MINUTES OF THE HOUSE COMMITTEE ON AGRICULTURE AND LIVESTOCK

Held in Room 423-S, at the Statehouse at 9:00 a. m./~~p. m.~~, on February 12, 1981.

All members were present except:

The next meeting of the Committee will be held at 9:00 a. m./~~p. m.~~, on February 17, 1981.

These minutes of the meeting held on February 12, 1981 were considered, corrected and approved.

Wm B Beezley
Chairman

The conferees appearing before the Committee were:

Joe King - Kansas Energy Office
Randall Noon, P.E. - Kansas Energy Office

The meeting of the House Agriculture and Livestock Committee was called to order by William Beezley, Chairman. Chairman Beezley told the Committee that he had a request from a farm organization to introduce a Resolution concerning the export of grains. Two years ago this was done in the House and he thought it should be introduced again to re-emphasize our concern. Rep. Polson moved to reintroduce this Resolution. Rep. Fuller gave a second to the motion. The motion carried.

Chairman Beezley introduced Mr. Joe King of the Kansas Energy Office who passed out several reports among which were Gasohol U.S.A., A "Power Grade" n-Butanol/Acetone Recovery System, Utilization of Alcohol By-Products As Feedstuffs and Soybean Oil as a Renewable Fuel, (see attachments). 1-4

There are many contributing factors to the energy problem. The conditions of unrest in the Middle East that cause reserve fuel to be used. Another problem is the amount of fossil fuel it takes to make the heat for alcohol fuel. Is it worthwhile to burn the coal to try to make other fuel sources? There is also a lack of funds; where to go for the money for these projects if there is no positive cash flow. Many times the cost of natural gas does not make it worthwhile to work for an alternative that will cost more to produce.

Randall Noon, a professional engineer from the Kansas Energy Office, said that in the future it may be necessary to move fuel plants away from the farm and to the cities for the biological waste. Bacteria are being genetically bred to eat garbage and in turn produce oil to be used as fuel. Numerous questions and comments of an energy related nature were volunteered by members of the Committee.

Chairman Beezley told the Committee of an invitation by President Acker to visit Kansas State University. The Committee responded that they would like to visit the University in the future.

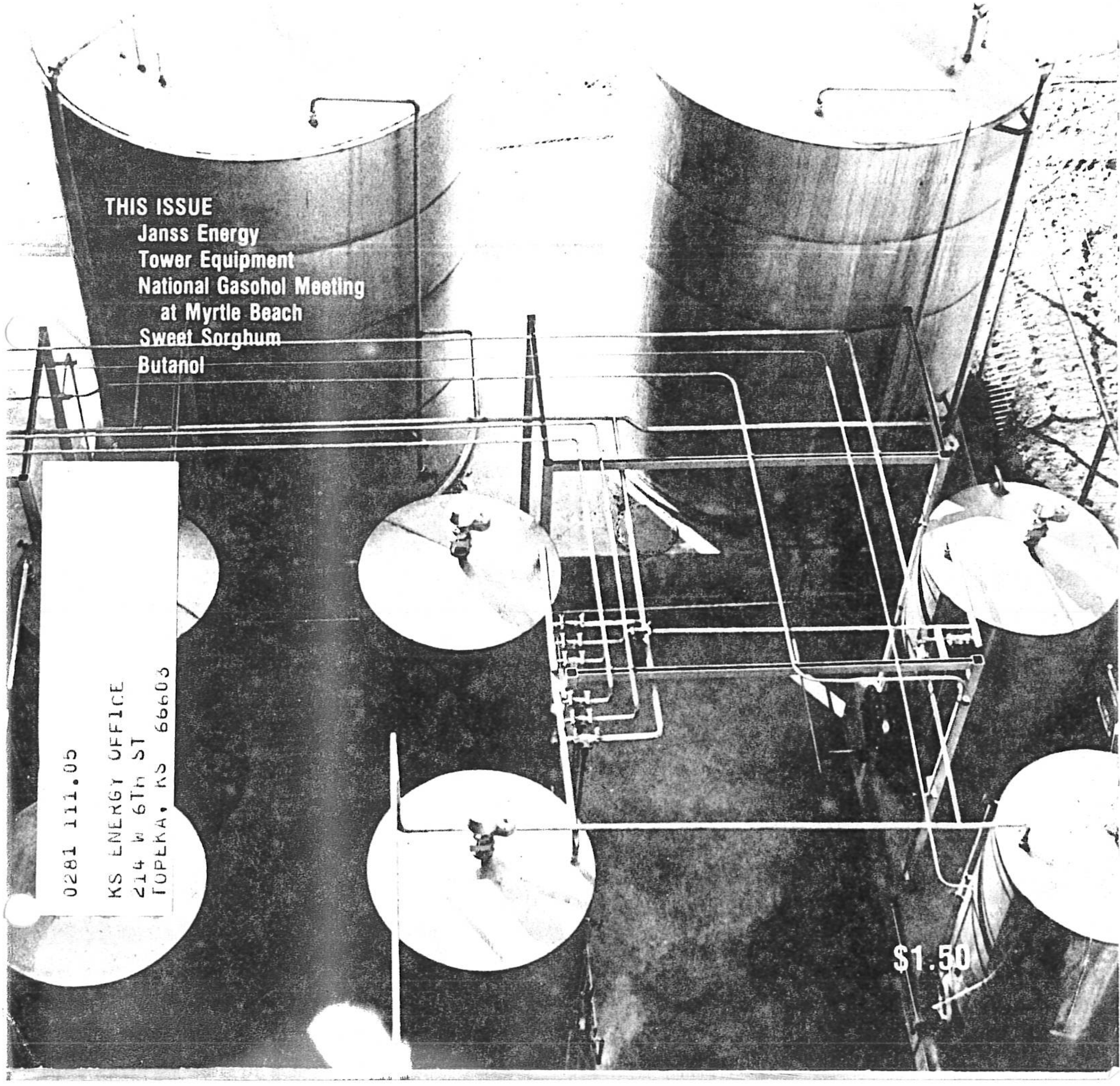
Chairman Beezley asked for action on the minutes. Rep. Johnson moved the minutes be approved. Rep. Teagarden gave a second to the motion. The motion carried. The meeting was adjourned.

Atch. 1

gasohol u.s.a.

DECEMBER 1980

VOL. 2, No. 12



THIS ISSUE
- Janss Energy
- Tower Equipment
- National Gasohol Meeting at Myrtle Beach
- Sweet Sorghum
- Butanol

$1.50

The Potential of Butanol

Butanol and acetone can be produced via a fermentation process similar to ethanol. Butanol/acetone fuel mixtures offer several advantages over straight ethyl alcohol/water fuel mixtures. Whereas ethanol fuels require licensing and strict observance of federal and state laws, butanol and acetone are not regulated. These and other advantages may make the production of butanol/acetone fuels from renewable agricultural resources an alternative choice for a gasoline substitute. Since butanol is rapidly gaining attention nationwide, even among members of the National Alcohol Fuel Producers Association, readers of Gasohol U.S.A. *will find this report by Randall Noon, Assistant Director of the Kansas Energy office to be of maximum interest.*

The organism called *Clostridium acetobutylicum* converts hexose sugars into n-butanol, acetone, and ethanol in ratios of 6:3:1 respectively. This is done in a process similar to methane digestion in that *Clostridium acetobutylicum* is an anaerobic bacteria. This means that it lives in the absence of free oxygen. Other byproducts of this anaerobic digestion are carbon dioxide gas, hydrogen gas, and protein enriched stillage, more or less identical to the stillage obtained from ethanol production.

In table 1 are shown the comparative physical characteristics of ethanol, acetone, and n-butanol. The specific gravities of all three are very close, less than 3% different. However, due to the increased molecular size, acetone and n-butanol have respectively 11% and 24% more heat of combustion per liter than ethanol. As a comparison, note that gasoline has a heat of combustion of 3.45 x 10^7 joules per liter. Ethanol has a combustion value 32% lower than gasoline, acetone and n-butanol are only 24% lower and 15% lower respectively.

In table 2 are shown the fuel products of ethanol fermentation and n-butanol/acetone production. While ethanol production produces 25% more liquid volume, it produces only 6% more liquid fuel value. However when the energy of the hydrogen gas is in-

Table 1
COMPARISIONS OF ETHANOL, BUTANOL & ACETONE

	Ethanol	n-Butanol	Acetone
Specific gravity (water = 1.000)	0.789	0.810	0.790
Boiling point	78.5 C.	117.25 C.	56.2 C.
Freezing point	−117.3 C.	− 89.5 C.	−95.4 C.
Molecular weight	46	74	58
Heat of combustion (20 C., 1 atm.)	2.35 x 10^7*	2.92 x 10^7*	2.61 x 10^7*

*JOULES PER LITER, 100% PURE SUBSTANCE

Table 2
RELATIVE ENERGY PRODUCTION FROM 1 BUSHEL OF CORN

Ethanol Fermentation	
Combustible products of fermentation	11.4 liters ethanol
Combustion value	26.79 x 10^7 joules
n-Butanol Fermentation	
Combustible products of fermentation	5.47 liters n-butanol 2.74 liters acetone 0.91 liters ethanol
Subtotal	9.12 liters liquid fuel 0.27 kilograms of hydrogen gas
Combustion value	15.97 x 10^7 joules n-butanol 7.15 x 10^7 joules acetone 2.13 x 10^7 joules ethanol 0.85 x 10^7 joules hydrogen
Total	26.10 x 10^7 joules

Table 3
SOLUBILITY

Substances	Miscibility
Ethanol in water	in all proportions
Acetone in water	in all proportions
n-butanol in water (20 C.)	Water layer - 92.2% water 7.8% n-butanol Alcohol layer - 20% water 80% n-butanol

cluded into this energy ledger we find the fuel energy output of ethanol production and the total fuel energy output of butanol production are nearly identical.

It is important to note the quality of the fuels produced in the two different fermentation processes. According to a number of tests performed by the National Bureau of Standards in 1945, butanol/acetone fuel combinations have fuel characteristics in the middle ground between ethanol and gasoline. *Journal of Research of the National Bureau of Standards*, volume 35, December 1945, "Utilization of Non-Petroleum Fuels in Automotive Engines," by Jesse Duck and Clarence Bruce, Research Paper #RP 1681. This would make butanol/acetone fuels a more reasonable alternative fuel choice for engines originally designed for gasoline consumption.

