the enzyme (for example, molasses or soy flour). Buffers are added to control pH, air is bubbled in, and the temperature is brought to about 37°C. Separately a population of the organisms is grown up, then added to the vessel. A typical fermentation process takes 2-5 days to complete. The cells are then removed by filtration and some preservatives added to the enzyme preparation. Table 2 gives a brief comparison of the two manufacturing processes.

Table 2 – Manufacturing information

	raw materials	temperature required	carcinogenic raw materials used?
g-PAM	3 reactive monomers, initiators, acid, caustic	80-85°C	Yes
Maximyze	selected organism produces enzyme; natural nutrients and buffers required	35-40°C	No

Enzymes are inherently much safer with regard to human health and the environment (e.g. in the case of a spill). Cellulases have been used in commerce for many years now in the textile industry and in home laundry detergents with no serious health issues.

One example of the environmental factor is shown in Table 1: the aquatic toxicity of the enzyme-based product is an order of magnitude lower. As natural proteins, in the final segment of the product life cycle enzymes are also inherently safer: processes exist in nature to recycle enzymes and they are completely biodegradable.

Benefits in a commercial application – (1) Reducing the amount of cellulose fiber required to make a quality paper product. With Maximyze, in many cases the *basis weight* of the paper product can be reduced, so less fiber (i.e. fewer trees) is required to create the same product. Example: in a paper manufacturing operation in the northwestern USA, Maximyze was added to bleached pulp. This pulp was subsequently used in the production of bleached paperboard for food packaging. As a result, it was possible to increase the production speed by 20 feet/minute, which translates into a 2 percent increase in production. 80 percent of the product is sold to customers in Asia, increasing the level of exports for this mill. At the same time the degree of mechanical refining required was reduced about 40 percent, a significant energy savings for the mill. The most significant benefit was that the basis weight of the paper could be reduced by 3 pounds/1000 square feet while maintaining all other quality specifications. The typical basis weight for food packaging produced at this mill is 150-250 pounds/1000 square feet. This allowed a reduction of at least 1 percent in the amount of wood pulp required in this machine (output is about 700 tons/day), reducing the annual amount of pulp needed to produce these food containers by at least 2500 tons. Using a conservative estimate that it requires 10 trees to produce one ton of paper, we can calculate that rate this reduces by 25,000 the number of trees required to produce food packaging on this one machine. Trees are a renewable resource, but the use of this technology can significantly reduce pressure on our forest resources. This represents improved sustainability and a substantial reduction in carbon footprint.

(2) Reduced resources required for shipping by manufacture of a lighter weight paper package translates into a lower carbon footprint. Research recently reported by M-REAL describes how the carbon footprint of specific brand of paperboard is reduced as its basis weight is decreased. Making a food container stronger to allow a 15% reduction in its weight equates to reducing its carbon footprint by 18 percent. This study assessed energy used in all stages, including harvesting the wood, manufacture and transport of the food package. Use of the Maximyze technology can make an important contribution to this effort.

(3) Usage of more recovered paper - one problem with recycling paper is that there is a loss of strength when paper is made from recycled fiber. The enzymatic action from Maximyze improves the strength of a sheet made from recycled fibers, allowing the use of less forest resources. Example: Maximyze was used at a mill producing paper towel from a combination of recycled paper and virgin softwood fiber. Virgin softwood fiber was used only to give the towel the strength needed. For many reasons, recycled fiber would be preferred. In addition to the "green" reasons for its use, the cost of recycled fiber was lower. When the stock was treated with Maximyze it was possible to eliminate the softwood pulp completely. The sheet strength in fact increased, due to the enzymatic action on the recycled fiber. Corollary benefits were a 14% reduction in energy used for refining, and improved drainage (which reduces the requirement for steam, another energy savings).

(4) Reduction in energy requirements for refining - Refining is a mechanical treatment unique to papermaking. This energy-intensive process collapses the fiber and modifies its surface to improve inter-fiber bonding. The wood fiber originally is a hollow tube with a fairly smooth surface; after refining it is collapsed and has fibrils extending from the surface. The result is a much higher surface area for hydrogen bonding, which is the basic source of strength in a sheet of paper. Refer to Figure 1 for an illustration of this effect. Figure 1a illustrates how a paper sheet is formed. Hydrogen bonds occur where one fiber contacts another. *Fibrils* that in the refining process are partially separated from the fiber increase surface area for bonding and so increase sheet strength. Arrows in the photomicrographs point to fibrils.

Figure 1b illustrates the effect of treating the fiber with Maximyze prior to the same amount of refining. Note the substantial increase in the number of fibrils, binding the fibers to each other. The enzymes modify the cellulose polymers in the fiber and the same level of mechanical treatment produces much more surface area for bonding.

