Dehydration of an ethanol-water mixture by sorption using barley as the sorbent
by James Patrick Law

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering
Montana State University

Abstract:
Experiments were conducted to determine the feasibility of utilizing barley as a dehydration agent for the separation of an ethanol-water mixture. The variables tested were mass flux, column geometry, grain particle size distribution, and the number of regenerations of the barley.

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The best results were obtained with the smallest particle size distribution and the lowest mass flux. The yield varied between 0.029 and 0.191 grams 99-wt% ethanol produced per gram dried barley. The column geometry had an effect at the low mass fluxes, but had no effect at the high mass fluxes. Effects of column diameter were larger than the effects of column length on the yield. Grain regeneration is necessary if the barley is to be used to produce fermentation ethanol. Ethanol along with water was adsorbed into the barley.

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James Patrick Law

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for admission to the College of Graduate Studies.

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ABSTRACT

Experiments were conducted to determine the feasibility of utilizing barley as a dehydration agent for the separation of an ethanol-water mixture. The variables tested were mass flux, column geometry, grain particle size distribution, and the number of regenerations of the barley.

The mass flux was varied between 0.035 and 0.35 gm/min-sqcm. A vapor phase, fixed-bed adsorption apparatus was used with three different adsorption columns. The adsorption columns used were 1.5" (diameter) X 14" (length), 1.5" X 24", and 2.5" X 23". Three particle size distributions of ground barley were tested. The particle size distributions were obtained by grinding the barley in a hammer mill with different screen sizes. The screen sizes used were 1/8", 1/16", and 1/32". A total of five regeneration runs were made with the 1/32" hammer-milled barley. The initial feed concentration was 75 weight percent ethanol in all runs.

The best results were obtained with the smallest particle size distribution and the lowest mass flux. The yield varied between 0.029 and 0.191 grams 99-wt% ethanol produced per gram dried barley. The column geometry had an effect at the low mass fluxes, but had no effect at the high mass fluxes. Effects of column diameter were larger than the effects of column length on the yield. Grain regeneration is necessary if the barley is to be used to produce fermentation ethanol. Ethanol along with water was adsorbed into the barley.

INTRODUCTION

Since the 1974 Arab oil embargo and the ever increasing tensions in the Middle East, the United States' need for alternate energy sources has grown tremendously. Ethanol has long been identified as a possible candidate for the extension of petroleum-based transportation fuels. Ethanol fuels could play an important role in the transition period between today's petroleum fuels and the synthetic fuels of the future.

The idea of using ethanol to supplement petroleum reserves is by no means new. Brazil has been testing different blends of gasoline and ethanol, which is called gasohol, since the 1920s [1]. In 1975 Brazil launched a program called Proa'lcool, whose purpose was to decrease Brazil's dependence on foreign oil. Under this program the average blending level of gasoline is 20-vol% (volume percent) ethanol. In addition to the increased use of gasohol, there has been an increase in the number of pure ethanol driven vehicles [2].

Gasohol with up to 20-vol% ethanol can be used without any engine modification. Researchers say the optimum blend is 10-15-vol% ethanol [3].

A major advantage of mixing ethanol with gasoline is that ethanol is an octane booster. Pure ethanol has a research octane number (RON) of 106-108 [4]. In general, ethanol will increase the octane number of gasoline by 0.5 units for every 1-vol% addition of ethanol [5]. Several oil companies are currently marketing super unleaded gasoline, which is a mixture containing 90-vol% unleaded gasoline and 10-vol% ethanol.

Ethanol can be produced by the fermentation of grains. The starch in the grain is converted into glucose by the addition of an enzyme. A specific yeast is then added to convert the glucose into ethanol and carbon dioxide. This is carried out until the ethanol concen-

tration reaches approximately 10-vol%. At that point, the ethanol is in sufficient concentration to kill the yeast [6].

Ethanol which is to be used for mixing with gasoline must be nearly anhydrous. A 20-vol% ethanol-gasoline mixture will tolerate only 1-vol% water at 70 F [7]. Simple distillation cannot be used to produce anhydrous ethanol because there is a minimum boiling point azeotrope at 94.4-wt% (weight percent) ethanol. There are, however, several methods available to produce anhydrous ethanol; the most common being azeotropic distillation. This involves using a third compound, such as benzene, to break up the minimum boiling azeotrope. There are, however, new methods being investigated that require less energy. Several of these methods are shown in Table 1, along with the approximate energy required to produce 1 liter of anhydrous ethanol [8].

Table 1. Common Ethanol-Water Separation Processes and the Approximate Energy Required to Produce One Liter of 100% Ethanol from a 10-vol% Ethanol Mixture.

Separation process	Energy requirements (KJ/l)
Vacuum distillation	7,600
Azeotropic distillation	7,400
Distillation to 95-wt%, and molecular sieve	6,100-7,600
Distillation to 95-wt% and low temperature blending with gasoline	5,860*
Carbon dioxide extraction	2,500**
Distillation to 95-wt%, and dehydration with calcium oxide	2,170
Distillation to 75-wt%, and dehydration with starches	< 2,000
Solvent extraction	1,000**

*Results in the direct production of gasohol.
**Requires a high capital investment.

This project looks at using the starch present in barley to remove the water from an aqueous ethanol mixture. Barley was chosen as a desiccant for several reasons; first, past research at Montana State University has shown great promise for the use of barley in

ethanol water separation [9]. Barley can also be used as a feedstock to produce fermentation ethanol. Also, barley is an abundant cash crop in Montana and several other states.