In table 3 are shown the solubilities of acetone, ethanol, and n-butanol in water. Of the three substances, ethanol and acetone are completely miscible in water. However, n-butanol is only slightly soluble in water. Once the water has become saturated with n-butanol, the remainder will layer out and float on the top. This effect can be enhanced by "salting out" the alcohol, that is, by adding salt, sodium chloride, the solubility of butanol and water is further decreased. When this happens, the butanol will layer out at 160 proof and float on top of the solution.

At 160 proof (80% n-butanol, 20% water) n-butanol has an approximate combustion value of 2.41 x 10^7 joules per liter and a specific gravity of 0.842. In other words, the heat of combusion for 160 proof n-butanol is about equal to 200 proof ethanol. In an internal combustion engine this water may be useful to help minimize temperatures to help reduce NO_x emissions.

The bacteria that accomplishes this conversion is often found in farmyard soils. *Clostridium acetobutylicum* (and also *Clostridium sacchrobutyl acetonicum liquefaciens*) is closely related to *Clostridium botuli*, the "bug" that causes botulism poisoning in improperly canned foods. The *C. acetobutylicum* is anaerobic, grows optimumly at 37 C, and belongs to the family of rod-shaped motile bacteria.

To ferment starches to n-butanol, the corn is prepared up to the point of yeast innoculation identical to ethanol production methods. In other words, if materials containing starches are used, the starches have to be hydrolized into sugars. After saccharification is complete, the *C. acetobutylicum* is added to the mash with ammonia nitrogen, and the mash is covered to prevent oxygen poisoning, much like a methane generator. Fermentation then proceeds while the mash is maintained at proper temperature and pH for approximately 48 hours.

Recovery of the fermentation products can be accomplished in several ways. The traditional technique is by fractional distillation. However, for fuel purposes, the fractional distillation need not proceed along conventional lines. In other words, it is not necessary to produce pure n-butanol, pure acetone, or pure ethanol through an extensive fractional distillation process. As long as most of the water is removed, the relative impurities are unimportant.

Another method of recovery which may be utilized is that of the molecular sieve. Zeolite, and other similar materials, allow the smaller water molecules to pass through, but not the larger molecules of butanol acetone and ethanol. They would be left behind in a liquid mixture, which is fine for fuel purposes.

The third way to recover the products of fermentation is to take advantage of the fact of n-butanol's limited solubility in water. As was mentioned before, in a binary system, water will absorb n-butanol until it is saturated with about 7 to 8% n-butanol. After the water is saturated, any excess butanol will layer out at the top in a 20% water, 80% n-butanol combination. However, in the presence of acetone and ethanol, and a small amount of salt, n-butanol will layer out before saturating the water at the 8% n-butanol level. This layer of butanol will be 160 proof n-butanol with acetone and ethanol impurities. For fuel purposes, this impure condition of the n-butanol is not a major concern. Thus the n-butanol layer could be decanted off the top of the mash. This is important because a significant fraction of the fuel produced by the fermentation process might not require distillation to be recovered.

After the butanol layer is decanted, the remaining mash will be made up of acetone, ethanol, water, salt and wet stillage. The acetone then can be distilled out at a very modest energy cost due to the fact that the vapor point of acetone is at 56.2 C. Much less energy is required to distill out acetone as, say for example, ethanol whose vapor point is 78.5 C. The remaining ethanol would be left in solution due to the small amount available for recovery.

One of the interesting facets of butanol production is the hydrogen gas byproduct. Both hydrogen and carbon dioxide are gaseous byproducts of this fermentation method. Hydrogen will represent approximately 40% of this byproduct gas. The energy available in the hydrogen that is given off could be useful in supplementing the energy required to run the system or it could be separated out and sold, depending on the economics.

Prior to WWII n-butanol was produced on a large scale in the United States specifically in Terre Haute, Indiana and Peoria, Illinois. However at that time it was not valued as a fuel, but rather as a chemical feed stock for rubber production. Prior to that, it was the main source for England during WWI. After WWII, petroleum became cheap and plentiful, and the production of butanol/acetone via fermentation dropped dramatically. So while the production of butanol via fermentation has been a known process since about 1910, the production of butanol as a fuel is a relatively new concept for chemical plant designers.

While all the elements of butanol production have worked in and of themselves at various times, they have not yet been melded together into a small scale fuel production system.

Atch.2

A "Power Grade" n-Butanol/Acetone Recovery System

DRAFT

A conceptual design for an n-butantol/acetone recovery system which takes advantage of the limited miscibility of n-butanol and water to reduce process energy consumption in producing a "power grade" fuel mixture.

by
Randall Noon, P.E.
Assistant Director, Kansas Enegy Office
Energy Research and Resource Development

January 1981

Abstract

Besides ethanol, there are several fermentation processes which can produce hydrocarbon compounds useful for fuel. In particular, the Weizmann Process produces n-butanol, acetone and ethanol via anaerobic fermentation. These fermentation products can be used individually for fuel, or in blends. Because of some particular physical characteristics of these products, anhydrous quality is not necessary for use in either gasohol-type blends or as a straight fuel. This and other factors allow substantial reductions in the process energy required for recovery of the products from the beer. Such a "powergrade" recovery system is proposed.

Introduction

Besides ethanol, there are a number of combustible fermentation products which could be utilized as alternatives to petroleum derived liquid fuels. One such fermentation product is normal butanol (n-butanol).

N-butanol can be produced via bacterial anaerobic fermentation of hexose or pentose monosaccharides. In some cases, the n-butanol can be produced via direct bacterial breakdown and subsequent fermentation of starch without separate enzymatic saccharification of the starch, although at usually a lower conversion rate than via direct monosaccharide fermentation. Table 1 lists some of the common n-butanol producing bacteria.

In association with n-butanol, liquid co-products of acetone and ethanol, and in some cases isopropanol, are formed. In addition to the liquid co-products, gaseous co-products of carbon dioxide and hydrogen gas are produced.

Weizmann Process

As listed in table 1, one of the common n-butanol producing organisms is Clostridium acetobutylicum. Cl. acetobutylicum is a rod shaped, motile, obligate bacterium in the same family of organisms as Clostridium botulinum, the "bug" that produces botulism poisoning in improperly canned food. Cl. acetobutylicum is able to ferment about 34% of the hexose monosaccharides obtained thru the saccharification of corn into n-butanol, acetone and ethanol. Typical time required for such fermentation ranges from 40 to 56 hours in an 8.5% corn meal mash. Production of n-butanol using Cl. acetobutylicum is often referred to as the Weizmann Process, in honor of the developer.

Table 1. Butanol Producing Bacteria

Organism	substrate	Liquid products ratio BtOH	 acetone	 EtOH	% of hexose sugar converted	Fermentation Temperature
Cl. acetobutylicum	corn	62%	30%	8%	34%	37°C
Cl. saccharo-acetobutylicum	corn	73%	23%	4%	33%	30°C
Cl. saccharo-acetobutylicum	molasses	73%	23%	4%	22%	30°C
Baccillus butacone*	beet molasses	70%	28%	2%	36½%	37°C
Cl. saccharo-acetoperbutylicum*	invert molasses	76%	22%	2%	30%	30°C
Cl. acetobutylicum	corn hydrol	62%	30%	8%	33%	37°C

*Able to convert starch

Liquid Fuel Production

Dry corn is about 72% starch which can be broken down enzymatically to monosaccharides. Furthermore, 34% of those monosaccharides can be fermented into fuel products of n-butanol, acetone and ethanol. Therefore, a bushel of corn (25.5 kg) can yield 25% of its weight in liquid fuel products of n-butanol, acetone and ethanol. The proportional distribution of the liquid fuel products consists of 62% n-butanol, 30% acetone and 8% ethanol. On a volume basis per bushel of corn this corresponds to 4.87 liters, 2.42 liters and 0.64 liters respectively. Small amounts of higher weight alcohols and other organics may also be produced.

Hydrogen Gas and Carbon Dioxide Production

On a weight basis, the Cl. acetobutylicum also converts 1.5% of the monosaccharide substrate into hydrogen gas, and 54% of the substrate into carbon dioxide gas. Using the above dry bushel of corn basis, this amounts to a production of 9.9 kg of carbon dioxide and 0.27 kg of hydrogen. On a volume basis, the proportional distribution is 62% carbon dioxide and 38% hydrogen gas.

Fuel Value Comparison to Ethanol Production

As a comparison to n-butanol fermentation production, consider the standard fermentation production of ethanol. Table 2 lists the comparative higher heating values of the products of both processes. The usual liquid fuel production figure quoted for ethanol from 1 bushel of corn is 9.4 liters. This compares to a combined production of 7.9 liters of liquid fuel per bushel using the Weizmann Process, a 16% reduction in volumetric production. However, the total higher heating value of the 9.4 liters of ethanol is 2.2 x 10^8 joules; the combined higher heating value of the n-butanol, acetone and ethanol also total 2.2 x 10^8 joules. Additionally, if the higher heating value of the hydrogen gas is considered, the total combined higher heating value is then 2.28 x 10^8 joules, about 3.6% greater than the total energy production thru ethanol fermentation. As a general rule, while butanol production produces less volume of liquid fuel than ethanol production, the caloric product value of the two processes are about equal.

Table 2. **Comparisons of Higher Heating Values**

Material	Higher Heating Value	Relative Caloric Value to Gasoline
n-butanol	2.92 x 10^7 joules/liter	84%
acetone	2.61 x 10^7 joules/liter	75%
ethanol	2.35 x 10^7 joules/liter	67%
hydrogen	3.15 x 10^7 joules/kilogram	70% (by weight)
gasoline	3.49 x 10^7 joules/liter	100%

Direct Use as a Fuel

As a liquid fuel substitute, n-butanol has a variety of potential uses. By A.S.T.M. motor octane standards, acetone is rated 93, and n-butanol is rated 83. Either compound can be successfully used as a fuel for Otto cycle engines, or they can be blended together. For example, a 28.5% acetone/71.5% butanol fuel blend has a motor octane number of 87 and a research octane number of 100. This would provide a pump grade of 93.5 octane (using R+M/2 rating system), which is considerably higher than the commonly supplied 87 or 88 pump grade octane of unleaded gasoline.

