

/ETHANOL PRODUCTION FROM GRAIN DUSTS, BREAD WASTE, AND  
CAKE WASTE WITH AND WITHOUT BREWERS' CONDENSED SOLUBLES (BCS)/

by

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## INTRODUCTION

The petroleum supply disruption of the 1970's and the resulting dramatic escalation of imported crude oil prices spurred substantial interest in the production of fuel alcohol from domestically abundant renewable resources (Gill and Allen 1985). During the past 6 years, production of fuel alcohol has expanded by almost 400% (USDA 1985a). Along with the promulgation of Environmental Protection Agency's (EPA) new regulation requiring a reduction in the lead content of gasoline from 1.1 g to 0.1 g per gal in January 1986, the demand for ethanol as an octane-enhancer is expected to pick up significantly (EPA 1985, Gill and Allen 1985).

Good quality conventional feedstocks have traditionally been used by the beverage alcohol industry. Although the beverage alcohol industry requires a good food grade feedstock and has used mainly corn and grain sorghum to make ethanol, such is not the case with the fuel alcohol industry. Modern technology permits the use of many nonconventional feedstocks, potentially making fuel alcohol production more economically feasible (Fahrenholz 1983). It is also possible to use many types of grain by-products such as grain dusts, bakery wastes, and brewery wastes. Complete utilization of those by-products is both a necessity and a challenge. Furthermore, substantial savings could be obtained if those waste materials were utilized as feedstocks for fuel alcohol production.

Brewers' condensed solubles (BCS) is a mixture of the concentrated water-soluble and suspended by-products from the manufacture of beer. BCS is a rich source of fermentable carbohydrates and contains peptides, phosphorous, calcium, trace minerals, and some water-soluble vitamins (Sebree et al 1983).

Grain dust is always present in grain handling facilities, and it constitutes a fire, explosion, and health hazard (Martin and Stephens 1977). Physical and biological characteristics of grain dust were determined by a number of investigators (Martin 1981, Martin and Sauer 1976, Martin and Stephens 1977). Grain dust consists of dirt, pieces of other plant materials, tiny fragments of grain kernels, and broken kernels. The amount of dust in grain is estimated to range from 0.01 to 1.0%. If we accept 0.05% as the average concentration of dust in grain, the total quantity of dust is 150,000 metric tons in grain in one year (Miller 1981).

The shelf life of most commercial white bread produced in the United States is only two days, even under optimum storage conditions, due to a complex phenomenon which is called bread staling. Staling results in the initial return to the bakery of an average of eight percent of the bread produced. Based on the production of 14 billion pounds per year, this represents over 1.1 billion pounds of bread per year which cannot be sold economically due to staling (Kim and D'Appolonia 1977).



## OBJECTIVES

The objectives of this study were: 1) to determine the fermentable sugars released upon saccharification of grain dusts, bread waste, and cake waste; 2) to determine the yield of ethanol from hydrolyzed grain dusts, bread waste, and cake waste with and without BCS; and 3) to determine whether BCS can be used to enhance the rate of fermentation and the yield of ethanol from grain dusts, bread waste, and cake waste.

## LITERATURE REVIEW

### Energy from grain alcohol

1

Ethanol, or "grain alcohol", is a versatile and commercially important liquid which has been used for a variety of purposes for centuries (OTA 1981). Most industrial ethanol was produced by direct hydration of ethylene, a gas derived from petroleum or natural gas liquids. Interest in fermentation of grain and other agricultural products to produce alcohol for use as a liquid fuel has grown tremendously with the increasing cost of petroleum-derived energy sources (Klopfenstein and Abrams 1981, OTA 1981).

Historical perspective of fuel alcohol production. Ethanol fermentation can be assumed to be the first microbial process used by man; its use can be traced back some 6000 years into

Sumerian and Egyptian times. By the 14th century A.D. the distillation of alcoholic spirits from fermented grain, a practice thought to have originated in China or the Middle East, was common in many parts of the world (Demain and Solomon 1981). Until recently, however, this bioprocess has served mainly the purposed of producing beverages (Faust et al 1983).

The use of alcohol as a fuel for the internal combustion engine goes back to the invention of that engine by Dr. Nikolaus August Otto in 1861. Henry Ford believed that alcohol was the best fuel for his early cars and he provided a means on the dashboard to adjust the engine for operation with either alcohol or gasoline (Scheller 1981). During World War II, largely as a war effort through government sponsorship, ethanol-gasoline mixes for automotive fuel were common in Europe (Cheremisinoff 1983). However, due to the early availability of gasoline, this technology was not utilized from the 1920's to the late 1970's. In the 1970's, with a tremendous increase in oil prices and in some areas the total non-availability of oil, alcohol once again received attention (Lyons 1983). In recent years, alcohol fuel production has expanded rapidly due to federal and state incentives to encourage production from domestically abundant renewable resources. In the United States, consumption of fuel alcohol rose from about 81 million gal in 1981 to 430 million gal in 1983, and is projected to reach 850 million gal by 1990 (Gill and Allen 1985).

In Brazil, the world's leading producer of alcohol,

production has increased from 147 million gal during the 1975/76 crop year to 1.8 billion gal in 1984/85. The target for 1985/86 is 3.0 billion gal (Gill and Allen 1985, Rothman et al 1983).

Encouraged by programs within the U.S. and Brazil, many other countries began their own fuel alcohol program, and operating plants now exist in Canada, New Zealand, and the Philippines (Lyons 1983).

Fuel economy of ethanol. Ethanol may be used as a neat fuel (100% ethanol) or in gasoline blends. In the United States, most fuel ethanol is used in gasoline blends. A mixture of 10% ethanol (fermented from agriculture materials) and 90% unleaded gasoline (10/90) is called gasohol (Gill and Allen 1985, NAFC 1980a).

Ethanol has a Btu content significantly higher than that of methanol (approximately 12,780 Btu/lb vs 9,500 Btu/lb for methanol). However, ethanol's Btu value is still significantly lower than gasoline's. A gallon of ethanol contains about 70% of the Btu capacity of gasoline. The addition of ethanol to gasoline causes the Btu capacity to drop (Cheremisinoff 1983). If fuel efficiency were proportional to enthalpy of combustion, one would expect an approximate 4% decrease in miles per gallon with gasohol, compared with gasoline (Chambers et al 1979). However, in the practical use of gasohol, the lower heating value of ethanol is offset by its octane-boosting properties, high

| fuel/air ratio for combustion in automobile engines, and greater volumetric efficiency due to the higher compression ratio, better ignition, and higher burning rate (Rothman et al 1983). A comparison between the properties of iso-octane and ethanol is presented in Table 1. Gill and Allen (1985) reported that ethanol could be used in place of tetra-ethyl lead to increase the octane rating of unleaded gasoline because of its high octane rating of 110-112.

Scheller (1974) noted at least three factors that were important to the future of gasoline, namely, the price of gasoline, the price of grain, and the value of by-products from the alcohol manufacturing process.

2 Energy savings with fuel alcohol. The energy objective of using alcohol fuels from biomass is the displacement of foreign oil and gas with domestic synthetic fuels. The effectiveness of a fuel alcohol program depends on the energy consumed in growing and harvesting the feedstock and converting it into alcohol, the type of fuel used in the conversion process, and the use of the alcohol (OTA 1981).

A number of investigators have studied energy balances with different sets of assumptions regarding variables such as energy requirements for agricultural production, energy credits allotted to by-products, conversion plant design, yield of alcohol from grain feedstock, etc. (Katzen 1979, NAFC 1980a, OTA 1981, Rothman et al 1983, Scheller and Mohr 1976).

Table 1. Comparison Between the Properties of Iso-octane and Ethanol<sup>a</sup>

	Iso-octane (C <sub>8</sub> H <sub>18</sub> )	Ethanol (C <sub>2</sub> H <sub>5</sub> OH)
Molecular Weight	114.224	46.07
Carbon Content, wt %	84.0	52.0
Hydrogen Content, wt %	16.0	13.0
Oxygen Content, wt %	0.0	35.0
Boiling Point, °C at 1 atm	99.24	78.3
Freezing Point, °C at 1 atm	-107.4	-114.1
Heat of Vaporization, Btu/lb at boiling point and 1 atm	116.9	361
Heat of Vaporization, Btu/lb at 25°C and 1 atm	132	395
Heat of Combustion, Btu/lb at 25°C		
Higher heating value	20,556	12,780
Lower heating value		
Liquid fuel-gaseous H <sub>2</sub> O	19,065	11,550
Stoichiometric Mixture, lb fuel/lb air	0.066	0.111
Autoignition Temperature, °C	417.8	362.8
Octane Number (research)	100	106

<sup>a</sup>From Cheremisinoff (1983).