Dehydration is not a new method for separating ethanol and water. Calcium oxide (CaO) has long been used as a desiccant in the dehydration of many gases and vapors, including ethanol and water mixtures [10]. The main disadvantage of using CaO as a desiccant is that it reacts with the water to form a hydroxide. This makes the regeneration of the solid very energy expensive. It has been known for many years that starches, such as those found in barley, could be used as a desiccant [11]. However, it was just recently found that starches would preferentially adsorb water vapor over ethanol vapor [12].

Sorption

There are three types of sorption:

1. Absorption
2. Physical Adsorption
3. Chemical Adsorption

First, adsorption should be distinguished from absorption. Absorption is the bulk penetration of a vapor or gas into the structure of the solid, thus forming a solid solution. Adsorption is the phenomenon where molecules of a gas or vapor will stick to the surface of the solid, but not form a solid solution. The term sorption is used when both processes may occur simultaneously.

Physical adsorption should be distinguished from chemical adsorption, sometimes called chemisorption. Physical adsorption is similar to condensation of a vapor. The gas or vapor is held to the solid surface by van der Waals forces. Chemical adsorption involves the formation of a chemical bond between the solid and the adsorbed liquid.

There are several important differences between physical and chemical adsorption listed below [13]:

1. Physical adsorption will occur on any gas-solid system, provided that the temperature and pressure are suitable. Chemisorption will occur only when the gas and solid are able to form a chemical bond.
2. The heat of physical adsorption is on the order of the heat of vaporization for a vapor and the heat of liquefaction for a gas. The heat of chemisorption is on the order of the heat of reaction.
3. Physical adsorption is easily reversible by simply reducing the pressure or increasing the temperature. Chemisorption is much less reversible and requires much more rigorous conditions.
4. Several adsorbed layers can be built up with physical adsorption, but only one layer will occur with chemisorption.
5. Chemisorption will occur at much lower pressures and much higher temperatures than physical adsorption.
6. Physical adsorption occurs almost instantaneously, where as chemisorption may occur instantaneously or might require an activation energy.

The adsorption of water onto biological materials is almost always physical adsorption [14].

Theories of Physical Adsorption

For a given weight of adsorbent the amount of gas or vapor adsorbed at equilibrium is a function of temperature and pressure only. Adsorption data is generally given in terms of isotherms. An isotherm is a plot of the amount of gas or vapor adsorbed versus pressure at a constant temperature. There are five types of isotherms for the adsorption of gases or vapors on solids. These are shown in Figure 1. Type I isotherms are associated with systems

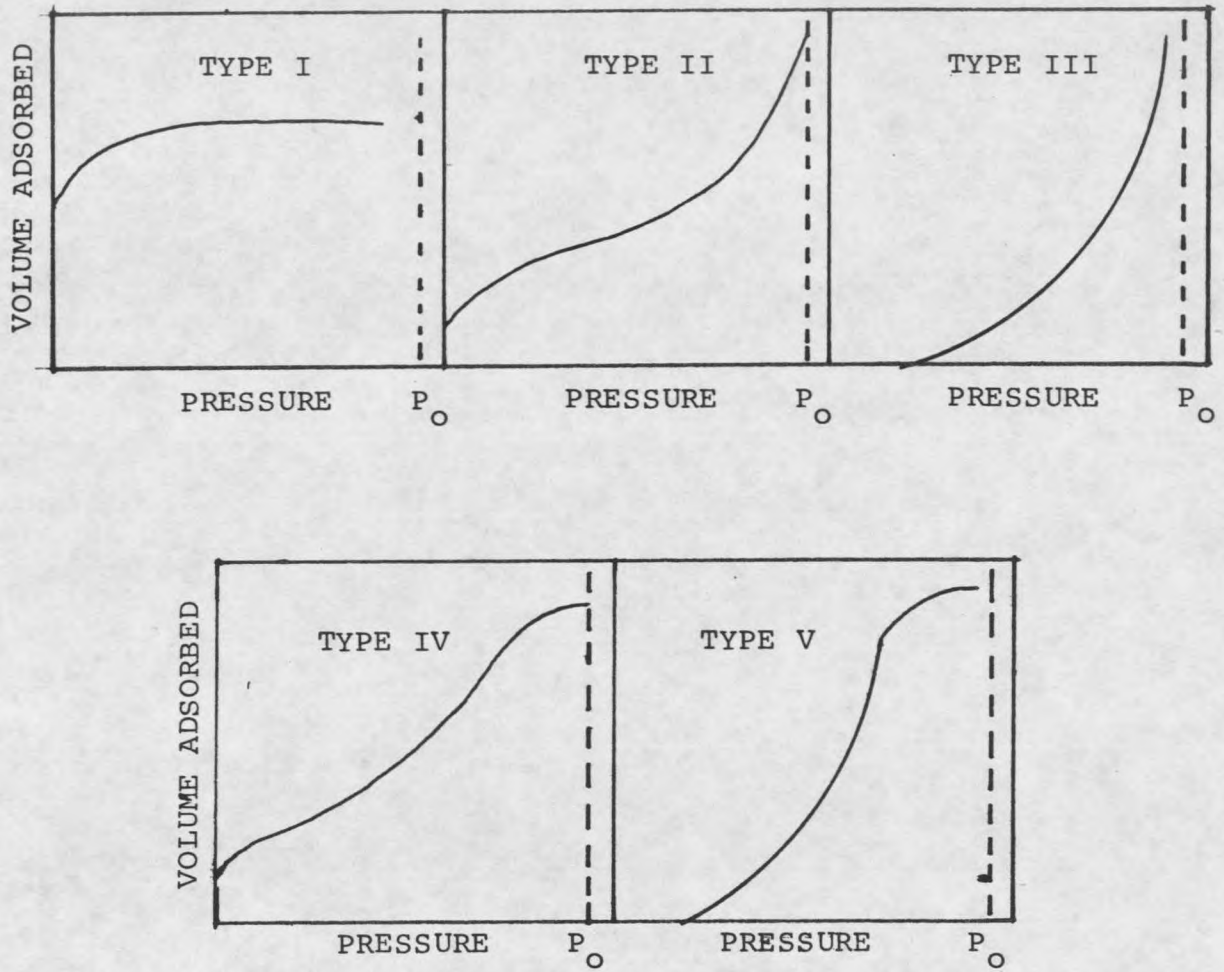

Figure 1. The five general types of adsorption isotherms. P_o is the saturation pressure.