In Gasohol-Type Blends

In gasohol-type mixtures, n-butanol has been shown to blend well with either gasoline or #2 diesel fuel, for use in either Otto or Diesel cycle engines. In Otto cycle engines, 20% n-butanol can be incorporated without modifications to the engine. Diesel cycle engines can incorporate 30-40% n-butanol without modifications.

Water Tolerance

Unlike ethanol, n-butanol is water tolerant in gasohol type blends. Whereas only a fraction of a percent of water is enough to cause the phase separation of ethanol and gasoline, or of ethanol and #2 diesel fuel, n-butanol and gasoline or n-butanol and diesel do not phase separate when water is present. The n-butanol component absorbs some of the initial moisture until it becomes saturated. Adding further moisture beyond the n-butanol saturation level will cause a water layer to form on the bottom, as water usually does when added to gasoline. This ability to absorb water and not phase separate may offer several advantages:

1. Using a combination of anhydrous n-butanol with gasoline or diesel would preclude water pockets from forming in the fuel lines.

2. Using water saturated n-butanol as a gasoline or diesel additive would allow incorporation of small amounts of water into the engine to reduce NO_x emmissions without the use of injection or aspiration equipment.

3. Being able to blend water laden n-butanol with gasoline or diesel without phase separation saves processing energy in the recovery of n-butanol from the fermentation beer.

With Vegetable Oils

Additionally, n-butanol blends well with vegetable oil fuels, such as soybean oil, rapeseed oil or peanut oil. It reduces the higher viscosity of the vegetable oils, a common problem in the utilization of such fuels. Furthermore, it can be used as an esterfying agent with vegetable oils to produce a more "diesel-like" fuel form.

Power Grade n-Butanol/Acetone Fuel

Brief History

N-Butanol and acetone production via fermentation began on an industrial scale during World War I. The acetone was prized by the military for use in the manufacturing of explosives and glues. During World War II, the n-butanol was valued as a feedstock for synthetic rubber. After the Korean War when inexpensive petroleum derivatives became plentiful, the production of n-butanol and acetone via fermentation became uncompetitive in the U.S.

Chemical Grade

During the approximately 40 years that n-butanol and acetone were commercially produced via fermentation in the U.S., the n-butanol and acetone were produced as chemical feedstocks. Recovery of the products of fermentation was done by standard fractional distillation techniques in order to achieve chemical grade purity. While this level of purity certainly enhances their use as a fuel, it is not required. A lower grade of n-butanol and acetone can be produced which is still useful as a motor fuel, but which requires substantially less process energy to achieve.

Power Grade

The term power grade is used here to refer to a fuel blend that is composed of 16.7% water and 83.3% combined n-butanol, acetone, and ethanol. The n-butanol, acetone, and ethanol are in ratios of 7.75:4:1, respectively. This particular fuel mixture is created by the blending of 80% n-butanol/20% water, 88% acetone/12% water, and 95% ethanol/5% water components. These solvent/water ratios represent the grades of n-butanol acetone, and ethanol that are theoretically producible in the particular power grade recovery system discussed in this paper.

The above fuel blend has an overall higher heating value of 2.39×10^7 j/l*, which is 2% higher than the corresponding value for anhydrous ethanol. Using the (R+M)/2 method, this fuel blend is estimated to have a pump octane rating of 94.

Stoichiometric Air/Fuel Ratio

The stoichiometric combustion equations for the n-butanol/acetone/ethanol/water fuel blend are as follows:

eq. (1) n-butanol $C_4H_{10}O + 6O_2 = 4CO_2 + 5H_2O$

---

* j/l = joules per liter

eq. (2) acetone $C_3H_6O + 4O_2 = 3CO_2 + 3H_2O$

eq. (3) ethanol $C_2H_6O + 3O_2 = 2CO_2 + 3H_2O$

Using the stated proportions of n-butanol/acetone/ethanol/water, and utilizing air, then on a per mole basis of the n-butanol component,

eq. (4) $$C_4H_{10}O + (0.617)\,C_3H_6O + (0.207)\,C_2H_6O + (1.080)\,H_2O + (10.089)(0_2) + (50.445)\,N_2 =$$

$$(6.265)\,CO_2 + (8.525)\,H_2O + (50.445)\,N_2$$

From equation (4), the stoichiometric air/fuel ratio is calculated to be 13.66. Including the water component as fuel, the air/fuel ratio is then 11.8. In comparison, the stoichiometric air/fuel ratios of anhydrous ethanol and gasoline are 9.0 and 14.7 respectively.

Expected Mileage

Assuming that the water content exits the exhaust ports as steam, an estimate of potential mileage can be made by relative comparisons of the lower heating values. From equation (4), the lower heating value, and of the n-butanol/acetone/ethanol/water fuel blend is calculated to be 2.21×10^7 j/l, which is 93% of its higher heating value, and 3% higher than the lower heating value for anhydrous ethanol. Based upon the relative lower heating values of gasoline and the n-butanol/acetone/ethanol/water fuel blend, a 38% decline in mileage would be expected as compared to usual gasoline mileage.

Power Grade Fuel Recovery System

The Basic System

Beer leaves the fermentation tank at 37°C at a concentration of 2.5% combined n-butanol, acetone and ethanol. The acetone will be recovered first in a standard distillation column. The acetone still bottoms products will consist then of water, n-butanol and ethanol. This bottoms solution is then passed to another distillation unit, where water is separated from the n-butanol and ethanol. As water is removed via distillation, the overhead will consist of n-butanol and ethanol vapors, and about 45% water vapor. Upon condensation, the n-butanol will phase separate from the water, carrying some of the ethanol by absorption. This n-butanol phase layer, which consists of mostly water saturated n-butanol, can be decanted off the solution, with the lower phase of n-butanol saturated water being returned to the still.

Acetone Recovery

As shown in figure 1, a water/acetone binary solution has an azeotropic boiling point at 56.1°C at atmospheric conditions. At the azeotrope, the concentration of acetone is 88.5%. This also represents the maximum concentration of acetone obtainable by simple distillation at atmospheric conditions.

Binary Solution Assumption

As shown in table 3, the boiling temperatures of n-butanol, water, ethanol and acetone are about 20°C apart in descending order. The fact that the concentrations of n-butanol and ethanol are low in comparison to the water, and that the corresponding boiling point depression effects would also be low, the solution can be assumed to be a binary system of acetone and water for distillation purposes at this point.

Table 3. Distillation Data

Material	boiling point	Relative Volatility to Water at 100°C
acetone	56.1°C	3.52
ethanol	78.5°C	1.90
water	100.0°C	1.00
n-butanol	117.7°C	0.42

Still Temperatures

The acetone still will have an overhead exit temperature of 56.1°C, and a bottoms temperature of 100°C.

ACETONE - WATER BOILING DIAGRAM

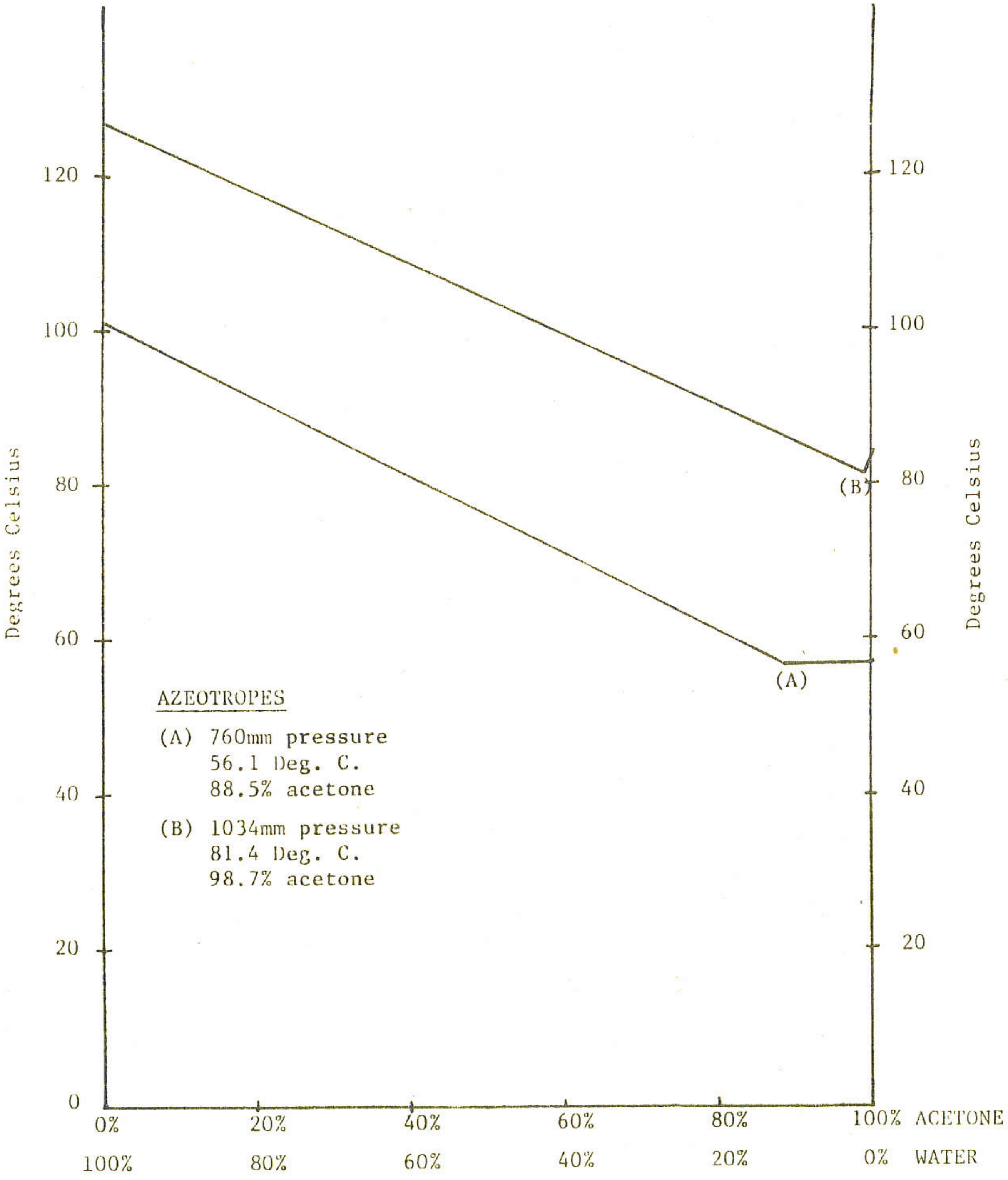


Figure 1.