Cnambers et al (1979) studied that the energy balance for gasohol production was computed according to the following equation:

$$E = yc (10m - 9) - x,$$

where E is the difference in nonrenewable energy consumption between gasohol production and gasoline production, y is the alcohol yield per bushel of corn, c is the nonrenewable energy cost to produce a gallon of gasoline, m is the relative volume efficiency of gasohol with respect to gasoline, and x is the total input energy to produce alcohol from a bushel of corn.

Results were shown to be strongly dependent on assumptions about the use of crop residues for fuel and the fuel economy rating of gasohol relative to that of gasoline. A small improvement in gasohol fuel economy resulted in dramatic improvements in the petroleum energy balance. They concluded that gasohol was close to the energy break-even point in terms of total nonrenewable energy, and gasohol was a unambiguous energy producer in terms of petroleum or petroleum-substitutable energy.

For 10 gal of automobile fuel, Scheller (1981) estimated that the energy saved through the use of gasohol compared to gasoline was equivalent in Btu's to 1.48 gal of crude oil or 1.63 gal of gasoline if the alcohol plant was fueled with coal.

NAFC(1980a) quantitatively evaluated net gains in premium

fuels that can be derived from the production and use of ethanol from biomass with the following basic concepts: a) efficient processes have notably reduced the energy needed to produce ethanol fuel; b) ethanol fuel used in gasohol can replace more liquid fuel than is consumed in its production; and c) using fuels such as coal or wood in producing ethanol effectively converts these abundant energy sources into premium liquid fuels.

### **Biomass raw materials for ethanol production**

Raw materials for alcohol production can be divided into two basic categories: renewable biomass and nonrenewable fossil fuels, primarily coal. The renewable biomass materials include sugar and starch crops (and their derivatives such as food wastes) that can be converted into ethanol. Cellulosic biomass materials (plant fiber and its derivatives, such as paper and garbage) can be converted into either ethanol or methanol. Nonrenewable sources can be converted into methanol (Keim 1983, NAFC 1981). Table 2 gives the major biomass materials estimated to be available for ethanol production in the U.S. by 1990 and 2000.

The availability of biomass raw materials for alcohol fuel production depends on more than the size of a crop harvest or the height of a waste heap. Competition with other uses, production methods (and their commercial availability), transportation and collection costs, and distribution networks all will play a part

Table 2. Biomass Resource Base for Ethanol Production in the U.S.<sup>a</sup>

Raw Material	Potential Ethanol Production (Billions of Gallons)	
	1990	2000
Grain	4.0	4.0
Cellulose		
Wood	3.2	1.9
Municipal Solid Waste	3.7	4.3
Crop Wastes	1.5	1.5
(Subtotal for Cellulose) (Wood, MSW, Crop Wastes)	(8.4)	(7.7)
Sugar Crops	3.0	5.0
Food Wastes	0.5	0.6
Total	15.9	17.3

<sup>a</sup>From U.S. National Alcohol Fuels Commission (1981)



in determining how much and what kind of raw materials will be used in future alcohol fuels production (NAFC 1981).

In tropical countries, sugar crops are being used as raw materials for alcohol production because they are available year-round. In 1975, Brazil's government established a national alcohol program (PROALCOOL) designed to produce fuel alcohol from mainly sugar cane (Stout et al 1978). Silva et al (1978) reported that sugar cane is a more efficient crop for ethyl alcohol production than sweet sorghum and cassava, from a net energy view point.

Grain is the primary fermentation feedstock in the U.S. for three reasons. First, it is widely available: cereal grains account for nearly 50% of the harvested acreage of all field crops in the U.S. Second, grain is a surplus commodity. Third, the technology for harvesting, handling, and processing grains for fermentation is well established (Chung 1986).

Corn is by far the most common feedstock for ethanol production. A small amount of grain sorghum is used in the Southwest, but very little wheat is used to produce ethanol. Most of the alcohol produced from corn is now being used for fuel (Coble et al 1985, USDA 1985a).

Cellulosic materials are the most abundant renewable biomass on earth. However, their conversion to ethanol is presently not economical because saccharification of cellulose is inefficient. Cellulose is difficult to hydrolyze for two reasons. First, cellulose is insoluble in water and exists in a semicrystalline

state. Enzymatic or acid attack can occur only in amorphous regions and on the surface of crystals. Secondly, cellulose of practical value for the production of ethanol is rarely pure but coexists with lignin and hemicellulose in well defined anatomical structures. Physical barriers consisting largely of three-dimensional lignin reduce the accessibility to cellulose enzymes (Tsao 1985).

Knappert et al (1988) reported partial acid hydrolysis of cellulosic materials before cellulase hydrolysis increased glucose yields due to the acid's removal of hemicellulose, reduced degree of polymerization, and a possible change in the crystal structure of the cellulosic substrates.

Food processing wastes from cheese, fruit, and sweet corn are practical raw materials for alcohol production only in limited circumstances. Collection difficulties, the seasonal nature of the materials, and competition from other users render food processing wastes usable only in small operations or when the waste has been contaminated (NAFC 1981).

#### **Ethanol production from grain by-products**

In the cereal industry, complete utilization of resources is both a necessity and a challenge. In recent years, the recovery and modification of wastes has become increasingly important. The ultimate aim is more complete utilization of the raw material while minimizing pollution and waste (Finley 1981).

Small scale ethanol production. Most grain by-products are generated in relatively small amounts each time grain is processed. One logical way to utilize these by-products is to collect them in a small community base and use them as feedstocks for producing alcohol in small size production units.

NAFC (1980c) investigated the advantages of on-farm or small community based fuel alcohol production: a) Feedstocks are readily available and damaged grain can be used; b) The technology for small fermentation is theoretically available; and c) Existing gasoline-powered farm equipment can be modified to run on high-proof ethanol.

The U.S. Department of Energy reported that ethanol production from small size plants with the production capacity of from 10,000 gal to 1 million gal per year was 6% of total ethanol production in 1980, and will increase to 20% by 1985. However, many small scale production farm plants which flourished in the early stages have now disappeared due to poorly designed plants, lack of operating capital, and lack of technical know-how (Lyons 1983). On farm production, if handled properly, could contribute significant levels of fuel alcohol.

A small scale ethanol production plant has been developed by Coble et al (1981) based on the production capacity of 30 L (7.9 gal) per hour or 60 L (15.9 gal) per hour with additional fermentation tanks. The estimated cost of producing alcohol at a rate of 35,000 L per year was \$ 1.43 per L, and at 550,000 L per year was \$ 0.59 per L, with an overall plants efficiency of 77%.

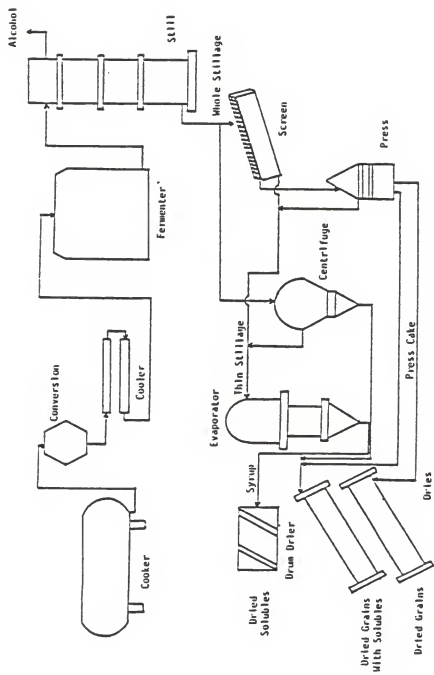
Small-scale plants with capacities of 15, 50, and 150 gal per hour were studied by NAFC (1980c) to evaluate the technical and economic feasibility of producing 190° proof and 199° proof Motor Fuel Grade (MFG) alcohol.