where adsorption is monomolecular. Types II and III isotherms are associated with systems where multilayer adsorption occurs. Types IV and V isotherms are associated with systems where a highly porous adsorbent is used [15]. The isotherms for biological materials are most similar to the type II isotherm [16].

Nygoddy and Bakker-Arkema [17] developed an isotherm equation for the sorption of water by starches. They obtained their equation by combining the three following adsorption theories:

1. Brunauer, Emmett, and Teller's (BET) theory of multilayer adsorption.
2. Zsigmond's capillary condensation theory.
3. Polyany's adsorption potential theory.

The most used theory of adsorption is the BET theory of multilayer adsorption. The BET equation appears to represent the shape of actual isotherms fairly well. It is also used to find the surface area of a substance because it yields a good value for the volume of gas required to form a monomolecular layer on the surface of the substance. This theory says that adsorption will occur on one layer until it is completely full, then adsorption will continue by building more and more layers [18].

Zsigmond's capillary condensation theory says that the adsorbate exists as a condensed liquid in the capillaries of the sorbent. The adsorbate's properties are the same as the bulk liquid phase [19].

Polyany's adsorption potential theory says the adsorbent exerts strong attractive forces. These forces attract gas molecules in the vicinity and as a result many layers can build up [20].

Physical adsorption of a gas or vapor on a solid is a spontaneous process, which causes a decrease in the Gibb's free energy of the system. The process also involves a decrease in entropy when the gas or vapor goes from the free gas to the adsorbed film. It follows from the equation,

$$\Delta G = \Delta H - T\Delta S$$

that physical adsorption must always be an exothermic process.

Desorption is the process by which the adsorbate is removed from the solid. Biological materials show a hysteresis effect present between the adsorption and desorption isotherms. During desorption more water is contained in the solid at a given pressure than during adsorption. Young and Nelson [21] tried to explain this phenomenon by assuming there are three types of water sorption in biological materials. First, there is a layer of water adsorbed directly on the outer surface of the cell. Then, there are several layers of condensed molecules that adhere to the adsorbed layer. There are also molecules that pass through the cell wall and become adsorbed into the interior of the cell. It was proposed that two or more adsorbed layers are required to push the adsorbed molecules into the interior of the cell. During desorption the water bound to the surface would have to be removed before the water in the cell. This would mean that at a given pressure more water would be present in the cell during desorption than during adsorption.

Physical Adsorption in Packed Beds

The unsteady-state adsorption of gases in packed beds is very common in industry. The main reason for this is the ease of operation and low cost of the adsorption systems. Adsorption is used in many recovery and purification operations such as: decolorizing mineral and vegetable oils, purifying air, dehydration of gases and vapors, and concentrating valuable solutes from liquid solutions [22].

In a packed bed where there is a vapor and strongly adsorbed solute, such as ethanol and water, the vapor enters the packed bed and at first the solid adsorbs the solute rapidly and effectively. The effluent from the bottom of the packed bed is practically solute free (see Fig. 2). The distribution of the adsorbate in the solid bed is indicated by the horizontal lines in Figure 2. The bulk of the adsorption takes place over a small adsorption zone,