Bottoms Products

As the acetone is withdrawn via distillation, the remaining bottoms product will consist of ethanol, n-butanol and water. This bottoms product is then passed to the butanol distillation unit.

N-Butanol/Ethanol Recovery

N-Butanol/Water Solubility

Water and n-butanol are not totally miscible in one another, as is the case with ethanol and acetone. Water will absorb n-butanol up to a 7.8% concentration (by weight). Beyond that level, the excess n-butanol will form a separate, upper phase consisting of 80% n-butanol/20% water. For example, if 100 grams of n-butanol were added to 200 grams of water, an upper layer would form containing 86 grams of n-butanol, with the remaining 14 grams of n-butanol contained in the lower layer.

Upper Layer/Lower Layer Solubility Equations

The following equations are developed for predicting upper layer/lower layer concentrations of n-butanol and water.

let x = butanol amount in upper layer (by weight)
let y = butanol amount in lower layer
let a = water amount in upper layer
let b = water amount in lower layer

eq. (5) $\mathbf{x/(x + a) = 0.80}$

eq. (6) $\mathbf{y/(y + b) = 0.078}$

let $a + b = c$
let $x + y = z$

by substitution into (5) and (6) respectively eq. (7) $(z - y)/(z - y + a) = 0.80$

eq. (8) $y/(y + c - a) = 0.078$

solving (7) and (8) yields

eq. (9) $z - 4a = y$

eq. (10) $(0.078)b = y$

rearranging and adding (8) and (9) yields

eq. (11) $c = 0.25z + 12.57y$

Thus, equation (11) indicates that if the total water and n-butanol quantities are known, "y", the amount of butanol in the lower layer, can be calculated. The n-butanol in the upper layer is then (z - y), the water in the lower layer is then 12.82y, and the water in the upper layer is then (c - 12.82y).

Figure 2 is a graphic representation of equation (11) where the total n-butanol content is held constant at 1 kilogram, and the amount of water is varied.

Still Temperatures

In the n-butanol recovery unit, the bottoms temperature will be at $100^{\circ}C$ with the exiting overhead temperature at $93^{\circ}C$, the azeotropic temperature. As shown in figure 3, the azeotrope of n-butanol and water forms at a ratio of 55.5% n-butanol to 44.5% water, which is also the main exiting overhead product.

Overhead Products

When the overhead product is condensed, two phases, or layers, will form. The upper phase will contain 95.7% of the n-butanol available in the azeotropic blend, and will constitute 71.5% of the volume of the condensed blend. The lower phase will be n-butanol saturated water which is returned to the still, though at a point above where the bottoms from the acetone still enters in order to take advantage of the lower phase's higher n-butanol concentration.

N--BUTANOL and WATER STRATIFICATION CHART
for TOTAL BUTANOL CONTENT OF 1.0 KILOGRAM

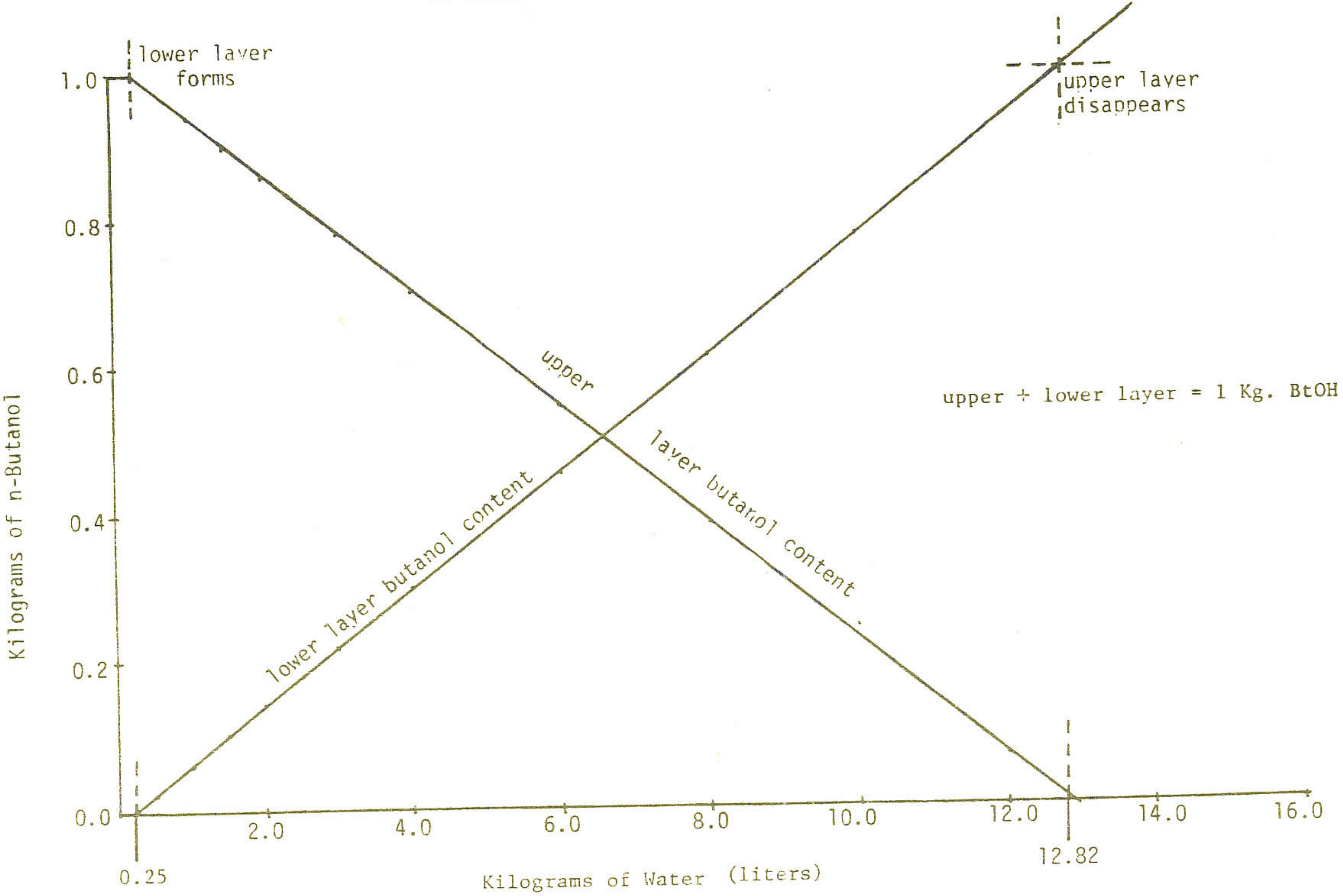


Figure 2.

N-BUTANOL - WATER BOILING DIAGRAM

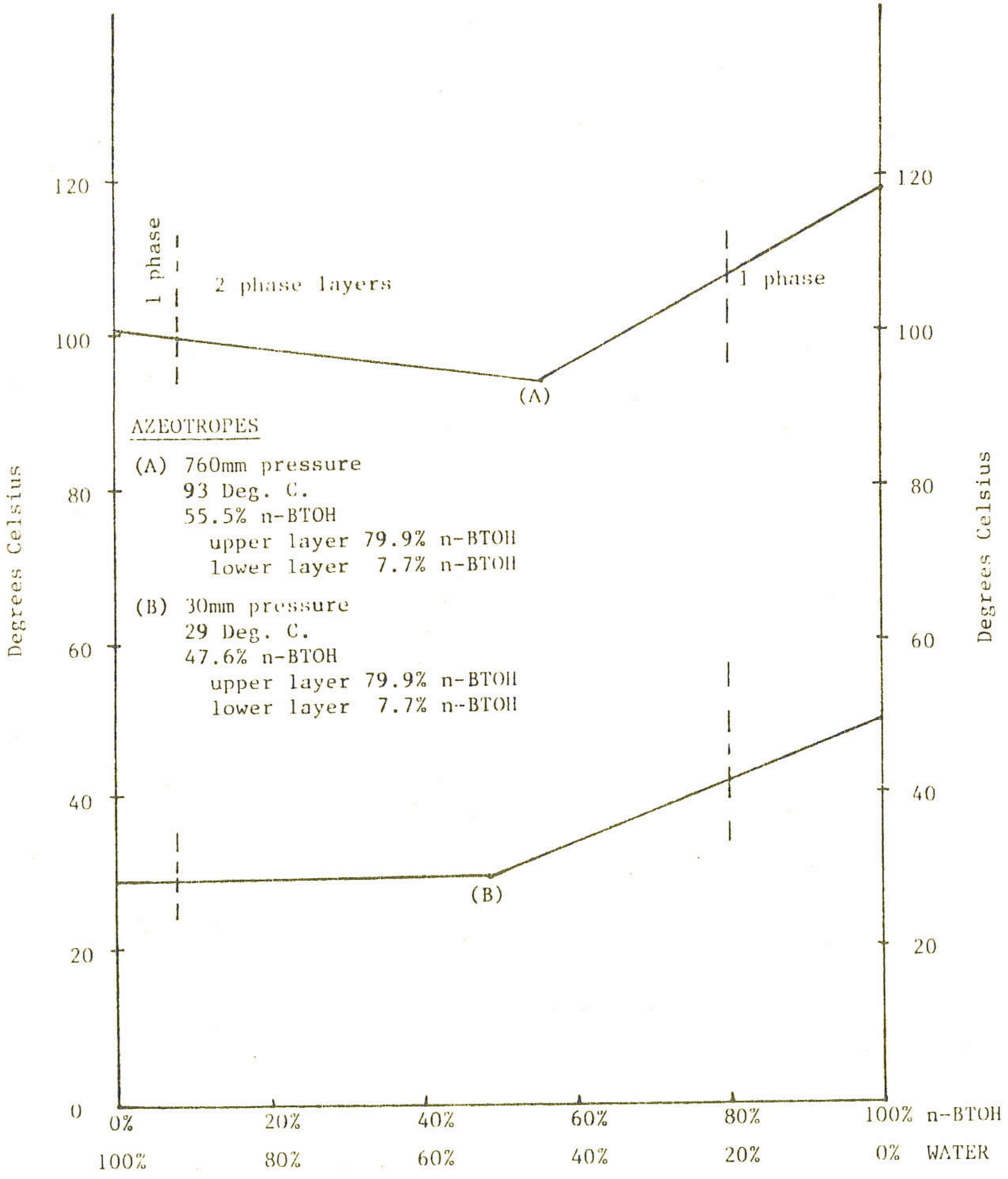


Figure 3.