Basics of ethanol production. The production of ethanol requires four basic steps: feedstock preparation, starch conversion, fermentation, and distillation. Although not a basic step in the procedure, the collection and further processing of the fermentation by-products is usually an integral part of fuel alcohol production (Fahrenholz 1983). Fig. 1 shows a flow diagram of an ethanol production process. To maintain optimum conditions during the operation, some operational factors such as temperature and pH of the mash must be monitored carefully.

a) Feedstock preparation: Grain materials must be mechanically reduced to make the starch more accessible to the enzymes which are used in the conversion of the starch to the mono- and disaccharides required by the yeast. Grinding is the most common method of particle size reduction. While some people advocate the use of roller mills in order to reduce fines (Nellis 1979), most grains are ground through hammer mills. Particle size is important because too coarse a grind increases the time and energy required for starch gelatinization (Maisch et al 1979).

Suggested particle sizes include throughs from 1/16 in to 3/16 in screens (Cnung 1986, Titus 1980). Coble et al (1981)

Figure 1. Flow diagram of an ethanol production process.  
(Source: Fahrenholz 1983)



used 2/16 in and 3/16 in screens for corn, but they found no significant differences in production or equipment operation.

b) Liquefaction and saccharification: Ground feedstock mixed with water is heated to gelatinize the starch and is subjected to enzymes to convert the starch to yeast-fermentable sugars. Traditionally the starch was converted to fermentable sugars with malt enzymes, prior to fermentation and distillation. More recently, microbial enzymes have been used to replace malt because they provide the distiller with a reliable alternative which is easy to handle and offers considerable savings in production costs (Aschengreen 1969). Alpha-amylase hydrolyzes the alpha 1-4 bonds, forming dextrans which contain 6 to 30 glucose units (Titus 1980). Liquefaction with alpha-amylase required rather sophisticated procedures to assure dispersion of all starch molecules. A typical procedure includes adding calcium to stabilize the enzyme, adjusting the pH to 6.0-6.5, adding part of the enzyme and cooking at 105°C with steam injection and holding for 10 min. Then the mixture is heated to 140°C and held for 2 min, after which it is cooled to 90°C, and the remaining enzyme is added and the mixture held for 60 min (Keim 1983).

Saccharification is the conversion of the dextrans to the simple sugars to be utilized by the yeast. Glucoamylase (amyloglucosidase) breaks both alpha 1-4 and alpha 1-6 links to yield single glucose units (Maisch et al 1979). At this stage the mash is cooled to 60-65°C and maintained 2 hr at pH 4.0-5.0

for complete saccharification (Keim 1983, Wu et al 1984).

c) Fermentation: Yeasts convert sugars to ethanol, carbon dioxide, and heat in the stoichiometric ratio of 2 moles each of ethanol and carbon dioxide for each mole of glucose (NRC 1981). The yeasts normally used in ethanol production are top fermenting facultative anaerobes belonging to the genus Saccharomyces (SERI 1980). In general, S. cerevisiae is especially tolerant of adverse environmental conditions, and it is generally preferred for industrial ethanol production. Mesophilic strains of Saccharomyces exhibit optimum cell yields and growth rates in the range of 28-35°C while the maximum temperature for growth is about 40°C (Jones et al 1981). Gray (1941) reported that one strain of S. cerevisiae had a lower alcohol tolerance at 35°C than at 30°C.

Hydrogen ion concentration is a significant factor in fermentation due to its importance in controlling bacterial contamination as well as its effect on yeast growth, fermentation rate, and by-product formation (Jones et al 1981). For fermentation of grain mash, initial pH was adjusted to 4.3-5.0 with either stillage equal to 20-25% of the final mash volume, or with sulfuric acid (Stark 1954). The mash for molasses, fermentation was adjusted to an initial pH of 4-5 with sulfuric acid, hydrochloric acid, or lactic acid (Hodge and Hildebrandt 1954).

If the sugar concentration of the mash exceeds 22% by weight, the high osmotic pressure will greatly inhibit yeast



activity (SERI 1980). Fermentation will continue until the substrate is depleted or the ethanol concentration is high enough to destroy the yeast, greater than 12 to 14% by weight (Maisch et al 1979).

d) Distillation: The purpose of distillation is to separate the ethanol from the fermented mash. Conventional distillation procedures use a system of two columns: a stripping column to separate ethanol from the mash and a rectifying column to concentrate the ethanol. Sieve trays in the columns improve liquid-vapor contact and encourage refluxing (SERI 1980).

The formation for an azeotropic mixture of water and alcohol at 1 atm limits the concentration to 95.6% by weight of ethanol (NAFPA 1979). Anhydrous alcohol can be obtained by azeotropic distillation using benzene (NRC 1981).

## MATERIALS AND METHODS

### Materials

The types of grain dusts tested were wheat-corn, corn-sorghum, and sorghum-soybean (2 samples each). The six samples of grain dusts were collected from three commercial grain elevators in northeast Kansas at three different harvesting times. The sources of grain, from which the dusts came, were determined before the samples were collected. Bread waste was obtained from the Baking Science Laboratory of the Department of Grain Science and Industry, Kansas State University. Cake waste was obtained from the American Institute of Baking, Manhattan, KS. BCS was obtained from Anheuser-Busch, Inc. in 1985; a sample with 48.5% solids was from the brewery in Columbus, OH.

Distillers' active-dry yeast was obtained from Biocon (U.S.) Inc., Lexington, KY. The recommended usage rate was 2-4 lbs/1000 gal (5-10 million cells/ml) of mash when the sugar concentration was between 15-25%. The optimum pH was between 4.0 and 5.5. The optimum temperature was 86° F (30°C). However, good yields were obtained between 80°F and 100°F with the rate of fermentation increasing with increasing temperature. A bacterial alpha-amylase (TAKA-THERM) was obtained from Miles Laboratories, Inc., Elkhart, IN. One gram of TAKA-TERM had a leveled activity of 170,000 Modified Wohlegemuch Units (MWU). One MWU is the amount of enzyme that dextrinizes 1 mg of soluble starch to a definite

size of dextrin in 30 min under the conditions of assay. A fungal glucoamylase (Diazyme L-200) was also obtained from Miles Laboratories, Inc. One ml of Diazyme L-200 has a leveled activity of 200 Diazyme Units (DU). One DU is the amount of enzyme that catalyzes the production of 1 g of glucose from starch in 1 hr at 60°C and pH 4.2.

## Methods

Sun-dried bread waste and cake waste were ground in a Burrows hammer mill using a 1/16 in (1.6 mm) screen and placed in cold storage with other grain dust samples. The moistures of grain dusts, bread waste, and cake waste were determined by evaporation at 95°C for 4 hr under vacuum of 4000 pa or 30 torr (A.O.A.C. 1984, Method 7.003). Total starch contents of the grain dusts were determined by A.A.C.C. method 76-11 (1976), and those of bread waste and cake waste were also determined using same method after extracting sucrose with 80% hot ethanol. Crude protein, crude fat, and crude ash were determined by A.O.A.C. methods 47.021, 7.060, and 7.009, respectively (1984). Amino nitrogen was determined by A.A.C.C. method 46-31 (1976). Glucose, fructose, and ethanol were determined by high-performance liquid chromatography (HPLC) using a Varian Model 5,000 LC (Varian Associates, Inc., Palo Alto, CA) chromatograph equipped with a loop-injection device (10 ul) and a refractometer as the detector. All separations were done using a Bio-Rad

Aminex Ion-Exclusion Column (HPX-87H, 300 mm x 7.8 mm, Bio-Rad Laboratories, Richmond, CA) operated at 45°C. Components were eluted with 0.01 M aqueous sulfuric acid at a flow rate of 0.9 ml/min. Sucrose was also determined by HPLC using a Beckman 100A system with Altex Model 156 refractive index detector. Sucrose was separated on an Amino Sepheri-5 column (Brownlee Labs, Santa Clara, CA). Standard curves were obtained from solutions of known concentrations of sugars and ethanol.

#### Liquefaction and saccharification

One hundred twenty grams (dry basis (db)) each of grain dusts, ground bread waste, and cake waste were dispersed in about 450 ml water. The pH of each slurry was adjusted to 6.2 with 2 M NaOH and 0.3 ml of TAKA-THERM was added. The temperature was maintained at 90°C for 1 hr with constant stirring to gelatinize and degrade starch to soluble dextrans. The thinned slurry was adjusted to pH 4.2 using 5 N HCl, and saccharified with 0.9 ml Diazyme L-200 at 60°C for 4 hr with stirring.