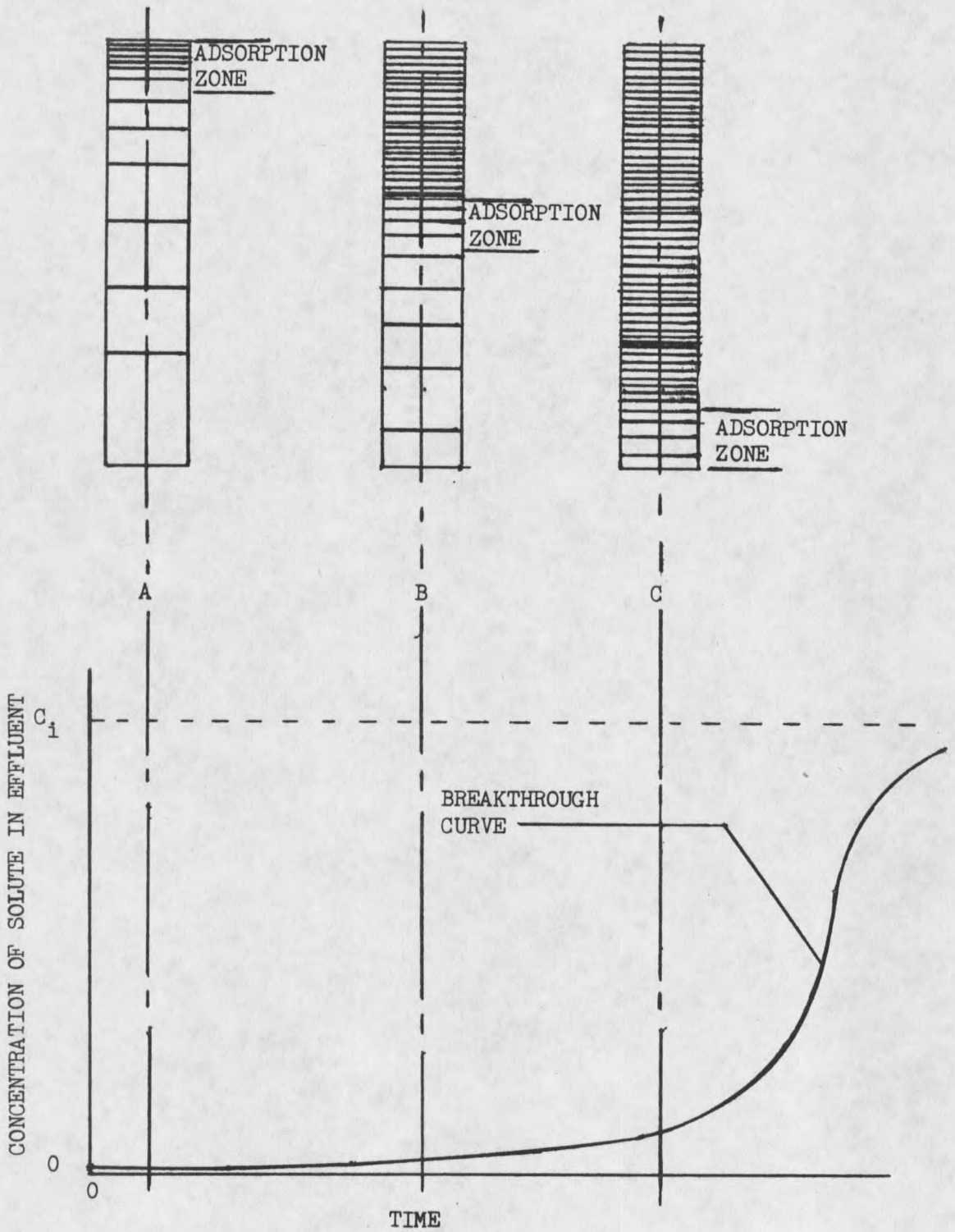

Figure 2. The adsorption wave and breakthrough curve.

which moves down the column like a wave. The speed of the wave is usually much slower than the linear velocity of the vapor in the column. As the adsorption zone gets closer to the bottom of the column, the concentration of the solute in the effluent starts to rise very rapidly. This is called the break point. Then the concentration of the solute in the effluent rises until it reaches the inlet concentrations. The portion of the curve after point C on Figure 2 is called the breakthrough curve [23].

If the process is highly exothermic a temperature wave will follow the adsorption wave. A rise in temperature of the effluent can be used as an indication of the start of the breakthrough curve [24].

Previous Research

There has been some previous work done with the separation of ethanol and water at Montana State University. Graham [25] did work with a 0.75" X 12" adsorption column and 1/16" hammer-milled Shabet barley. He obtained a correlation for yield as a function of initial temperature and mass flux. The correlation he obtained is shown below:

$$Y = 0.0229/((T-80)^{0.5209}F^{0.6436})$$

Y = Yield (milliliters 99-wt% ethanol produced per gram dried barley)

F = Mass flux (gm/min-sqcm)

T = Temperature (C)

He also determined that the initial feed concentration had little effect on the yield for feed concentrations between 75- and 85-wt% ethanol. Runs using specific barley particle sizes showed a decrease in yield for sizes larger than 0.83 millimeters.

RESEARCH OBJECTIVE

The purpose of this investigation was to determine the feasibility of using barley as a dehydration agent in the separation of an ethanol-water mixture. The following parameters were considered important in this investigation:

1. Feed space velocity
2. Barley particle size distribution
3. Adsorption column geometry
4. Number of regenerations
5. Initial barley temperature
6. Pressure
7. Initial feed concentration
8. Initial grain moisture content

Parameters 1-4 were varied while parameters 5-8 were held constant at the following values:

Initial grain moisture content	0%
Initial barley temperature	84-86 C
Feed concentration	75-wt% ethanol
Pressure	atmospheric (640 mmHg)

MATERIALS, APPARATUS, AND PROCEDURE

Materials

All the grain used in this project was Shabet barley. The barley was first separated into three parts, then each part was ground in a Bell Model 10 hammer mill with a different size screen. The three screen sizes used were 1/32", 1/16", and 1/8", thus giving three different particle size distributions. A comparison of the three particle size distributions obtained can be seen in Table 2. After grinding, all the grain was stored in sacks and kept in the refrigerator at 10 C.

The particle size distributions were found using screens, which varied in size from 16 mesh to 250 mesh. For a list of screen sizes used, see Table 2. The screens were stacked in order of decreasing mesh and then the sample, usually 115 grams, was placed on the top screen. A Ro-Tap was then used to shake and tap the screens. Two different samples were Ro-Tapped for each particle size distribution. The results that are shown in Table 2 are the average of the two runs. All grain was ground and sized when the moisture content was 7%.

All the ethanol used was anhydrous, and it was mixed with distilled water to form a 75-wt% mixture.

Apparatus

The equipment used consisted of five major parts:

1. Feed burette
2. Pump
3. Evaporator
4. Adsorber

Table 2. The Particle Size Distributions of the 1/8", 1/16", and 1/32" Hammer-Milled Barley.