Simultaneous Ethanol Recovery

It is expected that a significant portion of the ethanol will end up as impurity in the decanted n-butanol. The ethanol in the solution has a higher relative volatility than either water or n-butanol so that most of it will generally end up in the overhead as vapor. In the n-butanol condensate, the ethanol will be distributed between the two phases according to standard solution equilibrium balances, with most of it in the upper phase. Also present in this upper phase will be small amounts of higher alcohols and organics, such as iso-amyl alcohol.

Bottoms

The bottoms product of the n-butanol recovery unit will be relatively pure water suitable for setback to the mashing and fermentation process steps.

Energy and Mass Balance of the System

Referring to figure 4, when the beer leaves the fermentation tank, its temperature will be 37°C, the fermentation temperature. On a per kilogram input basis, the beer will consist of 975.0 g of water, 15.5 g of n-butanol, 7.5 g of acetone and 2.0 g of ethanol.

1st Preheater/ Acetone Condenser

The beer passes thru the first preheater, which also acts as the condenser for the acetone still. As a condenser, 7.5 g of acetone and 1.0 g of water are being cooled from the vapor state at 56.1°C to a liquid at 37°C, releasing 6,782 joules. Assuming 80% transfer, the incoming beer will pick up 5426 joules and be warmed to 38.3°C.

2nd Preheater/ Butanol Condenser

Next, the beer passes to the second preheater, which is also the condenser for the n-butanol still. As a condenser, 15.5 g of n-butanol, 2 g of ethanol and 12.7 g of water are being cooled from the vapor state at 93°C, to a liquid state at 39°C, releasing 45,186 joules. Assuming 80% transfer, the fluid will pick up 36,149 joules to increase the fluid temperature to 47°C.

N-BUTANOL/ACETONE RECOVERY SYSTEM

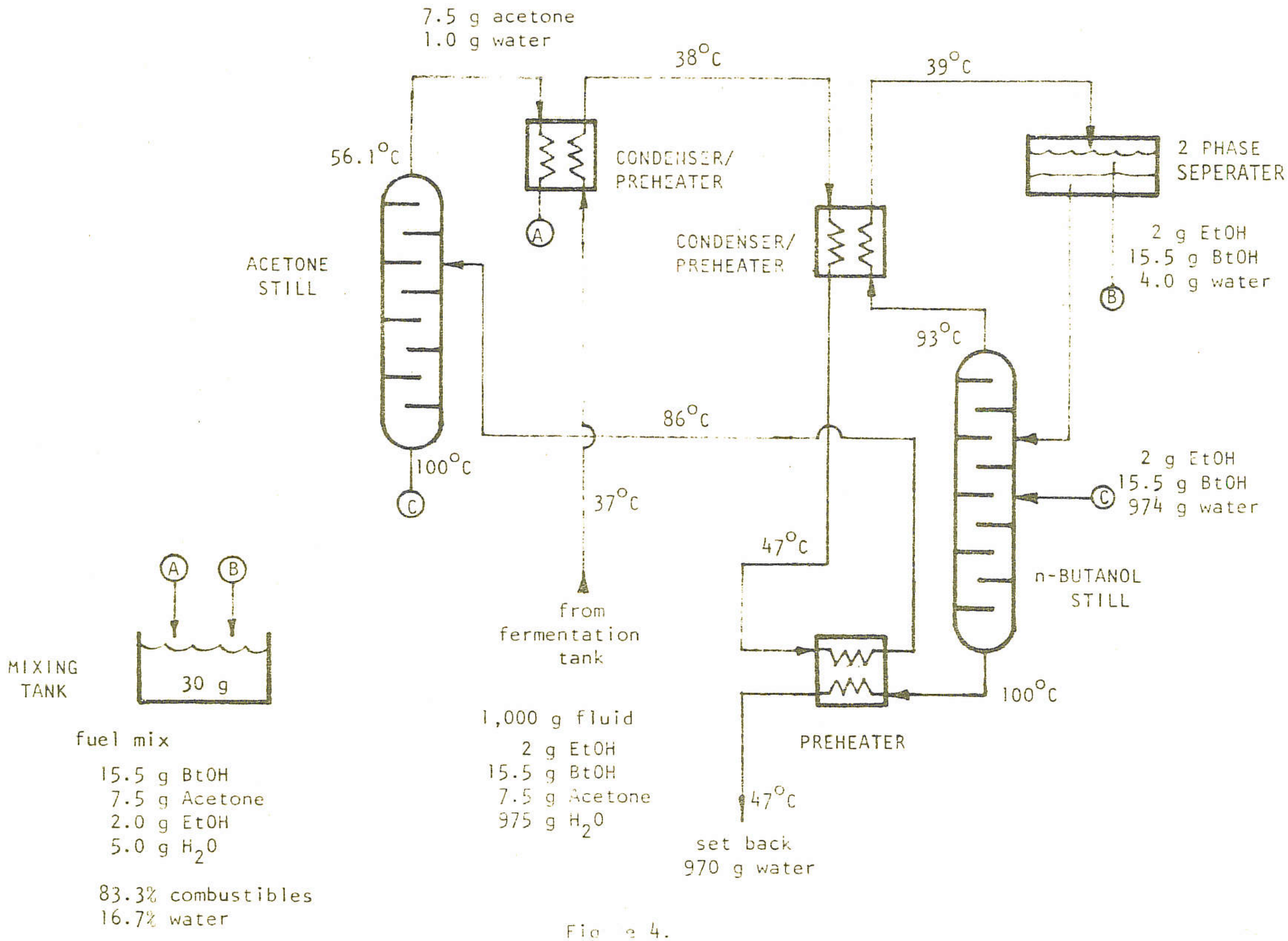


Figure 4.

3rd Preheater

The third preheater recovers the heat from the water coming from the butanol still bottoms. Entering at 100°C the bottoms water is cooled to 47°C, and is then dispatched back to the fermentation portion of the process to be reused. In cooling the setback, 215,100 joules are released. Assuming a 75% transfer, 161,325 joules are added to the beer, thus increasing its temperature to 86°C.

Acetone Still

The beer enters the acetone still at 86°C. In order to heat the beer to 100°C and vaporize the net acetone/water overhead, 64,782 joules are required from an outside source, such as a closed loop boiler. This will cause 7.5 g of acetone and 1.0 g of water to be distilled out. The bottoms will then consist of 2 g of ethanol, 15.5 g of n-butanol, and 974 g of water at 100°C.

Butanol Still

The butanol still requires 45,186 joules to vaporize 15.5 g of n-butanol, 12.7 g of water and 2 g of ethanol. Additionally, since 8.7 g of water and 0.65 g of n-butanol from the phase separater are returning at 39°C, 2011 joules are needed to bring that up to 100°C. Thus 47,200 joules are required from an outside source.

Energy Balance

In all, 112,000 joules are needed to produce a 30 g fuel mixture within the system boundaries. On a kilogram output basis, it requires 3.73×10^6 joules to produce a fuel mixture with a higher heating value of 2.88×10^7 joules/kilogram, a 7.7:1 ratio. Of course, inefficiencies not accounted for in the rather ideal model will cut into that ratio, perhaps reducing it to as low as 5:1. In comparison, the energy ratio for anhydrous ethanol recovery is often quoted at about 3:1.

Boilers

If closed loop boilers are used for which the above calculations were intended and an 80% boiler efficiency is assumed, a rating of at least 140,000 joules per kilogram of total fermented fluid is required. Location of boilers and steam feeds were not shown in figure 4 in order to simplify the schematic.

Reflux

It has been tacitly assumed throughout the above analysis that packed columns are used for the distillation equipment, hence no reflux return was shown. If plate columns are used, the energy balance calculations cited above will need to be adjusted to account for the reflux flows.

Extra Efficiency Due to Hot Water Utility

Of the water that enters the system at 37°C, 99% is returned as bottoms from the butanol still at 47°C. This hot water will be useful in providing heat for the front end of the n-butanol production system. It can be argued that since some of that heat will be recovered there, the 10°C difference should be accounted for as useful energy. This amounts to 40,546 joules, thus reducing the overall net consumption from 112,000 joules to 71,500 joules, a reduction of 37%. This being the case, on a per kilogram output basis, the energy requirement is only 2.5×10^6 joules, a 11.5:1 ratio. However to properly account for the extra advantage afforded by the hot water would require the fermentation and recovery process to be considered as a whole, which is beyond the scope of this paper.

Salting Out

As is the case with other partially water soluable alcohols, n-butanol's soluability in water may be reduced if an inorganic salt is added to the solution. This could be useful in the decanting of the n-butanol in the separator, in that a little more n-butanol would layer out in the upper phase. However, several disadvantages outweight this effect. Some of the salt would remain in the upper phase layer, and could end up as a deleterious deposit in an engine. Most of the salt would filter down the butanol distillation unit into the setback, making the setback unusable for fermentation. Strong salt solutions are especially corrosive on steel components so that special brine-environment alloys would be required, thus increasing the initial capital for equipment. In all, "salting out" the n-butanol, though possible, is not particularly advantageous.

