Food from Newspaper

FOOD FROM NEWSPAPER*

U. S. Army Natick Laboratories
Pollution Abatement Division
Food Science Laboratory
Natick, MA 01760

Cellulose is the most abundant organic material which can be used as a source of food, fuel and chemicals. The net world-wide production of cellulose is estimated at one hundred billion tons per year. This is approximately 150 lbs. of cellulose per day for each and every one of the earth's 3.9 billion people. The energy to produce this vast quantity of cellulose comes from the sun and is fixed by photosynthesis.

The energy from the sun, available over the United States alone is between 4 and 4 X 10^{19} BTU/Yr. This is approximately 600 times the annual energy consumption of the United States. Prior to 1900, our principal sources of energy were the wind, wood, water power and coal. During this century man has been relying very heavily on fossil fuels originally produced by photosynthesis. Energy consumption in the United States has been estimated at 7 to 8 X 10^{16} BTU/Yr. This total energy is obtained primarily from oil (43%), gas (35%), and coal (19%). Comparison of the annual energy consumption in 1873 (4.2 X 10^{15} BTU/Yr) with that of today, shows that current demand is approximately seventeen to twenty times more than what was used in 1873. This phenomenal growth in energy demand will be difficult if not impossible to support with current fuel reserves regardless of processing capabilities. By the year 2000, undoubtedly nuclear power will be a major source of energy; however, to achieve the ultimate goal of independence, man will have to harness effectively and economically the inexhaustible energy of the sun.

Since celluose is the only organic material that is annually replenishable in very large quantities, man must explore ways to utilize it as a source of energy, food, or chemicals. The utilization of this resource is greatly simplified if cellulose is first hydrolyzed to its monomer glucose as shown in Figure 1. Once glucose is formed, it can be used as a food consumable by man and animals, it can be converted to chemical materials, it can be converted microbially into single cell proteins, or it can be fermented to clean burning fuel (ethanol, solvents, acetone), and other chemicals. It is estimated that from one ton of waste paper, a 1/2 ton of glucose can be produced which can be fermented to produce 68 gallons of ethanol.

Conversion of cellulose to glucose can be done by either acid hydrolysis or by enzymatic processes. There are advantages in the use of enzymes to hydrolyze cellulose instead of acid. When using acid, expensive corrosion-proof equipment is required. Moreover the crystalline structure of

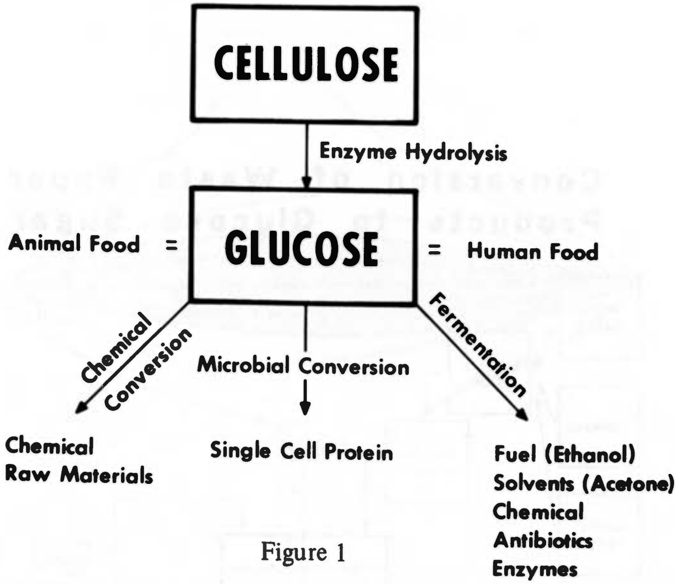

Figure 1

cellulose makes it very resistant to acid so that the temperature and acid concentration needed to achieve hydrolysis also cause decomposition of the resulting sugars. Consequently, the process must be balanced so that the rate of hydrolysis must be sufficiently high to compensate for the decomposition of the desired products. Glucose yields of approximately 50% of the weight of cellulose used have been obtained. Waste cellulose invariably contains impurities which will react with the acid thereby producing other unwanted by-products and reversion compounds.

The enzyme on the other hand is specific for cellulose and does not react with impurities that may be present in the waste. Moreover reaction takes place at moderate conditions so that the glucose yield is 111% of the weight of cellulose used. The glucose syrups produced enzymatically are fairly pure and constant in composition.

The U.S. Army Natick Laboratories are developing an enzymatic process, which is based on the use of the cellulose derived from mutant strains of the fungus *Trichoderma viride* isolated and developed at the Natick Laboratories. A schematic diagram of this process is shown in Figure 2. The first step is the production of the enzyme. This is accomplished by growing the fungus *Trichoderma viride* in a culture medium containing shredded cellulose and various nutrient salts. Following its growth, the fungus culture is filtered and the solids discarded. The clear straw colored filtrate is the enzyme solution