For a 1:1 mixture of each sample with BCS, 300 g of slurries containing 60 g (dry solids (ds)) samples were liquefied with 0.15 ml of TAKA-THERM under the conditions described previously. Then, each thinned slurry was mixed with 300 g of 20% (w/w) BCS, and saccharified with 0.9 ml Diazyme L-200 under the same conditions described previously. BCS (20% w/w) alone was also saccharified using Diazyme L-200 in the same manner. Hydrolyzed

slurries of each sample were diluted to 15% solids (as solids content before hydrolysis) for fermentation, and if necessary, pH was readjusted to 4.2 for grain dusts, and 4.6 for bread waste and cake waste.

### **Fermentation**

One gram yeast was rehydrated in 25 ml water (42°C) for 5-10 min prior to use. Media were sterilized at 121°C for 15 min and fermentations were performed at 30°C using 0.2 g yeast/kg medium (wet basis (wb)). The pH was readjusted to 4.2 for grain dusts and 4.6 for bread waste and cake waste.

To determine the yields of ethanol, the hydrolyzed slurries (50 g) were fermented in 125-ml Erlenmeyer flasks fitted with a water-seal. After fermentation, samples were centrifuged at 12,000 rpm for 10 min in a Beckman Model J2-21 Centrifuge. Residual sugars and ethanol were determined using HPLC.

To determine the rate of fermentation and the optimum fermentation times, carbon dioxide gas production was followed using a 12-channel recording gasograph (Rubenthaler et al 1983). A gasograph Model 12 manufactured by D&S Instrument Ltd. (Pullman, WA) was used in this experiment. A test tube (15 ml) containing 7 g substrate was placed inside a 250-ml jar that contained 70 ml water to improve heat transfer to the test tube. The jar was plugged with a rubber stopper and connected to a channel, which had a recording pen. Optimum fermentation times

found by the gasograph were 10-15 hr shorter than those found by ethanol production.

## RESULTS AND DISCUSSION

### Proximate Analysis

All samples were analyzed for total starch, crude protein, crude fat, and crude ash. Data are presented in Table 3. Grain dusts contained high amounts of ash and varied widely in starch content even though the sources of grain, from which the dusts came, were the same. Average sugar compositions in enzyme-digested bread waste and cake waste were measured by HPLC during preliminary work and values are presented in Table 4. Sucrose in the bread waste might have come from non-yeast bread or from sucrose-containing ingredients added after baking.

### Fermentation of Hydrolyzed Grain By-products and Their Mixtures with BCS

From the results shown in Table 3, grain dust samples chosen for fermentation were low and high starch wheat-corn dust, low and high starch corn-sorghum dust, and a 1:1 mixture of the two sorghum-soybean dust samples.

The rates of fermentation were measured by carbon dioxide production during fermentation using the gasograph. The gasograph

Table 3. Proximate Chemical Composition of Grain By-products and BCS (dry basis)<sup>a</sup>

Source	Total Starch ( % )	Crude Protein <sup>b</sup> (%, N x 6.25)	Crude Fat ( % )	Crude Ash ( % )
Wheat-corn				
Dust 1	27.0±0.8	10.4±1.1	4.2±0.6	20.9±0.1
Dust 2	41.9±0.5	8.9±0.6	3.9±0.3	17.7±1.3
Corn-sorghum				
Dust 1	29.5±1.0	10.3±0.7	4.1±0.4	19.1±0.3
Dust 2	41.7±0.5	9.1±0.5	4.2±0.5	15.2±0.4
Sorghum-soybean				
Dust 1	37.9±0.6	8.3±0.7	3.3±0.1	20.3±0.7
Dust 2	40.8±0.6	9.6±1.0	3.6±0.3	15.4±0.4
Bread waste	66.2±0.5	12.1±0.9	2.2±0.1	2.0±0.1
Cake waste	32.4±0.2	5.7±0.3	16.9±0.1	2.1±0.1
BCS <sup>c</sup>	-	8.9±1.1	1.4±0.3	2.5±0.2

<sup>a</sup>Each value is a mean of four replications ± S.E. except BCS.

<sup>b</sup>The nitrogen factor of 5.7 was used for bread waste and cake waste.

<sup>c</sup>From Sebree et al (1983).

Table 4. Average Sugar Composition in Saccharified Bread Waste and Cake Waste

Sugars	Bread Waste (g/100g ds)	Cake Waste (g/100g ds)
Glucose	67.1	34.2
Sucrose	1.3	28.3
Fructose	0.3	2.2



was introduced by Rubenthaler et al (1930) to measure and continuously record the volume of gas produced at constant temperature and pressure in a fermenting dough. Values are recorded in gasograph units (GU). GU can be converted to mm of Hg by multiplying by the factor of 7.3. Gas production in gasograph units may also be expressed in cc by multiplying GU by 2.38.

The results of fermenting hydrolyzed grain dusts and the mixture of BCS and each sample (1:1) are given in Table 5, and also are plotted in Figures 2 to 4. Optimum fermentation times measured by gasograph are reported in Table 6. For grain dusts containing low starch, gas production leveled off in 20 hr, and high starch in 25-26 hr. For 1:1 mixtures of BCS and grain dusts, the gas production reached its peak in 25-26 hr. When equal amounts of BCS were added to grain dusts, optimum fermentation times were not reduced, but carbon dioxide produced during fermentation was markedly increased, probably due to the high amounts of available carbon in BCS (Table 3). Table 7 and Fig. 5 show the results of gas production from bakery wastes, and from the mixture of BCS and each sample (1:1). Addition of BCS to bread waste and cake waste did not increase CO<sub>2</sub> gas production but did reduce the optimum fermentation times from 62 hr to 34 hr, and from 76 hr to 35 hr, respectively. This significant reduction ( $p < 0.05$ ) of optimum fermentation time might be due to some nutrients in BCS. Chung (1986) reported that addition of BCS to corn, grain sorghum, and wheat resulted in the

Table 5. Carbon Dioxide Production during Fermentation of Saccharified Grain Dusts and Their Mixtures with BCS

Source	CO <sub>2</sub> Production (GU <sup>a</sup> )						
	8	12	16	20	24	28	32(nr)
Wheat-corn dust							
Low-starch (WLS)	4.4	11.1	21.3	30.1	29.7	28.9	-
WLS + BCS (1:1)	5.0	12.6	25.2	43.3	52.2	52.1	51.2
High-starch (WHS)	5.6	14.4	24.8	36.5	42.9	44.4	44.1
WHS + BCS (1:1)	7.0	18.3	32.6	48.3	57.2	53.3	57.5
Corn-sorghum dust							
Low-starch (CLS)	6.2	16.2	27.9	31.8	31.4	31.1	-
CLS + BCS (1:1)	5.3	13.3	25.8	42.6	52.2	52.1	51.2
High-starch (CHS)	6.2	16.4	29.4	40.6	44.1	44.3	43.4
CHS + BCS (1:1)	4.6	11.4	22.2	38.8	56.1	58.5	57.4
Sorghum-soybean dust (SSD)							
SSD + BCS (1:1)	3.9	9.8	19.7	35.8	51.0	55.2	54.6

<sup>a</sup>GU X 2.38 = cc, or GU X 7.3 = mm Hg.

Figure 2. Carbon dioxide production during fermentation of saccharified mixtures of wheat-corn dust and BCS. Fermentations were done using 15% solids with 0.2 g dry yeast/kg at 30°C and pH 4.2. GU X 2.38 = cc, or GU X 7.3 = mm Hg.

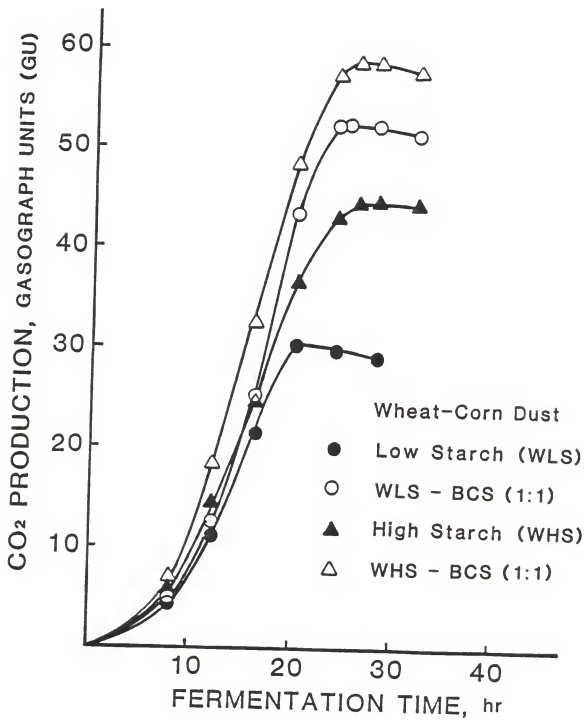


Figure 3. Carbon dioxide production during fermentation of saccharified mixtures of corn-sorghum dust and BCS. Fermentations were done using 15% solids with 0.2 g dry yeast/kg at 30°C and pH 4.2. GU x 2.38 = cc, or GU x 7.3 = mm Hg.