Summary/Conclusions

It has been shown that the Weizmann process fermentation products of n-butanol, acetone, and ethanol have potential for use as a fuel. Some of the particular characteristics of n-butanol seem to be especially advantageous, such the ability of water saturated n-butanol to mix with gasoline or diesel without phase separation. Capitalizing on that fact, a recovery system is suggested that instead of producing standard chemical grades of n-butanol, acetone and ethanol, produces a power grade n-butanol, acetone, ethanol, and water solution from the beer, which is suitable for fuel use. By recovering at power grade quality, the process energy investment costs are very modest, especially in comparison to anhydrous ethanol recovery.

The investigation of butanol production from biomass for liquid fuel is only beginning to be explored. The fact that n-butanol can be fermented from both hexose and pentose sugars holds the promise of being able to produce double the liquid fuel energy from cellulose conversion technology as ethanol fermentation, which utilizes only the hexose sugar components. Much work remains to be done, and it is unlikley that butanol will be a panacea for all our liquid fuel needs. Like ethanol, butanol is just one choice among many others in the spectrum of fuels available from biomass.

References

Microbiology

Beesch, S., 1952, 1952, "Acetone-Butanol Fermentation of Sugars", Ind Eng Chem, Vol. 44, pgs. 1677-1682.

Beesch, S., 1953, "Acetone-Butanol Fermentation of Starches", Applied Microbiol, Vol. 1 #2, pgs. 85-95.

McCutchan and Hickey, 1954, "The Butanol-Acetone Fermentations," Industrial Fermentations, Vol. I, pgs. 345-388.

Weizmann, C., 1919, U.S. Patent #1,315,585.

Compere and Griffith, 1979, "Evaluation of Substrates for Butanol Production", Development in Industrial Microbiology, Chap. 48, Vol. 20.

Wendland, Fulmer and Underkofler, "Butyl-Acetonic Fermentation of Jerusalem Artichokes", Ind Eng Chem, Vol. 33, pgs. 1078-1081.

Fuel Use

Miller and Smith, 1980, "Diesel Engine Performance Using Butanol Fuel Blends", Amer. Soc. of Agri. Eng., Paper #80-1524.

Dick and Bruce, 1945, "Utilization of Nonpetroleum Fuels in Automotive Engines", J. of Research of the Nat'l Bureau of Standards, Vol. 35, pgs. 439-465.

_________, 1980, "Engine Performance Using Butanol", Earth Energy, Vol. 2, #2.

Brooks, D., 1945", Single Cylinder Engine Tests of Substitute Motor Fuels", J. of Research of the Nat'l Bureau of Standards, Vol. 35, pgs. 1-37.

Boruff, Goering, Schwab, and Pryde, 1980, "Engine Evaluation of Diesel Fuel-Aqueous Ethanol Microemulsions", Amer. Soc. of Agri. Eng., Paper #80-1523.

Recovery Systems

Grosset, Folk and Lemarchand, 1980, "Recovery of Neutral Solvent Fermentation Products", Oak Ridge Nat'l Lab., ORNL/MIT-307.

Fuel System

Noon, 1980, "Agri Fuel Potentials of Butanol/Acetone Production", Proceedings from 7th Annual UMR-DNR Energy Conference, Univeristy of Missouri-Rolla.

Sklar, 1980, "Will Butanol be the Next On-Farm Liquid Fuel", Gasohol, U.S.A., Vol. 2, #8, pg. 19.

Oliver, 1980, "Agriculture: Industrial Raw Materials for the Future", Revue Du Marche Commun, April.

Exhibit A

UTILIZATION OF ALCOHOL BY-PRODUCTS AS FEEDSTUFFS

Atch. 3

A revised research proposal submitted to the
Kansas Energy Office

by

Kansas State University
Department of Animal Sciences and Industry
Manhattan, KS 66506

Principal Investigator B. E. Brent Date 12/30/80
B. E. Brent

Department Head Don L. Good By B. E. B. Date 12/30/80
D. L. Good

Director Ag. Experiment Station Stanley E. Blandford for FWS Date DEC. 30 1980
Floyd W. Smith

Comptrollers Office Ralph H. Perry Date DEC 31 1980
Ralph H. Perry
Comptroller

Utilization of Alcohol By-products as Feedstuffs

A revised research proposal submitted to the
Kansas Energy Office

by

Department of Animal Sciences and Industry
Kansas State University
Manhattan, KS 66506

Contact Persons: Don L. Good or B. E. Brent (913) 532-5654 for technical matters only.

JUSTIFICATION:

Effluent from ethanol distillation is normally dried to produce distillers dried grains and/or distillers dried solubles, with the consequent expenditure of considerable energy. These products are normally produced economically only by large distillers, leaving smaller distillers with the problem of how to dispose of the effluent economically without creating polution problems. The effluent contains valuable nutrients useful to the livestock industry. However, the high water level makes transportation and storage in the wet form impractical.

This document proposes a series of research trials to evaluate using the effluent in the wet form in livestock rations. Should economical uses for wet stillage be found, the small distillers should benefit from cost reduction and an additional income source, and grain producers should benefit through increased prices.

Research Objectives:

The research objectives will be studied in two phases, contingent upon the funding schedule, as follows:

Phase I:

1) To determine the nutrient composition and storage life of wet stillage from a variety of sources and grains.

2) To evaluate grain sorghum stillage in cattle growing and finishing rations.

Phase I, con't.

3) To evaluate grain sorghum stillage as a nutrient source in sow gestation diets.

Phase II:

1) To evaluate grain sorghum stillage as a nutrient source for cow herds.

2) To evaluate grain sorghum stillage for reconstituting dry grains and forages prior to ensiling.

3) To evaluate grain sorghum stillage as a nutrient source in swine growing and finishing rations.

Research Procedures:

Because of the nature of the proposed research, it is impossible to establish "iron-clad" research protocols. The following procedures are general. Experimental procedures used in most trials will depend on results of the previous trial or trials.

Phase I:

1) Analytical and storage life studies

About 100 representative samples of stillage will be obtained and analyzed for the following components:

water
crude protein
residual alcohol
fiber fractions (crude fiber, acid detergent fiber,
neutral detergent fiber, lignin)
residual starch
volatile fatty acids (acetic, propionic, butyric)
soluble carbohydrates
pH

In addition, titration curves, as an indication of buffering capacity, will be run on selected samples.

Half of the samples will be from the source used in the feeding trials and half will be obtained from various other alcohol plants in order that results represent a variety of production techniques and feed stocks. From these data, tables will be prepared showing nutrient content and amount of variability that may be expected for stillage from various sources. Samples will be solicited from corn and wheat, in addition to milo samples.

Samples will be analyzed "fresh" and following storage for varying lengths of time.

2) Stillage for growing and finishing cattle

A. Palatability and daily intake studies

Twenty steers will be individually fed straight stillage to determine daily consumption when:

1. Fed as the only source of feed and water
2. Fed as the source of feed but with access to water

Depending on the results from the above project, we will decide whether use of straight stillage is a realistic, feasible alternative.

If the stillage needs to be diluted with additional dry matter to encourage consumption and to benefit performance, we will proceed with a second series of individual feeding studies where stillage will be fed at different proportions of the ration. Initial plans are to feed stillage as:

(1) 0% of the ration - 5 individually fed steers
(2) 10% of the ration - 5 individually fed steers
(3) 20% of the ration - 5 individually fed steers
(4) 40% of the ration - 5 individually fed steers
(5) 80% of the ration - 5 individually fed steers

B. Use of stillage as a protein source

Based upon results from part A, we will be able to select levels of stillage that need further evaluation. This series of studies would compare steer performance when stillage is the protein source vs. soybean oilmeal as protein source. Moisture content of the rations would be similar.

Once again 20 steers will be individually fed.

(1) 5 steers soybean meal supplement
(2) 15 steers stillage as supplemental protein at 3 levels of stillage based upon trials in part A

C. Use of stillage as protein source in finishing rations

Results from part B will enable us to determine one or two levels of stillage that need further evaluation using more animals and a more typical feedlot ration. The specific number of pens and level of stillage may need to be altered based upon results from part B but tentatively would be as follows:

(1) 3 pens - (5 steers per pen) 85% concentrate 15% SBOM Supplement
(2) 3 pens - (5 steers per pen) 85% concentrate 15% Urea Supplement
(3) 3 pens - (5 steers per pen) 85% concentrate 15% Stillage Supplement
(4) 3 pens - (5 steers per pen) 85% concentrate 7.5% Stillage and 7.5% Urea

D. Optimum level of stillage in growing-finishing rations

Results from parts A-B-C should enable us to know how to handle and feed the stillage and should have given us guidelines about intake at various levels and the value as a protein source. This trial would be conducted in our small group-fed pens with 5 steers/pen and would involve 3 pens for each of 4 stillage levels. The stillage levels would be selected based upon results from parts A-B-C.

E. Storage and Handling

Information relating to methods of handling and storing will be important throughout the trial. Special consideration will given to:

(1) Keeping grain particles in suspension during storage or immediately prior to feeding
(2) Rate of deterioration during storage
(3) Influence of environmental conditions on storability

Scientifically recognized "bunk life" monitoring procedures will be used. Sample numbers will be consistent with statistical requirements.

3) Stillage for gestating sows

Twenty individually-fed sows will be fed stillage as the only source of feed and water to determine daily consumption. Then, eight sows adapted to these stillage diets will be placed in metabolism crates to measure how well the sow utilized the protein and energy in stillage. This study would demonstrate how much of the sow's daily nutrient requirements could be met from stillage.

Phase II:

1. Stillage for beef cows

A. Two groups of cows are available with approximately 20-25 cows/lot. One group will be fed a conventional soybean oilmeal supplement and the other group will be fed the same amount of protein but the source will be stillage.

2. Stillage used to reconstitute dry grain and forage

A. Dry forages such as prairie hay, alfalfa hay and wheat straw will be used initially. The forage will be ground and mixed with stillage to approximately 65% moisture. They will be packed and stored in 55 gallon laboratory silos to evaluate fermentation parameters and storability. At least 5 silos will be used per forage source.

B. Corn, milo and wheat will be used initially. Grain will be mixed with the stillage to raise the final grain moisture content to 25%. The reconstituted grain will then be packed into 55 gallon laboratory silos and fermentation parameters evaluated. At least 5 silos will be used per grain source.

3. Stillage for growing-finishing swine

Stillage will be used as both a protein and an energy source for growing-finishing pigs.