Figure 1 – Bonding of Cellulose Fibers (500x)

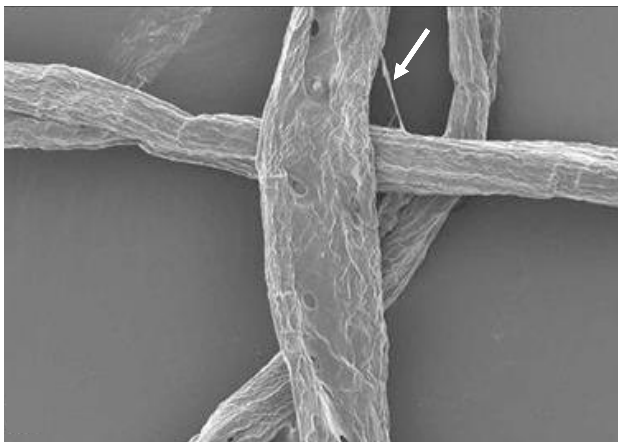

Fig. 1a - Refined, no enzyme treatment

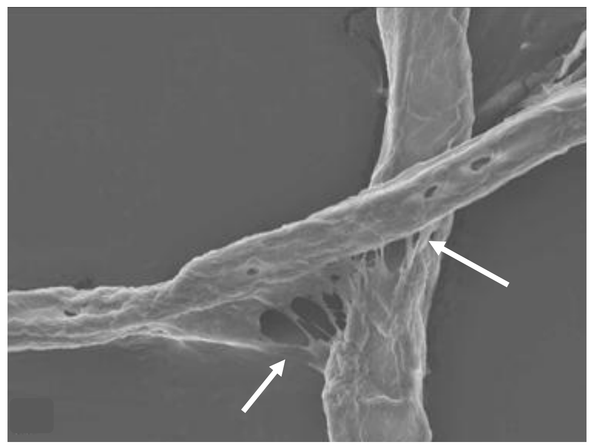

Fig. 1b - treated with Maximyze, then refined

The untreated fibers (Figure 1a) display minimal amounts of fibrillation that contribute to inter-fiber bonding. There are limited examples of fibrils interconnecting adjacent fibers. With Maximyze alternatively (Figure 1b), a stronger sheet can be made. Or paper with equal strength can be produced with reduced mechanical refining. This benefit has been shown in numerous commercial applications.

Commercial examples: Example 1 – Recently, Maximyze was utilized in the production of coated fine paper (mill in northern USA, using maple). The production rate could be increased 10 percent and sheet strength was maintained with 77 percent less refining energy. In addition to other benefits, the energy savings alone totaled to a cost savings of $1.70/ton of paper produced.

Example 2 – The following example shows many of the numerous benefits gained from the use of this new technology. This particular paper machine produces about 125 tons/day of copy and offset grades of paper. In order to reach quality specifications (a sheet of paper with very low porosity) it is necessary to do extensive refining of the fibers. This (1) requires significant energy input and (2) makes it difficult to dry the sheet. So machine speed and productivity is reduced.

Maximyze was used with the goal of reducing the amount of refining and improving (i.e. reducing) sheet porosity. The results:

- Sheet porosity was reduced – the quality goal was reached
- Improved drainage allowed machine speed increase from 1510-1565 feet/min (+3.6%)
- Reduced refining energy 120 KWH/ton
- Reduced softwood fiber used (cost savings)
- Excellent machine runnability (no lost production time)
- Reduced steam consumption 15%
- Mineral filler increased from 23 to 24 percent of sheet (1% reduction in fiber demand)

The sustainability of this manufacturing plant is improved: reduced energy is used per ton paper (less steam due to improved drainage and production rate and less electricity for refining). There is a reduced carbon footprint as well: an increased portion of filler in the sheet means a reduced fiber demand. (The filler used is calcium carbonate produced on site.) In this mill reduced (purchased) softwood usage means more hardwood usage (produced onsite), also reducing the carbon footprint. At this mill Maximyze has been running on all production since January 2010. Table 3 gives a summary of the economic effects of some of these benefits.

Table 3 – Economic and Environmental Benefits of Maximyze

Parameter	Before	With Maximyze	Benefit ($/ton)
tons of steam per ton paper (@$16/ton of steam)	2.23	1.86	$5.90
average production (ton/day) incremental value = $100/ton	125.8	147.6	$15.60
Total Filler (%) @ $5 benefit/1% filler replacing fiber in sheet	23	24	$5.00
Total Benefits (US$/ton)			$26.50
Estimated total savings (US$/day)			$3,200
Estimated total savings (US$/year)			$1,058,000

Sustainability improved: reduced energy used per ton paper (less steam due to improved drainage and production rate and less electricity for refining). *Reduced carbon footprint*: increased filler in sheet translates into a reduced fiber demand; reduced softwood usage (purchased) means more hardwood usage (produced onsite).

SUMMARY: Maximyze is now widely used in paper manufacture. This technology makes it possible to produce high quality paper for writing and for packaging using less fiber, reducing the need for trees to supply the pulp. Other benefits from this technology are energy savings, reduced used of products made from non-renewable resources, and more utilization of recycled paper. Enzymes are extremely efficient tools for replacing conventional chemicals in certain applications. Maximyze is an example of new biotechnology, coming from renewable resources, safe to use, completely recyclable, and providing economic benefits to an important US industry.