Screen number	Screen size U.S. mesh	Screen opening millimeters	Percent of total sample		
			1/8" Hammer-milled barley	1/16" Hammer-milled barley	1/32" Hammer-milled barley
1	10	2.0	3.25	1.7	0.0
2	18	1.0	38.75	36.4	8.2
3	30	0.589	10.4	9.2	14.2
4	40	0.417	24.7	19.7	24.7
5	50	0.297	4.9	8.2	13.9
6	60	0.246	4.5	4.4	7.0
7	70	0.210	1.6	1.4	2.0
8	100	0.147	5.2	5.4	7.8
9	140	0.106	2.4	3.0	4.0
10	200	0.075	3.3	3.1	13.3
11	270	0.053	3.3	3.2	3.0
12	bottom	—	1.7	1.1	1.9

5. Condenser

A flow diagram of the complete apparatus is shown in Figure 3.

A 50 milliliter glass feed burette was used for runs 1-25; it was accurate to 0.1 ml. A 100 milliliter glass feed burette, accurate to 0.2 ml, was used starting with run 26. The reason for changing burettes was due to the volume of feed required.

A four channel, low pressure, peristaltic pump was used with 3/32" tygon tubing. The maximum output of the pump was approximately 4 ml/min for each channel. The higher flow rates were obtained by connecting two or more channels in parallel.

The aqueous ethanol was transported from the feed burette to the pump and from the pump to the evaporator via 3/32" I.D. plastic tubing.

The evaporator, which would vaporize the aqueous ethanol, consisted of one inch pipe filled with copper-clad BB's. The entire evaporator was wrapped with heating tape and was insulated. It was placed vertically so the aqueous ethanol would enter the top and drip down through the hot BB's. The evaporator was packed with BB's in order to supply a high surface area so complete vaporization could take place. A thermocouple was placed right below the output of the evaporator so the temperature of the exiting vapor could be monitored. The output of the heating tape for the evaporator and the other equipment was controlled by a Powerstat variable transformer.

After the vapor left the evaporator, it passed through a 12 inch section of 1/4" I.D. copper tubing. This tubing was wrapped with heating tape and insulated. The purpose of this section was to insure complete vaporization of the aqueous ethanol. When the higher flow rates were used (4.5 ml/min and above), the evaporator was not able to vaporize all the incoming aqueous ethanol. In those cases, the remainder of the aqueous ethanol was vaporized in this section of tubing. Complete vaporization was insured by monitoring the temperature at the end of this section of tubing.

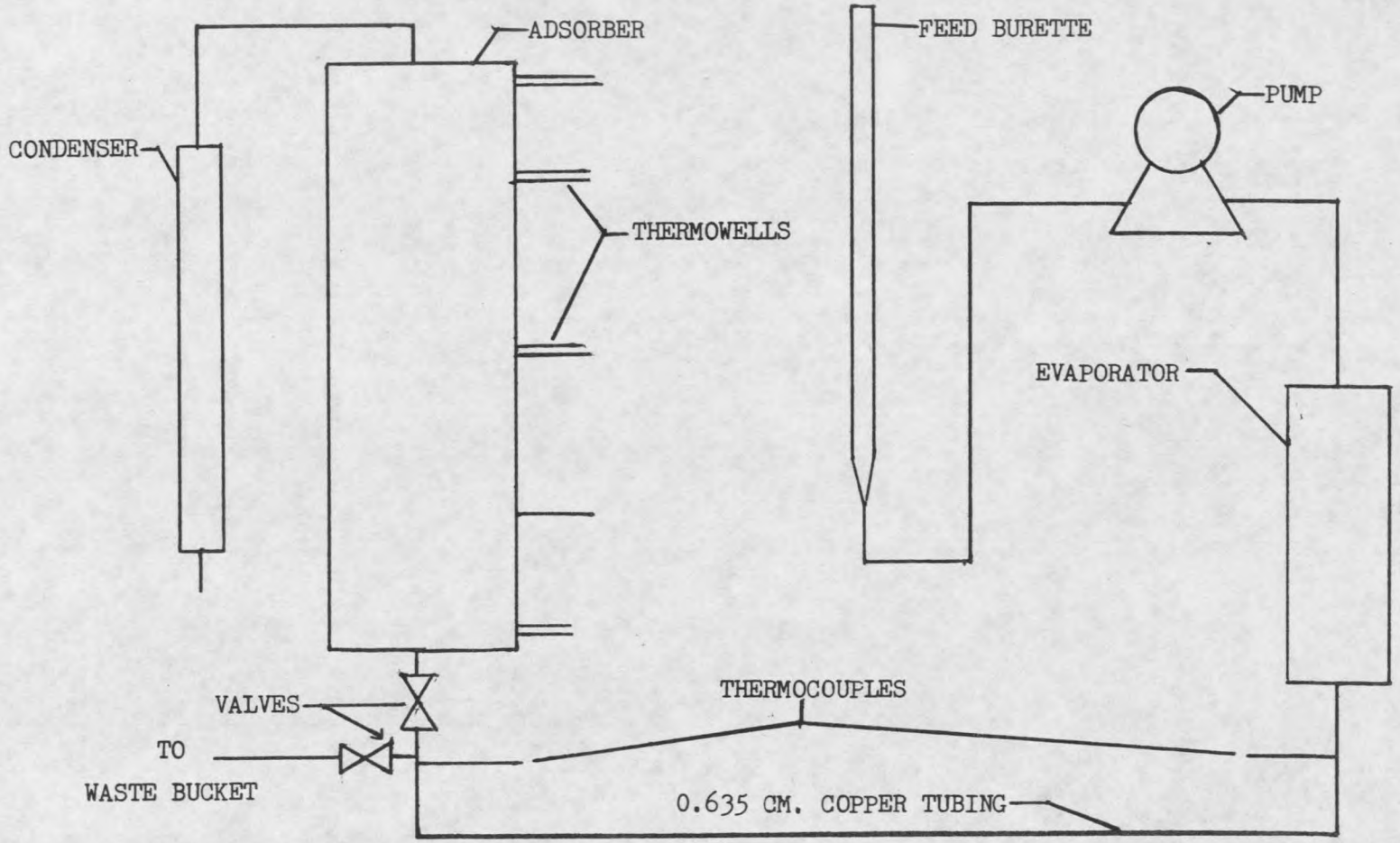

Figure 3. Flow diagram for the barley adsorption process.