A. Palatability and Intake Studies:

Ten individually-fed pigs will be fed stillage to determine daily consumption when fed as:

1. The only source of feed and water
2. The only source of water
3. Mixed with dry feed and fed as a liquid feed

B. Stillage as a Protein and/or Energy Source:

Based on studies in A, following treatments will be used with 2 pens of 5 to 10 pigs per treatment.

(a) Basal ration - sorghum grain and soybean meal
(b) Stillage added to the basal ration replacing sorghum grain
(c) Stillage added to basal rations replacing sorghum grain and soybean meal on a lysine basis
(d) Stillage used as the water source and protein reduced in the basal ration based on intakes in A 1.
(e) Stillage and basal ration fed in liquid rations with stillage replacing sorghum grain and soybean meal on a lysine basis

Publication of Results:

Results will be made public through various KSU publications, public meetings, and scientific journals, with appropriate recognition for funding organizations.

Personnel:

Analytical studies: B. E. Brent

Beef cattle and reconstitutions studies: Jack Riley, Larry Corah

Swine studies: Gary Allee

Projected time table:

Phase I

Analytical studies can start as soon as funding for this phase is approved. Feeding studies must be delayed until spring because of stillage freezing problems. All feeding Phase I studies should be completed within 1 year of initial phase I funding. Final statistical analysis and submission to scientific journals will be completed by December 31, 1982.

Phase II

Stillage feeding studies on cows and growing finishing swine will be initiated in spring, 1981. Reconstitution studies on grain can be started whenever danger of freezing is past. Obviously, the timeliness of this research will depend on when and if Phase II is funded. Provided funding for phase II is in hand prior to July 1, 1981, all phases should be complete by December 31, 1982.

Stillage procurement

A contract for stillage procurement has been negotiated with Wood Enterprises Alcohol, of Manhattan, KS. Timely performance of those parts of this proposal requiring large quantities of stillage will, of course, be predicated on the performance of these vendors.

Budget

Phase I - January 1, 1981 - December 31, 1982

	Kansas Energy Office	K.S.U.
Equipment for transporting and feeding	$13,500	-
Salaries, including benefits		
a) Graduate research assistant	12,048	-
b) Student labor	4,000	-
Stillage @ 18.75¢/gal.	13,125	-
Analytical services	2,500	-
Animal feed and maintenance	5,000	-
Travel	327	-
Indirect costs (38.4% of MTDC costs)		14,208
	$50,500	$14,208
Total, Phase I	$64,708	

Phase II - July 1, 1981 - December 31, 1982

	Kansas Energy Office	K.S.U.
Feed for reconstitution	$6,000	-
Stillage @ 18.75¢/gal.	5,625	-
Analytical Services	1,000	-
Publication costs	1,000	-
Student labor	3,000	-
Animal Maintenance	3,500	-
Travel	375	-
Indirect costs (38.4% of MTDC)		$7,872
	$20,500	$7,872
Total, Phase II	$28,372	

Atch. 4

Soybean Oil as a Renewable Fuel

A report on the potentials of soybean oil as
a renewable fuel, as compared to ethanol production.

by Randall Noon, P.E.
Assistant Director
and
Thomas Hochstetler
Energy Research Assistant

Kansas Energy Office
Topeka, Kansas

July, 1980

Abstract

In comparison with farm production of ethanol, soybean oil is easier to process, has better adaptability for diesel powered equipment and produces a better animal feed by-product. Additionally, the energy balance of soybean oil production is greatly superior to the overall energy balance of ethanol production. However, important long-term engine performance data is presently lacking to establish the viability of soybean oil for extended use..

Introduction

Modern American agriculture is predicated upon the ready availability of cheap and abundant energy. Since World War I, the increasing ability to produce more food per unit land has been accomplished by an even greater increase in investment energy per unit land. Without energy for chemicals, irrigation and mechanization, the American food machine would simply stop.

Since 1973, the year of the grain embargo, the premise of future supplies of cheap and abundant petroleum energy has been questionable. In an effort to develop local, alternate energy resources, the production of ethanol (ethyl alcohol) has been encouraged.

Ethanol is being viewed by some as the fuel for the agricultural sector. It can be fermented from most crops containing starch or sugar, and can be concentrated to fuel grades using multi-plate distillation columns.

However, ethanol is not the only alternative fuel. The choice of ethanol has been more of technical convenience than deliberate optimization. There are several other biomass derived fuels which may offer greater advantage than ethanol, such as higher chained alcohols, long chain organic acids, and vegetable oils.

The following paper examines one of these other alternatives, soybean oil, and compares it with ethanol.

Physical Characteristics

Soybean oil has a specific gravity of 0.905. This is about 16% heavier than ethanol, but approximately equal to the specific gravity of #2 diesel fuel. By weight, soybean oil has 33% more combustable energy than ethanol, and only 10% less than #2 diesel. By volume, soybean oil has 56% more combustable energy than ethanol, 4% more than gasoline, and 11% less than #2 diesel.

In terms of engine utilization, soybean oil has a cetane number of about 25, and an octane number of about 35. This means that soybean oil could be used in blends of up to 25% with #2 diesel fuel in standard diesel engines with compression ratios of between 15:1 and 18:1. Using a cetane enhancer, such as the addition of 2.0% amyl nitrate, soybean oil could be used "straight" in standard diesel engines. In high compression diesel engines it could be used "straight" without the use of cetane enhancing additives.

Soybean oil is soluable in ethanol. Since spark ignition engines presently utilize a fuel octane rating of 88, soybean oil can be combined with alcohol to substitute for gasoline. A mixture of 75% ethanol and 25% soybean oil would produce a fuel with an octane rating of 88 and an energy density of 95,300 BTU/gal, or about 13% greater than anhydrous ethanol alone.

Table 1 shows a comparison of the fuel characteristics of soybean oil, #2 diesel fuel, ethanol, and gasoline.

Unlike ethanol, which is a single chemical, soybean oil is composed of five major chemical components: linoleic acid, oleic acid, palmitic acid, stearic acid and linolenic acid. These are organic acids composed of carbon, hydrogen, and oxygen with mostly 18 carbon atom chain length molecules. The average molecular weight is about 280. In general, all five components have similar chemical fuel properties to one another. In fact, if two other organic acids, erucic acid and hydroxysteric acid are included with these five, just about all the common vegetable oils could be described as combinations of these seven components. This, of course, accounts for the general similarity of most vegetable oils. Table 2 lists the component proportions of soybean oil. As a comparison, table 3 lists the component proportions of six additional vegetable oils.

Energy Balance

In 1974 the United States Department of Agriculture undertook a study of the amounts of energy needed to grow various crops in various regions. Since this study represents the best comprehensive data available in this subject area to date, all figures in this section are 1974 farm year statistics in order to correspond to the parameters derived from the study.

In terms of the total agricultural system, soybean oil production is on the average an excellent net energy producer in Kansas. Comparatively, ethanol is a net energy producer in Kansas only if milo is used.

Table 1. Comparative Fuel Characteristics of Soybean Oil, Diesel, Ethanol and Gasoline

	Soybean Oil	#2 Diesel Fuel	Ethanol	Gasoline
Specific gravity	0.905	0.920	0.794	0.739
Higher heating value (BTU/lb)	17,000	19,110	12,800	20,300
Lower heating value (BTU/lb)	15,500	18,000	11,500	18,900
Cetane Number	25	45	-0-	12
Research Octane No.	35	15	106	85-94
Energy density* (HHV) (BTU/gal)	130,000	146,450	84,660	125,000
Energy density (LHV) (BTU/gal)	120,000	138,000	76,000	116,300
Cost* $/Gallon	$ 1.81	$ 1.00	$ 1.80	$ 1.21
per 10^6 BTU (HHV)	$ 13.91	$ 6.83	$ 21.26	$ 9.68
per 10^6 BTU (LHV)	$ 15.07	$ 7.25	$ 23.68	$ 10.40

*As of July 8, 1980

Table 2. Soybean Oil Components

Component	Empirical Formula	Molecular Weight	Specific Gravity	% of Composition
Linoleic Acid	$C_{18}H_{32}O_2$	280	0.905	51.5
Oleic Acid	$C_{18}H_{34}O_2$	282	0.895	33.4
Palmitic Acid	$C_{16}H_{32}O_2$	256	0.841	6.8
Stearic Acid	$C_{18}H_{36}O_2$	284	0.847	4.4
Linolenic Acid	$C_{18}H_{30}O_2$	278	0.923	2.4
Other fats and fatty acids	-------	-----	------	1.5

Table 3. Components of Some Common Vegetable Oils

Component	Soybean Oil	Cotton Seed	Linseed Oil	Corn Oil	Rapeseed Oil	Sunflower Oil	Castor Bean Oil
Linoleic Acid	51.5%	50%	15%	54%	22%	57%	3.5%
Oleic Acid	33.4%	25%	22%	37%	22%	35%	3.2%
Palmitic Acid	6.8%	21%	-0-	5%	1%	5%	1%
Stearic Acid	4.4%	2%	-0-	2%	1%	2%	1%
Hydroxystearic Acid	-0-	-0-	-0-	-0-	-0-	-0-	89%
Erucic Acid	-0-	-0-	-0-	-0-	50%	-0-	-0-
Linolenic Acid	2.4%	-0-	50%	-0-	4%	-0-	-0-
Other	1.5%	2%	13%	1%	-0-	1%	-0-
Specific Gravity	0.905	0.890	0.905	0.895	0.883	0.895	0.910

From one bushel (56 pounds) of soybeans, about 1.1 gallons of oil (15%) can be expressed mechanically. At 130,000 BTU/gal of soybean oil, there is 143,000 BTU of fuel in each bushel of soybeans. In Kansas in 1974, it took an average of 95,000 BTU of energy to grow and harvest soybeans. This includes the energy invested in pesticides, and fertilizers. Additionally it takes 10,000 BTU to express the oil from one bushel of soybeans. Thus for a fuel output value of 143,000 BTU/bu, soybeans required an input of 105,000 BTU/bu of investment energy. This is an energy ratio of 1.36 to 1.