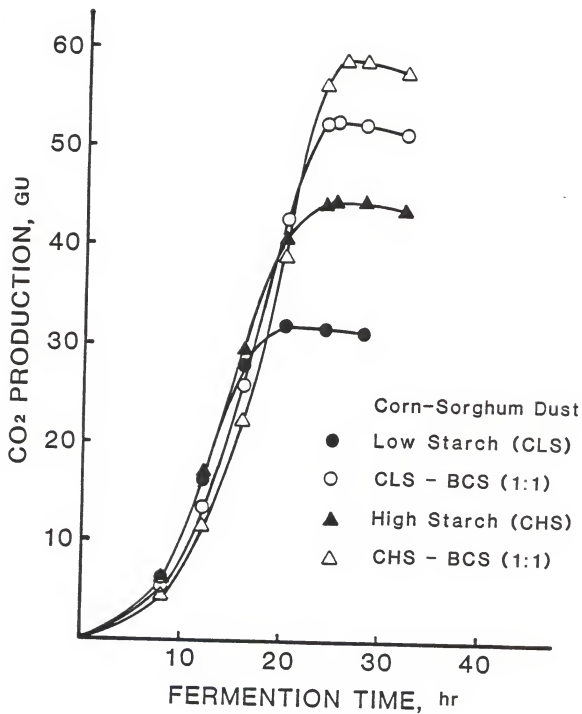


Figure 4. Carbon dioxide production during fermentation of saccharified mixtures of sorghum-soybean dust and BCS. Fermentations were done using 15% solids with 0.2 g dry yeast/kg at 30°C and pH 4.2. GU X 2.38 = cc, or GU X 7.3 = mm Hg.

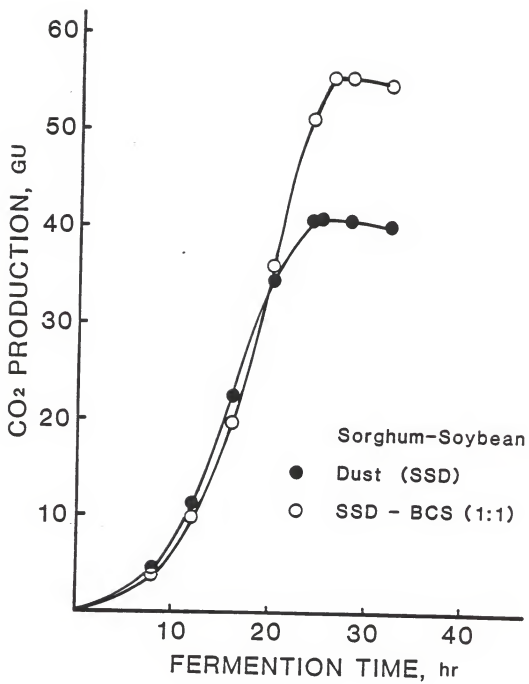




Table 6. Ethanol Yields Produced by Yeast Fermentation of Saccharified Grain By-products and Their Mixtures with Glucoamylase-Treated BCS; Optimum Fermentation Times and Fermentation Efficiencies.

Source	Total Fermentable Sugars <sup>a</sup> (% db)	Ethanol Yield <sup>b</sup> (ml/kg ds)	(gal/ton)	Optimum Fermentation Time <sup>c</sup> (hr)	Fermentation Efficiency <sup>d</sup> (%)
Wheat-corn dust					
Low-starch (WLS)	28.0	164 <sup>a</sup> ± 7.5	39	20 <sup>a</sup>	90.4
WLS+BCS (1:1)		305 <sup>b</sup> ± 4.5	73	25 <sup>b</sup>	
High-starch (WHS)	43.3	263 <sup>a</sup> ± 3.8	63	26 <sup>a</sup>	93.7
WHS+BCS (1:1)		353 <sup>b</sup> ± 5.6	85	26 <sup>a</sup>	
Corn-sorghum dust					
Low-starch (CLS)	30.6	177 <sup>a</sup> ± 5.9	42	20 <sup>a</sup>	89.4
CLS+BCS (1:1)		308 <sup>b</sup> ± 7.0	74	25 <sup>b</sup>	
High-starch (CHS)	43.9	262 <sup>a</sup> ± 3.3	63	25 <sup>a</sup>	92.1
CHS+BCS (1:1)		347 <sup>b</sup> ± 6.5	83	26 <sup>a</sup>	
Sorghum-soybean dust (SSD)					
SSD	40.5	229 <sup>a</sup> ± 6.7	55	25 <sup>a</sup>	87.3
SSD+BCS (1:1)		343 <sup>b</sup> ± 6.8	82	26 <sup>a</sup>	
Bread waste (BW)					
BW	68.8	427 <sup>a</sup> ± 5.0	102	62 <sup>a</sup>	95.7
BW+BCS (1:1)		441 <sup>a</sup> ± 11.6	106	34 <sup>b</sup>	
Cake waste (CW)					
CW	66.2	435 <sup>a</sup> ± 9.1	97	76 <sup>a</sup>	94.4
CW+BCS (1:1)		437 <sup>b</sup> ± 10.7	105	35 <sup>b</sup>	

<sup>a</sup>Total fermentable sugars were determined after hydrolysis. Total fermentable sugars included glucose, sucrose, and fructose. All sucrose were assumed to be converted to glucose and fructose

<sup>b</sup>Each value is the mean of 4 replications ± S.E. Mean comparisons within every two rows followed by the same letter are not significantly different ( $p < 0.05$ ).

<sup>c</sup>Each value is the mean of 2 replications. Mean comparisons within every two rows followed by the same letter are not significantly different ( $p < 0.05$ ).

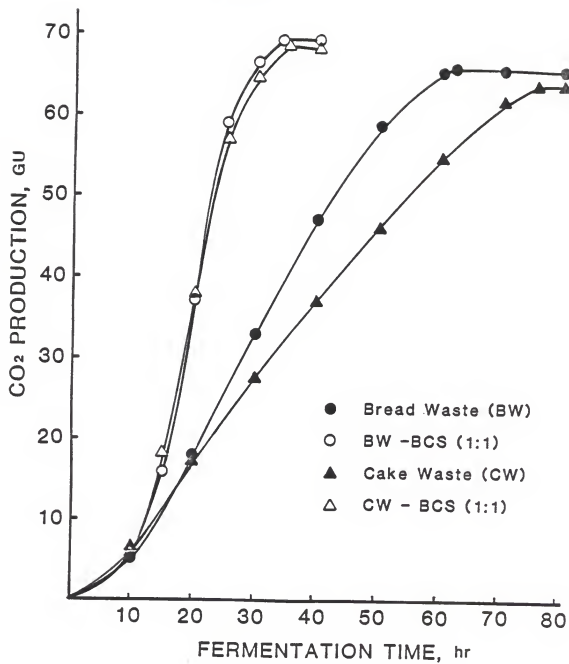
$$d \text{ \% fermentation efficiency} = \frac{\text{actual alcohol produced}}{\text{theoretical alcohol from sugar fermented}} \times 100$$

Table 7. Carbon Dioxide Production during Fermentation of Saccharified Bakery Wastes and Their Mixtures with BCS

Source	CO <sub>2</sub> Production (GU <sup>a</sup> )								
	10	20	30	35	40	50	60	70	80(nr)
Bread waste (BW)	5.2	17.8	33.0	39.5	47.0	58.6	65.1	65.2	64.9
BW + BCS (1:1)	6.1	37.3	66.3	69.1	68.9	-	-	-	-
Cake waste (CW)	5.9	17.3	27.5	31.6	37.0	46.0	54.5	61.3	63.3
CW + BCS (1:1)	6.6	37.8	64.5	68.2	67.9	-	-	-	-

<sup>a</sup>GU X 2.38 = cc, or GU X 7.3 = mm Hg.