There was a series of valves at the end of the 12 inch section of tubing. During preheat, the valve leading to the waste bucket was opened and the vapor was condensed and discarded. When the run was started, that valve was closed and the valve leading to the adsorption column was opened.

Four different adsorption columns were used. Runs 1-32 used a 1.5" (diameter) X 14" (length) copper column; runs 33-42 used a 1.5" X 24" copper column; runs 43-60 used a 1.5" X 24" black iron column; and runs 60-75 used a 2.5" X 23" black iron column. All regeneration runs, numbers 57, 62, 64, 65, and 75 used the 1.5" X 24" black iron column. The reason for switching from the copper column to the black iron column on run 43 was because leaks were developing at the entrance and exit of the copper column.

The purpose of the adsorber was to hold the grain in a fixed position. Heating tape was wrapped around the adsorber and the entire adsorber was insulated. One piece of heating tape was used with the 1.5" X 14" column. Two separately-controlled pieces of heating tape were used on the other columns. There were thermowells at the entrance, exit, and every 3-4 inches along the adsorption column. Thermowells were placed so the ends were at the center of the adsorption column. One thermowell was placed at the edge of the column about halfway up. The thermowells consisted of 3/16" copper tubing with the ends soldered shut. Thermocouples were placed inside the thermowells as far as they would go.

After the vapor left the adsorber, it entered a water-cooled condenser where the samples were collected in test tubes. The vapor was kept hot until it entered the condenser. This was done in order to prevent the vapor from condensing and dripping back into the adsorption column.

All the thermocouples used were chromel-alumel. A Cole-Palmer digital thermometer that was accurate to 1 C was used to record temperatures. The thermocouples used to measure the temperature of the vapor leaving the evaporator and the vapor entering the adsorber were held in place with a Swagelok fitting filled with epoxy.

Procedure

Before the run could begin, the barley had to be dried to 0% moisture. This was accomplished by placing the grain in large aluminum pans with the grain 0.5-0.7 centimeters deep. The pans were placed in one of two ovens that were kept at 110 C. The samples were allowed to dry for 72-96 hours. It was found that this was sufficient to completely dry the barley.

The pump was then set up depending on the flow rate required. The maximum output of the pump was a 4 ml/min for each channel. To keep a constant flow rate during the run, 3/32" tygon tubing was used and changed often.

The adsorption column was then blown out with compressed air in order to insure that all the old grain was removed. Teflon tape was wrapped around the threads at both ends of the column. The bottom screen was then placed in the column and the cap was put on. A preweighed sample of barley (230 grams for the 1.5" X 14" column, 400 grams for the 1.5 X 24" column, and 900 grams for the 2.5" X 23" column) was added. The barley came to within 0.5-1.5 inches of the top of the column. The top screen was fitted into place and the top cap screwed on. Both the top and bottom caps were then tightened in a pipe vise to prevent leaks. The adsorption column was wrapped with heating tape and an insulation jacket was placed around the entire adsorber. The adsorber was fitted into place and the thermocouples were placed in the thermowells.

The Powerstats were turned on and the system was allowed to heat up. The valve to the adsorber was closed, and the valve to the waste bucket was opened.

When the temperature of the evaporator reached 80-83 C the pump was turned on and adjusted to the correct flow rate. The Powerstats controlling the evaporator were set so the output of the evaporator was 84-92 C. The temperature of the vapor entering the adsorber was kept at 100-110 C. When the high flow rates were used (above 4.5 ml/min),

the evaporator could not vaporize all the incoming feed. In those cases the power to the heating tape on the 12 inch section of tubing was turned up. This would allow complete vaporization to occur before the feed entered the adsorber.

The barley inside the adsorber was heated until a uniform 84-86 C was obtained. Then the vapor was routed up the adsorber and the run was started. At the start the level of the burette was recorded along with all the temperatures.

When the 1.5" × 14" column was being used, the power to the heating tape was turned off when the vapor was routed up the adsorption column. Due to the heat of adsorption, the temperature of the adsorber would rise to 90-95 C. The exception to this was the slowest space velocity (0.035 gm/min sqcm). In this case a small amount of heat had to be added to maintain the temperature above 84 C. When the other two columns were being used, the power to the bottom section of heating tape would be shut off at the beginning of the run. The upper section of heating tape was kept on so the outlet temperature would not drop below 84 C. Again, the only exception to this was the slowest space velocity where some heat addition was required from the lower section of heating tape.

Temperatures were recorded at various time intervals depending on the space velocity. Generally, temperatures were recorded after every 20-30 milliliters of feed additions. Sample tubes were changed at various times depending on run conditions. At the beginning of the runs, samples were changed every 10-15 grams. As the ethanol concentration started to drop, 3-4 gram samples were taken. A good indication of when the ethanol concentration would start dropping was when the exit temperature started to rise.

The run was stopped when the barley was saturated. The Powerstats were turned off, and the last sample was allowed to set for 10-15 minutes to collect the last bit of output.

The sample tubes were then weighed, and the samples were transferred to smaller sample bottles for analysis. A Beckman gas chromatograph with a Poropack-R packed column operated at 190 C was used to find the ethanol concentration. A calibration curve

of weight percent versus area percent was obtained by making up samples of known weight percents.