Soybean meal by-product contains 40% protein by weight. It does not require drying, or other further processing since it is already essentially dry. On a per bushel basis, soybeans produce 47.6 pounds of meal, which contains 19 pounds of protein.

Using a average yield of 20 bushels per acre, it takes 2.1 x 10^6 BTU per acre to grow, harvest and express out soybean oil. For this effort, about 2.8 x 10^6 BTU per acre in fuel value and 952 lbs of soymeal (containing 380 lbs of protein) will be produced per acre.

From one bushel of corn or milo, about 2.5 gallons of anhydrous ethanol can be produced. At 84,600 BTU/gal, this is a fuel value of 211,500 BTU per bushel of corn and 124,000 BTU per bushel of milo to grow and harvest each grain.

In order to process the grain into anhydrous ethanol about 33,600 BTU per gallon, or 84,000 BTU per bushel of process energy is required if the by-product is utilized wet. Thus, for a fuel value of 211,500 BTU/bu, 284,600 BTU/bu of investment energy using corn or 208,000 BTU/bu of investment energy using milo is required. This is an energy ratio of 0.73 and 1.02 to 1, respectively. About 86% more process energy is required if the by-product is dried into DDG.

The ethanol by-product, wet stillage or DDG, contains 27% protein per dry weight basis. On a per bushel basis, corn or milo produces 16.5 lbs of dry weight feed by-product which contains 4.5 lbs of protein.

Using a average yield of 76 bu/acre for corn and 40 bu/acre for milo, it takes 21.6 x 10^6 BTU and 8.3 x 10^6 BTU respectively to grow, harvest and process the grains into ethanol from 1 acre of average Kansas land. For this effort, corn will yield 16 x 10^6 BTU and 8.3 X 10^6 BTU and milo will yield 8.4 X 10^6 BTU in fuel value per acre, plus 1,231 dry pounds of corn by-product (332 lbs protein) or 648 dry pounds of milo by-product (175 lbs protein).

While corn and milo can produce more fuel value per acre, they both require greater amounts of energy to grow, harvest and be processed into ethanol. Expressing oil from soybeans requires a very small amount of energy in comparison to cooking, fermentation and distillation. Also, soybeans require less fertilizer and are generally not grown under irrigation; this reduces the comparative required energy investment.

Whereas, the ethanol by-product is wet and is problematic to store for longer than 36 hours, soybean meal is storable and more economically transportable due to its higher protein content. Furthermore, soybeans produce more pounds of pure protein per acre than either corn (14% more) or milo (120% more).

In short, soybean oil in Kansas is more energy positive and produces more of a higher quality by-product than ethanol produced from corn or milo. However, soybeans require more land to product an equivalent amount of fuel derived from corn or milo. Table 4 summarizes the energy balance data on a per acre basis.

Production and Utilization Advantages

In Kansas, the great majority of farm equipment is diesel engine powered. The use of ethanol is such engines is somewhat problematic. Ethanol is a fine spark ignition fuel, but is not a good compression ignition fuel due to its inherent low cetane number and low lubrication value. Many farm ethanol operations produce a grade of ethanol containing 5% or more water. This water renders the ethanol unsuitable for diesohol type fuel mixtures due to the water sensitivity of the diesel fuel component. When anhydrous ethanol is used, about 10% ethanol can be incorporated into diesel fuel before the overall cetane number becomes drops below specifications. Some aspiration systems have been divised to carburate greater percentages of ethanol or ethanol/water combinations directly into the cylinders rather than using tank mixtures.

Soybean oil, however is intrinsically more "diesel" like, and does not pose the same limitations as ethanol. Soybean oil mixes well with diesel fuel for tank fuels, or it can be used straight in some cases. In most respects, soybean is more compatable with diesel engine equipment than ethanol and requires less modification of the equipment.

Table 4. Relative Energy Balances of Soybean Oil versus Ethanol
(figures: U.S. Department of Agriculture,
Economic Research Service 1974)

	Soybeans	Corn	Milo
(1) Crop yield	20 bu/acre	76 bu/acre	40 bu/acre
(2) Fuel yield	22 gal/acre*	190 gal/acre	100 gal/acre
(3) Fuel energy yield**	2,800,000 BTU/acre	16,036,000 BTU/acre	8,440,000 BTU/acre
(4) Energy investment***	1,900,000 BTU/acre	15,244,000 BTU/acre	4,961,000 BTU/acre
(5) Process energy, wet	NA	6,380,000 BTU/acre	3,360,000 BTU/acre
(6) Process eenrgy, dry	200,000 BTU/acre	11,860,000 BTU/acre	6,240,000 BTU/acre
(7) Net energy production ratio****			
a. wet (3)/(4)+(5)	NA	0.74	1.01
b. dry (3)/(4)+(6)	1.33	0.59	0.75
(8) By-product, whole	952 lbs/acre	1231 lbs/acre	648 lbs/acre
(9) By-product, protein content	380 lbs/acre	332 lbs/acre	175 lbs/acre

*Mechanically pressed out

**Higher heating value used

***Includes fertilizers and pesticides

****Does not include by-product credit

Soybean oil is easier to produce than ethanol. Compared to ethanol, the mechanical equipment for expressing soybean oil is cheap, unsophisticated, and can be operated on demand without having to wait on fermentation. Unlike ethanol no significant amounts of water are required for processing soybean oil, nor is there any need for subsequent effluent processing or ponding. Soybean meal stores well and has export mobility due to its higher percentage of protein content. Unlike wet stillage, soybean meal is well documented as a feed supplement and has well established domestic and international marketability.

In short, soybean oil is a more compatable fuel with agricultural equipment, it is easy and cheap to process into oil, and it produces a by-product with superior handling and nutritional characteristics than the on-the-farm ethanol production plant.

Economics*

Soybean oil at the wholesale level sells for 24¢ per pound, or about $1.81 per gallon. At the wholesale level, anhydrous ethanol also sells for about $1.81 per gallon. However, due to the greater energy density of soybean oil, soybean oil is 36% less expensive than ethanol per million BTU (see table 1).

Soybean meal sells for $221 per ton. That equates to 27.6¢ per pound of protein. On a pound per pound of protein basis, that places a value of $149 per dry weight ton for ethanol by-product. On a per acre basis, that means that soybeans will produce $105.20 worth of feed supplement. Corn and milo will produce $91.70 and $48 28 worth of dry weight feed supplement per acre, respectivley. Because of its greater bulk, shipping ethanol by-product of corn or milo will cost more than shipping soybean meal. This is even more so if the ehtanol by-product is used wet.

The difference between the meal and oil value of a bushel of soybeans, and the raw per bushel cost is about 45¢. This reflects the low costs associated with processing the soybeans into oil and meal. Comparatively, the difference between the ethanol and by-

*All numbers as of July 8, 1980.

product value of a bushel of corn or milo, and the raw per bushel costs are \$2.90 and \$3.03, respectively. While one bushel of corn or milo will produce 48% more fuel energy than soybeans, its processing costs are about 6 2/3 times more per bushel. On a per unit energy basis, it is 4½ times more expensive to process ethanol than soybean oil at current market values.

Soybeans are nitrogen fixing plants in that they tend to enrich the soil's nitrogen content rather than depleting it like corn or milo. If soybeans were properly managed and rotated in a multi-crop operation, it could result in economic savings by reducing the amount of nitrogen fertilizers required by the other crops. This is one of the main reasons why soybeans require less investment energy than corn or milo (see table 4).

State Impact

In 1978, Kansas produced 401,450,000 pounds or 43,252,000 gallons of soybean oil and 876,629 tons of soybean meal. This translates to a yield of 18.6% oil from each bushel of soybeans, a slightly higher rate of yield than the 15% used in earlier calculations. However, the 18.6% yield figure includes soybean oil that was chemically extracted using hexane rather than being mechanically expressed which is slightly less efficient, as would be the case for on the farm production. Assuming that a diesel car travels an average of 12,000 miles per year at 20 miles per gallon, this would be theoretically enough to service about 90,000 such vehicles, or about 1.2 such vehicles for each farm in Kansas.

While the investment in land may preclude being able to generate fuel for everyone, there is enough soybean oil potential to substantially supplement the agricultural sector's need for diesel engine grade fuel. The handling advantages of the soybean meal mean that a farm could grow some soybeans as a hedge against temporary fuel shortages, but not have to own cattle or otherwise use the feed by-product locally like the wet by-product for ethanol production.

Need for Research

While various vegetable oils have been run in short, engine tests, the long term effects are unknown. Performance, engine wear, residue build up, corrosion, erosion, emissions, and cold weather starting are areas where there exists a capacity of reliable data. Before soybean oil can be effectively utilized as a reliable, agricultural fuel, these areas will have to be investigated.

These tests may point out potential problems or useful engine modifications. Furthermore, such testing would provide a basis for manufacturer exceptance. While potentially promising, more information is needed.

Summary

Soybean oil can potentially substitute for diesel fuels in agricultural equipment. Soybean oil is easy and cheap to process compared to ethanol production, and has a superior overall system energy balance. Soybean meal is easier to market than ethanol by-product and is less troublesome because it is already "dry". Soybean oil costs the same per gallon as ethanol, but contains 54% more combustable energy. While it takes more land than with ethanol to produce a given BTU amount, the production of soybean oil appears to be easier to manage than ethanol for farm fuel production. However, further basic engine tests are needed to confirm this.

References

"High Grade Fuel From Biomass Farming," by Weisz and Marshall, Science, Vol. 206, #5, Oct., 1979.

Small Scale Fuel Alcohol Production, USDA, Washington, D.C., 202050, march, 1980.

Castor, Sesame, and Safflower, by E. Weiss, Leonard Hill Publishers, London, 1971.

Kansas Agriculture, 62nd Annual Report, Kansas Board of Agriculture, Topeka, 1979.

Net Energy Analysis of Alcohol Fuels, API Publication 4312, November 1979.

Energy and Agriculture 1974 Data Base, (Kansas section 1, Vols. I & II, Economic Research Service, U.S. Department of Agriculture and the Federal Energy Administration, Washington, D.C. 20250, 1976.

Small Scale Ethanol Production for Gasohol, by David, Buzenberg, Hammaker and Pfost, Ozark Regional Commission and Kansas Energy Office, April, 1980.