Figure 5. Carbon dioxide production during fermentation of saccharified mixtures of bakery wastes and BCS. Fermentations were done using 15% solids with 0.2 g dry yeast/kg at 30°C and pH 4.6. GU X 2.38 = cc, or GU X 7.3 = mm Hg.



reduction of fermentation time (Table 8), and maximum fermentation benefit could be obtained when the mixture ratio was 1:1.

The fermentation rate of cake waste was also followed by measuring the ethanol content in ferments done in water-sealed flasks. Fig.6 and Table 9 represent the sugar consumption and ethanol production during fermentation of cake waste. Sucrose was quickly hydrolyzed to glucose and fructose by yeast invertase in the first 10 hr of fermentation, and fructose was consumed by yeast at a significantly slower rate than glucose. These data are in agreement with what Kulp et al (1985) observed in fermentation of liquid ferments for white pan bread. Similar observations were also reported for straight doughs by Koch et al (1954).

Fermentation rate measured by ethanol production showed a trend similar to that found by the gasograph (Fig. 5). Ethanol production was almost complete in 90 hr. However, CO<sub>2</sub> production appeared to be completed 14 hr earlier. This phenomenon might be due to CO<sub>2</sub> absorption in the water, and reduction of total CO<sub>2</sub> volume by the increased pressure in the gasograph jar. The declines in total CO<sub>2</sub> after the peaks support this explanation. Also, there was a decrease in the pH of the water (5.7 to 3.9-4.0) in the jar after fermentation, indicating probable CO<sub>2</sub> absorption by the water.

The effects of pH on fermentation of hydrolyzed bread waste and cake waste are presented in Table 10. The large drop in pH

Table 8. Ethanol Yields and Optimum Fermentation Times Obtained from Yeast Fermentations of Enzyme-Digests of Grains Mixed with Glucoamylase-Treated BCS<sup>a</sup>

Source	Glucose Released by Enzyme Hydrolysis (% db)	Ethanol Yield (ml/kg ds)	Optimum Fermentation Time (hr)
Corn	73.7	429	61
Corn+BCS(1:1)		443	33
Sorghum	75.7	448	65
Sorghum+BCS(1:1)		448	33
Wheat	69.0	403	57
Wheat+BCS(1:1)		440	33
BCS	76.4	460	29

<sup>a</sup>From Chung (1986).

Table 9. Sugar Consumption and Ethanol Production during Fermentation of Cake Waste

Fermentation Time (hr)	Ethanol (ml/100g ds)	Sugar (g/100g ds)		
		Glucose	Fructose	Sucrose
0	0	34.2	2.2	28.3
10	2.7	44.0	16.4	1.4
20	8.3	35.2	16.3	1.4
30	14.1	27.1	15.1	1.4
40	19.9	19.1	13.6	1.4
50	24.9	12.6	12.1	1.4
60	28.4	8.1	10.2	1.4
70	32.0	4.3	8.7	1.4
80	37.6	1.7	4.5	1.4
90	40.0	0.9	1.6	1.4
100	40.5	0.9	1.1	1.4

Figure 6. Sugar consumption and ethanol production during fermentation of cake waste. Fermentations were done using 15% solids with 0.2 g dry yeast/kg at 30°C and pH 4.6.



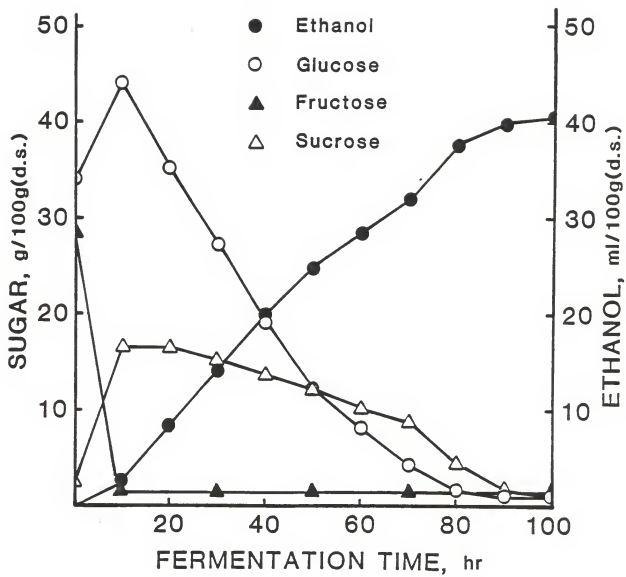


Table 10. Effect of pH on Fermentation of Saccharified Bread Waste and Cake Waste.

Source	Initial pH	Final pH	Fermentation Time (hr)	CO <sub>2</sub> Production at Peaks <sup>a</sup> (GU <sup>b</sup> )
Bread waste	4.2	3.6	63	66.2 <sup>a</sup>
	4.6	3.8	62	65.5 <sup>a</sup>
	5.0	4.0	65	65.5 <sup>a</sup>
Cake waste	4.2	3.4	78	62.7 <sup>a</sup>
	4.6	3.5	76	63.3 <sup>a</sup>
	5.0	3.6	77	62.5 <sup>a</sup>

<sup>a</sup>Each value is the mean of 2 replications. Mean comparisons within every three rows followed by the same letter are not significantly different ( $p < 0.05$ ).

<sup>b</sup>GU x 2.38 = cc, or GU x 7.3 = mm Hg.

after fermentation implied that bread waste and cake waste had poor buffer capacities.

Fermentation of sucrose and fructose solutions is more sensitive to pH than fermentation of glucose. The control of brew pH affects the sugar utilization, allowing a high fermentation rate to be maintained (Jones et al 1981, Kulp et al 1985). Because cake waste contained relatively large amount of sucrose and fructose (about 30% db), optimum pH during fermentation was expected to give a high rate of fermentation. Carbon dioxide production during fermentation of bread waste and cake waste was not affected ( $p < 0.05$ ) by the initial pH, which ranged from 4.2 to 5.0. However fermentation times were slightly reduced when the initial pH was adjusted to 4.6.

#### **Yields of Ethanol**

Total fermentable sugars in grain by-products after successive treatments with alpha-amylase and glucoamylase were measured by HPLC. Glucose, sucrose, and fructose were included in total fermentable sugars and the values, which were proportional to the starch content except for cake waste, are presented in Table 6. Chung (1986) found that maltose was not quantitated in the digests because it eluted together with isomaltose. Coble et al (1981) reported that the average efficiency for conversion of starch to sugar was 90% when corn and grain sorghum were hydrolyzed using alpha-amylase and

glucoamylase in a small scale ethanol production plant.

The yields of ethanol from hydrolyzed grain by-products and their mixtures with hydrolyzed BCS are also reported in Table 6. The ethanol production by fermentation of grain dusts ranged from 164 ml/kg ds to 263 ml/kg ds. Addition of BCS in grain dusts increased ethanol production by 32-86%, with yields of 305 ml/kg ds to 353 ml/kg ds. When BCS was added in bakery wastes, no significant difference ( $p < 0.05$ ) in ethanol yield was found in bread waste, but ethanol yield was increased about 7% in cake waste. In all cases, only trace amounts of residual sugars were detected after fermentation.

Adding BCS did not increase ethanol yield in corn and sorghum fermentation (Table 8), because BCS and these grain materials gave about equal amounts of glucose upon enzyme hydrolysis. But the yield was slightly increased in wheat fermentation (Chung 1986).

The fermentation efficiencies of grain by-products were generally more than 90% and tended to get higher as total fermentable sugar amounts increased in hydrolyzed substrates (Table 6). Bakery wastes were very high in fermentation efficiencies (94-96%) and sorghum-soybean grain dust was the lowest (87%). Stark (1954) reported that fermentation efficiency was an index of the physiological condition of the yeast, and that overall processing plant efficiency was a standard for the evaluation of all process operations, from handling of the raw materials through fermentation, or through distillation if based

on the alcohol in storage tank. He found that 92-95% fermentation efficiencies (plant basis) were obtained for corn, 82-90% for wheat, and 93% for grain sorghum. Coble et al (1981) reported that the average efficiency for fermentation of sugar to alcohol was 90% with overall plant efficiency of 77% when corn and grain sorghum were used as feedstocks for small scale ethanol plant.