The column was allowed to cool for several hours. Then three samples of barley were taken, one from the top, one from the middle, and one from the bottom. These samples were dried in order to find the moisture content. The overall grain moisture content was taken as the average of the three individual moisture contents.

RESULTS AND DISCUSSION

A total of 75 runs were made and of that number, 54 were used in my analysis. The results for all the useful runs are shown in Appendix A along with a list of all rejected runs and the reason for their rejection. The purpose of the runs was to determine the effects of:

- Particle size distribution
- Space velocity
- Column geometry
- Multiple grain regenerations

Before the above points are discussed, a few general points should be mentioned.

As explained in the procedure section, the moisture content of the barley was taken as the average of the three small samples taken from the adsorption column. This method worked well for the 1.5" X 14" and the 1.5" X 24" adsorption columns. All the grain from two columns was dried and the actual moisture contents were 3-5% higher than the estimated moisture contents. The method did not work as well for the 2.5" X 24" adsorption column. All the grain from one column was dried and the actual moisture content was 13% lower than the estimated moisture content. This is the reason for the higher percentages (above 100%) of the amount of feed accounted for when the 2.5" X 23" adsorption column was being used.

The results in Appendix A show that some ethanol was adsorbed by the barley. The amount ranged from 12-35% of the ethanol in the feed. These figures were only estimates due to the method of calculating barley moisture content. That is the probable cause for the large range of values obtained. No trend could be found for the differences as a function of space velocity, particle size distribution, or adsorber geometry.

A typical breakthrough curve is shown in Figure 4. The concentration of water in the effluent was small for 5 minutes. Then the concentration rose very rapidly and leveled out at about 5-6-wt% below the inlet concentration. This phenomenon was most likely due to the fact that as the grain became saturated many adsorbed layers were built up. As stated in the Introduction, Young and Nelson [26] proposed that once two layers were built up, absorption of the water into the interior of the barley cells occurs. This would suggest that as the barley became saturated it would start to absorb water molecules making more sites available for adsorption. This process would occur at a much slower rate than the initial adsorption rate, thus removing only 5-6-wt% of the water in the feed. This would make sense, since initially barley cells contain some water that was removed when the barley was dried. Graham [27] obtained the same results with his experiments.

As stated before, the adsorption process releases heat causing the barley temperature to rise. The faster the adsorption takes place the higher the barley temperature rises. Figure 5 shows the maximum temperature of the barley versus mass flux for the 1/32" hammer-milled barley. This is typical of the other particle size distributions. The temperatures shown on Figure 5 are the average maximum temperature the barley attained at the center of the adsorption column. The temperature of the barley increased as the size of the adsorber increased, due to the fact that less heat could escape in the larger columns. The temperature of the barley would rise as the adsorption wave, as discussed in the Introduction, would move up the column. The fastest temperature rise observed was with the 1/32" hammer-milled barley, a mass flux of 0.212 gm/min-sqcm, and the 2.5" X 23" column. A temperature rise of 11 C was observed in 45 seconds. It should be noted that the thermocouples were placed in thermowells, which would tend to slow down their response. In most cases the temperature would increase 3-7 C in 3-4 minutes.

There were some radial temperature gradients in all the columns. These gradients would occur just after the adsorption wave would pass a point. The 1.5" adsorption col-