Conversion of Waste Paper Products to Glucose Sugar

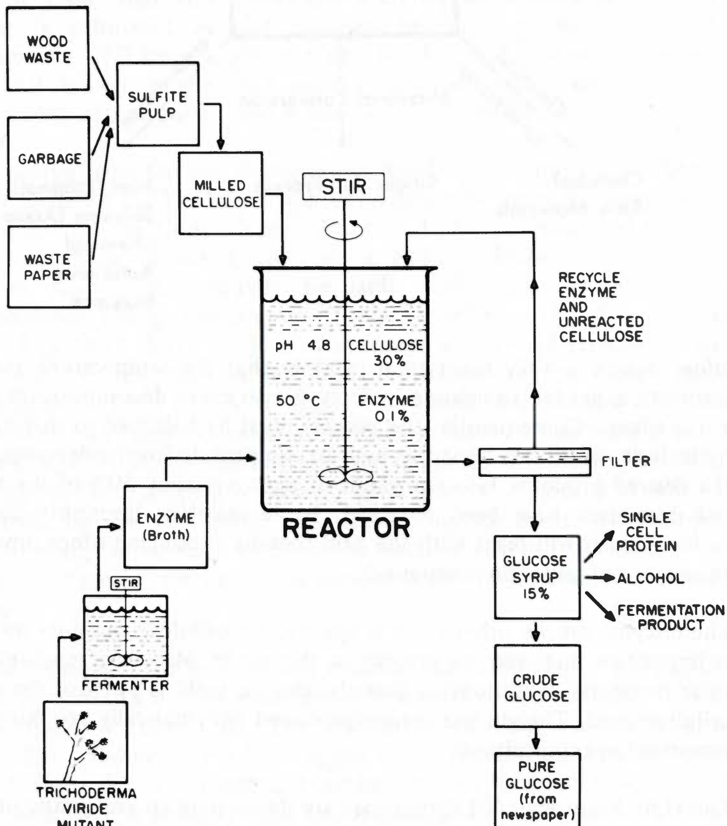

Figure 2

CELLULOSE STRUCTURE SHOWING CRYSTALLINE AND AMORPHOUS COMPONENTS

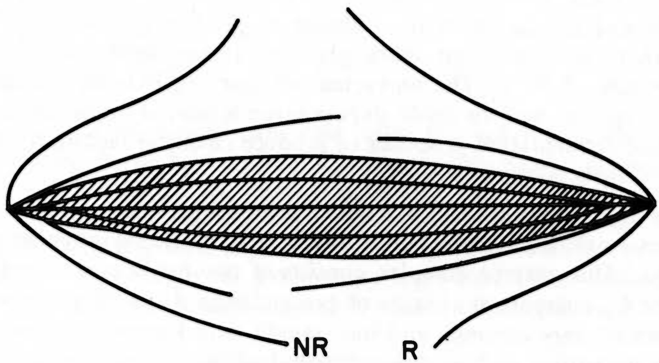

Figure 3

also developed mutant strains that produce 2 to 4 times as much cellulase as the wild strain. In this area Natick Laboratories believe that they have yet to reach the upper limit.

Recent improved experiments achieved with newspaper show that it is technically feasible to produce glucose syrups in good yield and at a fair rate from waste cellulose. Newspapers were selected as the model substrate since such waste is representative of cellulosic waste present in municipal trash.

Having proved that the process is technically feasible, the next step is an intensive pre-pilot plant study to optimize all variables and to obtain the engineering and economic data needed for the design of a demonstration plant.

Many U.S. chemical companies, pulp and paper mills, processors of agriculture products and various state and municipal governments have shown definitive interest in the exploitation of this process. Because of this interest, the U.S. Army Natick Laboratories are working very closely with several industrial firms to assure the transfer and translation of this new technology to a commercial scale as soon as practicable for the benefit of the nation and mankind.

*This article was rewritten from a release sent to the ISTJ from the Natick Laboratories. For further details concerning techniques and procedures write the Natick Laboratories and request the paper, "Enzymatic Hydrolysis of Cellulose Wastes to Glucose," by L. A. Spano, J. Medeiros, and M. Mandels.

that is used in a saccharification reactor. Prior to its introduction into the reactor, the enzyme broth is assayed for cellulase and its acidity adjusted to the pH or 4.8. Milled cellulose is then introduced into the enzyme solution and allowed to react with the cellulase to produce glucose sugar. You will note that saccharification takes place at atmospheric pressure and at a temperature of 50° C. The unreacted cellulose and enzyme is recycled back into the reactor, and the crude glucose syrup is filtered for use in chemical, or microbial fermentation processes to produce chemical feedstocks, single cell proteins, fuels, solvents, or other uses.

The key to this process is production of a high quality cellulase enzyme complex from *Trichoderma viride* capable of hydrolyzing insoluble crystalline cellulose. This enzyme complex consists of two major components, C_1 and C_x. The C_x component consists of exo andendo β , 1, 4, glucanases. These enzymes are very common and they rapidly attack amorphous cellulose or soluble derivatives such as carboxymethyl cellulose (CMC) producing glucose and cellobiose.

The C_1 is an enzyme required along with C_x for the hydrolysis of insoluble and particularly crystalline cellulose. The action of C_1 is not yet clear although it has been separated from C_x and it is a protein. The simplest explanation and the one held by E. T. Reese is that it is a prehydrolytic enzyme, i.e., it decrystallizes or hydrates cellulose chains so that C_x can act upon them.

Figure 3 graphically shows a crystalline portion of a fiber with close packed, hydrogen-bonded molecules. C_1 has acted on the surface of these to cleave the chain thereby setting free end-portions of the molecules, and permitting them to become fully hydrated. The C_x components are now able to catalyze the hydrolysis of these to glucose.

C_x enzymes are fairly common but C_1 enzymes are quite rare. The best source known is *Trichoderma viride*. When considering large scale hydrolysis of cellulose, C_1 is the limiting factor, consequently, it is essential to use cellulases containing both C_1 and C_x for effective saccharification. Most commercial cellulases are obtained from *Aspergillus niger* and contain chiefly C_x with only traces of C_1. The cellulase produced by *Trichoderma viride* is rich in C_1 and endo β , 1, 4 glucanase. It also contains lower levels of exo β, 1, 4 glucanase and β glucosidase.

During the past twenty years, extensive studies of *Trichoderma viride* and its enzyme have been made at the Natick Laboratories in connection with the program on prevention of deterioration of cellulosic materials. Today interest is focused on accelerating the breakdown of cellulose. To date, Natick has defined the conditions needed to produce the enzyme in quantity. They have