#### **Amino Nitrogen in Hydrolyzed Grain By-products and BCS**

The nitrogen content of yeasts is about 10% of the dry weight, representing that nitrogen is an important constituent of any growth medium (Jones et al 1981). The amino nitrogen content in hydrolyzed grain by-products and BCS was determined as formal nitrogen by the method of Sorenson, and the values are presented in Table 11. With the amounts of 67-81 mg/100g ds, grain dusts were relatively rich in amino nitrogen compared to grain itself (Table 12). Bread waste and cake waste contained very low concentrations of amino nitrogen, with amounts of 15 mg/100g ds and 12 mg/100g ds, respectively. BCS had 3-20 times more amino nitrogen than any of the grain by-products.

Chung (1986) reported that adding vitamins and minerals to the hydrolyzed grain materials had no effect on either fermentation time or ethanol production because grains were rich sources of these nutrients. However, addition of nitrogen to the hydrolyzed grains markedly increased the rate of fermentation.

Table 11. Amino Nitrogen in Saccharified Grain  
By-products and BCS

Source	Amino Nitrogen <sup>a</sup> (mg/100 g ds)
Wheat-corn dust	
Low-starch	78.5 ± 1.3
High-starch	67.4 ± 1.0
Corn-sorghum dust	
Low-starch	80.9 ± 0.7
High-starch	75.8 ± 1.3
Sorghum-soybean dust	72.1 ± 2.9
Bread waste	14.8 ± 0.1
Cake waste	11.7 ± 0.7
BCS <sup>b</sup>	230.0

<sup>a</sup>Each value is a mean of two samples ± S.E.

<sup>b</sup>From Chung (1986)

Table 12. Amino Nitrogen in Hydrolyzed Grain Materials and Their Optimum Fermentation times<sup>a</sup>

Source	Amino Nitrogen (mg/100 g ds)	Optimum Fermentation Time (hr)
Corn	39	61
Sorghum	33	65
Wheat	31	57
Wheat screenings	81	25
Low-grade flour	72	31

<sup>a</sup>From Chung (1986).

Kirsop and Brown (1972) have shown that if the concentration of all the noncarbohydrate constituents of malt wort were halved, the rate of fermentation was reduced but it could be completely restored by the addition of serine or arginine. They also found that the rate of fermentation was proportional to the values for amino nitrogen (Table 13), suggesting that exhaustion of nitrogenous compounds was the limiting factor for yeast growth.

Addition of BCS to hydrolyzed bakery wastes significantly reduced the fermentation times (Table 6). This effect might be due to the high amino nitrogen content of BCS. With equal amounts of initial glucose, adding BCS to grain dusts did not reduced ( $p < 0.05$ ) fermentation times (Table 14). This phenomenon suggested that grain dusts had enough nitrogen content for yeast growth. From the results shown in Tables 6, 11, and 12, a good linear relationship ( $r = -0.97$ ) was found between optimum fermentation time and amino nitrogen in the hydrolyzed grains and their by-products (Fig. 7).

#### Cost Analysis for Ethanol Production

Grain dust collected from elevators is frequently returned to the grain and moves with the grain through the marketing channels (Martin and Sauer 1976). In some grain elevators in northeast Kansas, about 3-5% of the grain dust is returned to the grain, and the rest of it is discarded or given away for animal feed. Stale bread and cake is sometimes collected by a



Table 13. Time Required for Fermentation and Amino Nitrogen Content of Various Worts<sup>a</sup>.

Wort	Amino Nitrogen (mg/100 ml)	Exponential Growth (mg/ml)	Extent of Fermentation Time (hr)
A	9.5	1.3	79
B	14.5	1.9	56
C	16.0	2.4	56
D	19.0	2.6	43
E	23.0	2.8	38
F	24.0	2.9	35
G	28.0	3.2	29
H	34.0	3.3	28

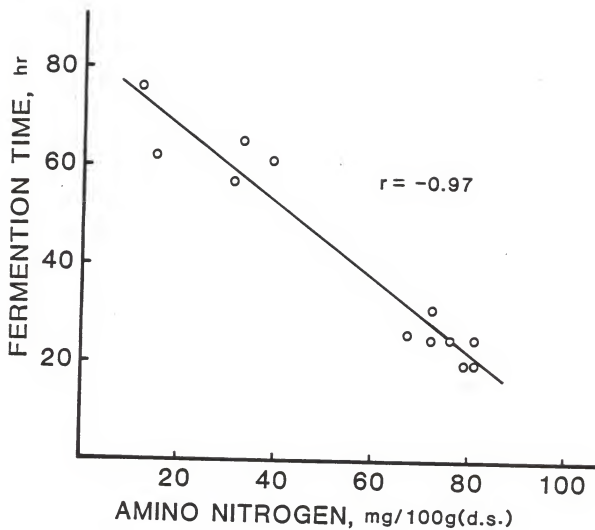
<sup>a</sup>From Kirsop and Brown (1972).

Table 14. Fermentation Times of Saccharified Grain Dusts and Their Mixtures with BCS Based on Equal Initial Glucose Contents (5.6% wb)

Source	Optimum Fermentation Time <sup>a</sup> (hr)
Wheat-corn dust	
Low-starch (WLS)	22 <sup>a</sup>
WLS + BCS (1:1)	23 <sup>a</sup>
High-starch (WHS)	25 <sup>a</sup>
WHS + BCS	25 <sup>a</sup>
Corn-sorghum dust	
Low-starch (CLS)	22 <sup>a</sup>
CLS + BCS (1:1)	24 <sup>a</sup>
High-starch (CHS)	23 <sup>a</sup>
CHS + BCS (1:1)	24 <sup>a</sup>
Sorghum-soybean dust (SSD)	
SSD + BCS (1:1)	25 <sup>a</sup>

<sup>a</sup>Each value is a mean of 2 replications. Mean comparisons within every two rows followed by the same letter are not significantly different ( $p < 0.05$ ).

Figure 7. Relationship between amino nitrogen in enzyme hydrolyzed substrates and their fermentation times measured by gasograph.



distributor and sold for animal feed at \$1 per bucket (50-100 lbs), but this bakery waste is usually discarded.

Estimated net feedstock costs for grain dust, bakery waste, and grains, to produce one gallon of absolute ethanol, with and without added BCS, are presented in Table 15. Since the cost of plant-derived feedstock represents over 50% of the total cost for ethanol production (Faust et al 1983), it is important to identify economical feedstocks. The total cost of the grain dust was calculated as 5% of the corn price ( $\$2.34/\text{bu} * 0.05 = \$0.12/\text{bu}$ ), because about 5% of the dust was mixed back with the grain (mostly corn), and the other grain dust was free. The cost of bakery waste was assumed to be \$1/100lbs. BCS is presently selling around \$20/ton. Feedstock costs for grain dust and bakery waste might be decreased when these feedstocks are purchased on a regular basis.

Based on a typical small scale ethanol production plant (50 gal of ethanol per hr), total costs for producing one gallon of ethanol from grain dust, bakery waste, and grains, with and without BCS, were calculated and are shown in Tables 16 and 17. The U.S. National Alcohol Fuels Commission (1980b) has performed a detailed cost calculation on a 300,000 gallon per year (50 gal per hr) for producing 190° proof fuel ethanol from corn (Table 18). Twenty five percent inflation from 1981 dollars was applied for calculating fixed and variable cost. By-product credit was not subtracted from the estimated production cost, but it could be an important factor.

Table 15. Estimated Feedstock Costs from Various Raw Materials and Their Mixtures with BCS

Raw Material <sup>a</sup>	Price (\$/dry ton)	Ethanol Yield (gal/dry ton)	Net Feedstock Cost (\$/gal ethanol)
Grain dust (GD)	12.40	52	0.24
GD + BCS <sup>b</sup> (1:1)	26.20	79	0.33
Bakery waste (BW)	32.25	100	0.32
BW + BCS (1:1)	36.13	106	0.34
Corn	94.94	103	0.92
Corn + BCS (1:1)	67.47	106	0.64
Sorghum	87.23	107	0.82
Sorghum + BCS (1:1)	63.62	107	0.59
Wheat	124.20	97	1.28
Wheat + BCS (1:1)	82.10	105	0.78

<sup>a</sup>Based on cash price of grain at Kansas City Market on May 19, 1986: corn (No.3), \$2.34/bu; sorghum (No.3), \$2.15/bu; and wheat (No.3), \$3.28/bu. Moisture content for grain and grain dust = 12%, and bakery waste = 38%. Bulk density of grain dust = 22 lbs/bu, corn and sorghum = 56 lbs/bu, and wheat = 60 lbs/bu.

<sup>b</sup>The price of BCS was assumed to be \$20/ton. Solid content of BCS = 50%.

Table 16. Costs for Ethanol Production from Various Feedstocks and Their Mixtures with BCS<sup>a</sup>

Feedstock	Feed Rate <sup>b</sup> (lb ds/hr)	Ratio of Fermentation Time <sup>c</sup>	Variable Cost <sup>d</sup> (\$/gal)
Grain dust (GD)	2140	0.38	0.37
GD + BCS (1:1)	1410	0.42	0.27
Bakery waste (BW)	1120	1.13	0.57
BW + BCS (1:1)	1050	0.57	0.27
Corn	1080	1.00	0.48
Corn + BCS (1:1)	1050	0.54	0.26
Sorghum	1040	1.07	0.50
Sorghum + BCS (1:1)	1040	0.54	0.25
Wheat	1150	0.94	0.49
Wheat + BCS (1:1)	1060	0.54	0.26

<sup>a</sup>Based on 190° proof alcohol from corn (NAFC 1980b).  
Alcohol production rate = 50 GPH.

<sup>b</sup>Distillation efficiency = 95%. Alcohol recovery = 95%.

<sup>c</sup>Relative to the fermentation time of corn (61 hr).

<sup>d</sup>Variable cost was assumed to be proportional to the feed rate and the ratio of fermentation time.

Table 17. Total Production Cost for Ethanol from Various Feedstocks and Their Mixtures with BCS<sup>a</sup> (\$/gal ethanol)

Feedstock	Net Feedstock Cost	Fixed Cost <sup>b</sup>	Variable Cost <sup>c</sup>	Total Production Cost <sup>d</sup>
Grain dust (GD)	0.24	0.54	0.37	1.15
GD + BCS (1:1)	0.33	0.54	0.27	1.14
Bakery waste (BW)	0.32	0.54	0.57	1.43
BW + BCS (1:1)	0.34	0.54	0.27	1.15
Corn	0.92	0.54	0.48	1.94
Corn + BCS (1:1)	0.64	0.54	0.26	1.44
Sorghum	0.82	0.54	0.50	1.86
Sorghum +BCS (1:1)	0.59	0.54	0.25	1.38
Wheat	1.28	0.54	0.49	2.31
Wheat + BCS (1:1)	0.78	0.54	0.26	1.58

<sup>a</sup>Based on 190° proof fuel alcohol from corn (NAFC 1980b). Alcohol production rate = 50 gal per hr (GPH).

<sup>b</sup>Fixed cost included depreciation (10 yr), maintenance, and insurance.

<sup>c</sup>Variable cost included electricity, fuel(coal), labor, enzyme, yeast, and other chemicals.

<sup>d</sup>By-product credit was not included.



Table 18<sup>a</sup>

Total Production Cost - 1981 Basis  
 190° Proof Fuel Alcohol from Corn  
 50 GPH - Base Case  
 300,000 GPY Production  
 TFI = \$714,000

	\$/yr	\$/gal
	-----	-----
Fixed charges		
Depreciation (10 yr), 10% TFI	71,400	0.238
Maintenance, 6% TFI	42,840	0.143
Taxes and insurance, 2% TFI	14,260	0.047
	-----	-----
	128,500	0.428
Raw materials		
Corn (\$2.70/bu)	356,400	1.188
Enzyme (\$0.88/lb, liquid)	21,000	0.070
Yeast (\$1.00/lb, cake)	4,000	0.013
Other chemicals	1,500	0.005
	-----	-----
	382,900	1.276
Utilities		
Electric power (\$0.035/kwh)	15,100	0.050
Fuel (Coal, \$40/T)	27,000	0.090
	-----	-----
	42,100	0.140
Labor		
1 Operator * 3 Shifts * \$15,000/yr	45,000	0.150
	-----	-----
Total production cost	598,500	1.994

TFI = Total Fixed Investment

<sup>a</sup>From NAFC (1980b)

Dehydration of stillage from small-scale production systems does not appear promising because of the high energy requirements and costs (Coble et al 1981). However, the whole stillage could be sold for animal feed as Wet Distiller's Grains (WDG) containing 25-35% dry solids by using low energy methods such as screening, pressing, and sedimentation.

Compared to using grain as a feedstock, ethanol production from grain dust cost only half as much, and ethanol from bakery waste cost three-fourths as much (Table 17). Adding BCS to grains decreased the ethanol production cost by 25-30%. The cost was also decreased by 20% when BCS was added to bakery waste. The cost was only slightly decreased when BCS was added to grain dust. This result might be due to the relatively high price of BCS compared to that of grain dust. However, more cost benefit would be observed if the cost estimation had included the higher productivity and better by-product credit resulting from adding BCS.

## CONCLUSIONS

Grain by-products such as grain dusts and bakery wastes could be used as good feedstocks for ethanol production with high fermentation efficiencies. When BCS was added to these hydrolyzed substrates, fermentation was improved in two ways: one for the fermentation time and the other for the ethanol yield.

In some grain by-products which were low in amino nitrogen, exhaustion of nitrogenous compounds in substrates was determined to be a limiting factor for yeast growth. Because BCS was a very rich source of nitrogen, adding BCS to saccharified bread waste and cake waste reduced fermentation time from 62 hr to 34 hr and from 76 hr to 35 hr, respectively. Addition of BCS in grain dusts did not reduce the fermentation time due to the high concentration of assimilable nitrogen in grain dusts themselves. When hydrolyzed grain by-products were low in fermentable sugar content, addition of BCS increased the yields of ethanol because of the high content available carbon in BCS. The yields of ethanol were increased from 164 - 263 ml/kg ds to 305 - 353 ml/kg ds on grain dusts when equal amounts of BCS were added. However, adding BCS only slightly increased the ethanol yields from bakery wastes.

Compared to using grain as a feedstock, ethanol from grain dust cost only half as much, and ethanol from bakery waste cost three-fourths as much. Adding BCS to grains decreased the ethanol production cost by 25-30%. The cost was also decreased by 20% when BCS was added to bakery waste. The cost was only slightly decreased when BCS was added to grain dust. This result might be due to the relatively high price of BCS compared to that of grain dust. However, more cost benefit would be observed if the cost estimation had included the higher productivity and better by-product credit resulting from adding BCS.

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ETHANOL PRODUCTION FROM GRAIN DUSTS, BREAD WASTE, AND  
CAKE WASTE WITH AND WITHOUT BREWERS' CONDENSED SOLUBLES (3CS)

by

CHUL-HO CHOI

B.E. Han-Yang University, Korea, 1980

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AN ABSTRACT OF A MASTER'S THESIS

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## ABSTRACT

Alcohol fermentation was performed on bread waste, cake waste, and grain dusts from wheat-corn, corn-sorghum, and sorghum-soybean. Each sample was consecutively saccharified using alpha-amylase and glucoamylase before fermentation. A 1:1 mixture of glucoamylase treated brewers' condensed solubles (BCS) and each of these samples was also fermented to determine whether the mixture increased the rate of fermentation and the yield of ethanol. Distiller's active dry yeast was used at 30°C. The gasograph was used to determine the optimum fermentation times. The yields of ethanol and total fermentable sugars were determined with HPLC.

When equal amounts of BCS (as dry solids) were added, the optimum fermentation times were not affected for grain dusts, but were reduced from 62 hr to 34 hr and from 76 hr to 35 hr on bread waste and cake waste, respectively. Because BCS was a very rich source of available nitrogen, fermentation time was reduced by adding BCS when the substrate was low in nitrogen.

Addition of BCS to grain dusts increased the yields of ethanol from 164 - 263 ml/kg ds to 305 - 353 ml/kg ds. But adding BCS only slightly increased the ethanol yields from bakery wastes. When grain by-products had low starch contents, addition of BCS increased the yields of ethanol due to the high available carbon in BCS.

Compared to using grain as a feedstock, ethanol production from grain dust cost only half as much, and ethanol from bakery waste cost three-fourths as much. Adding BCS to grains decreased the ethanol production cost by 25-30%. The cost was also decreased by 20% when BCS was added to bakery waste. The cost was only slightly decreased when BCS was added to grain dust. This result might be due to the relatively high price of BCS compared to that of grain dust. However, more cost benefit would be observed if the cost estimation had included the higher productivity and better by-product credit resulting from adding BCS.