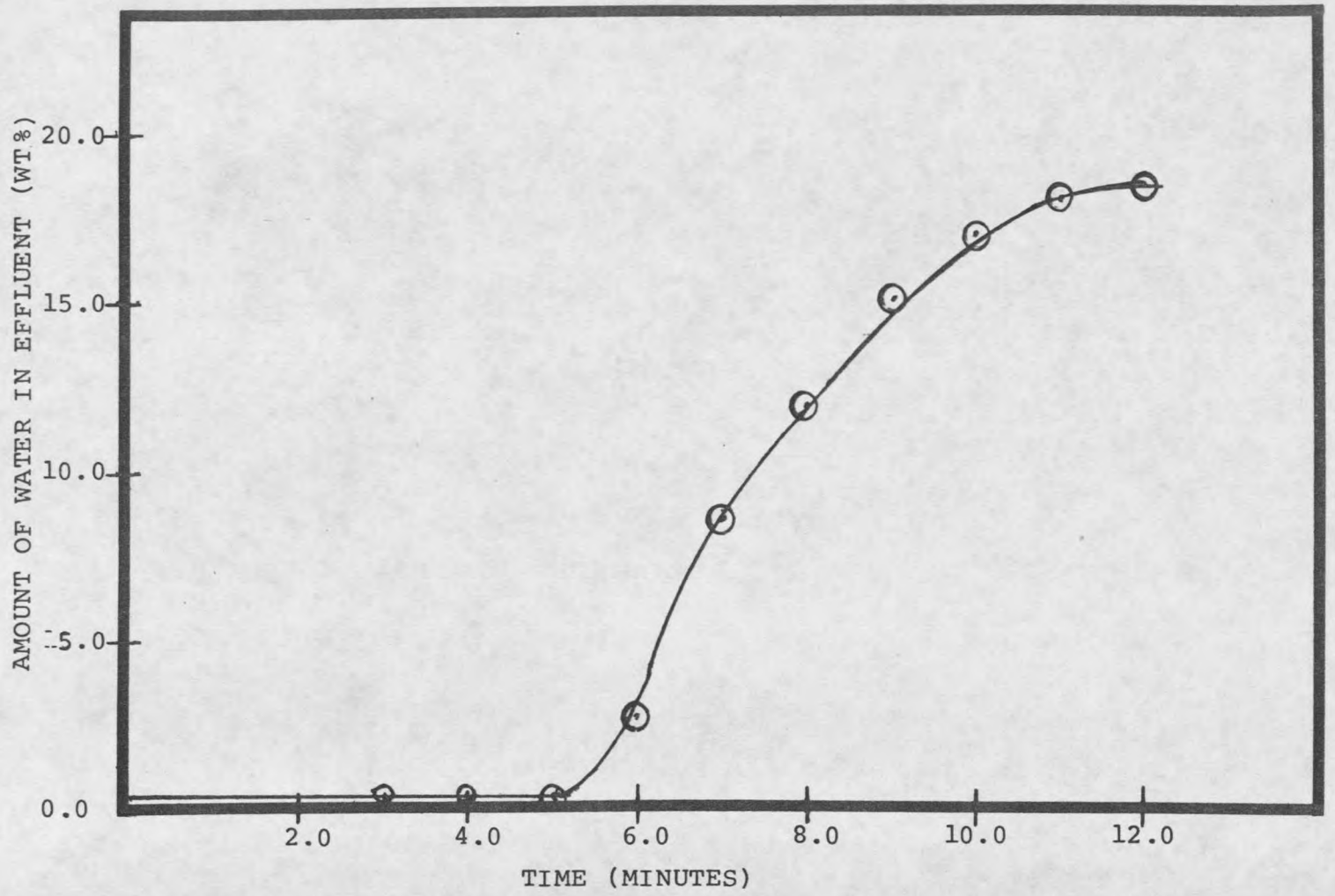

Figure 4. Breakthrough curve for Run 20.

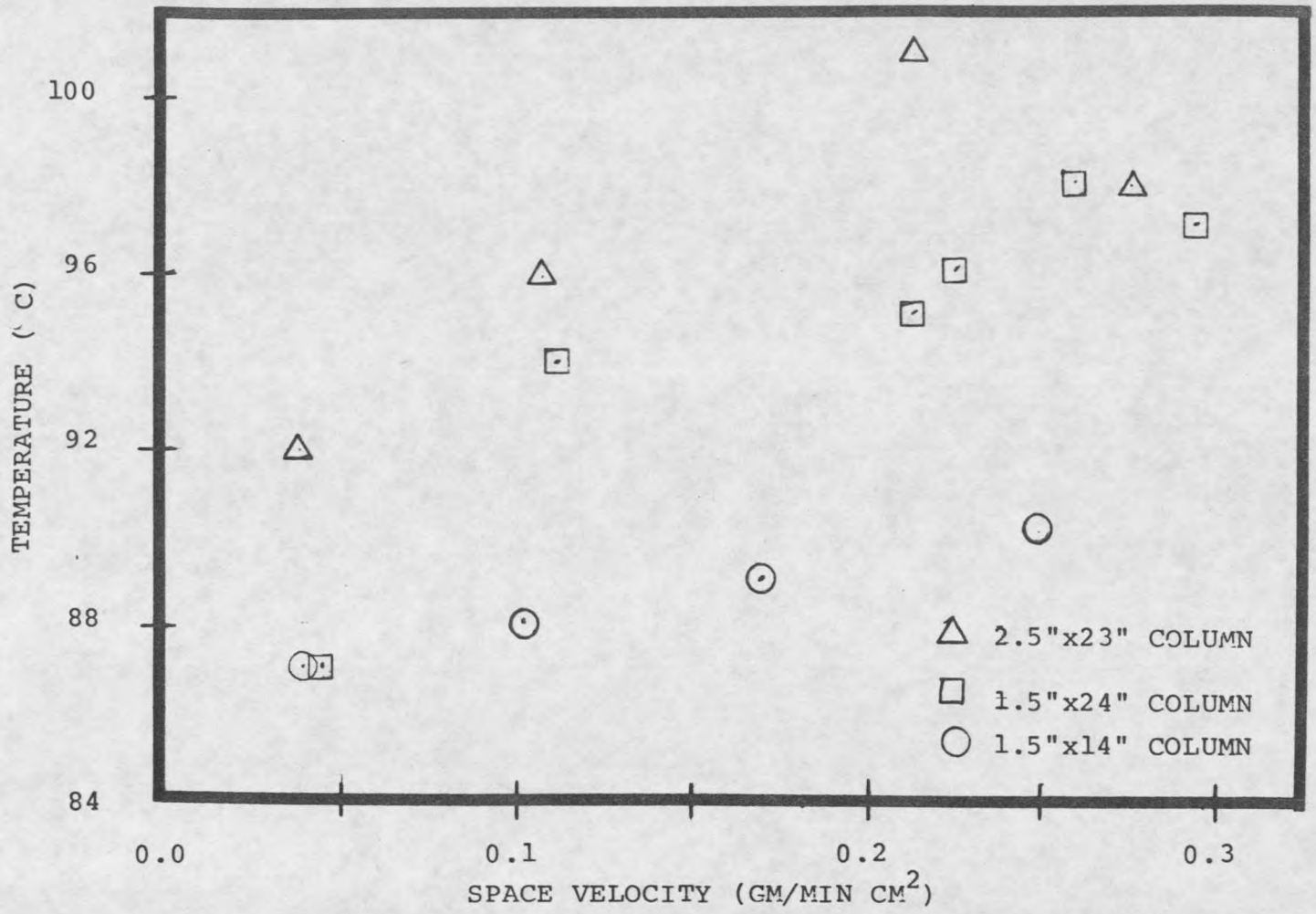

Figure 5. Temperature as a function of space velocity for 1/32" hammer-milled barley.

umns had gradients of 2-4 C, while the 2.5" adsorption column had gradients of up to 6 C. The radial temperature gradients did not last very long. After the adsorption wave had passed the temperature at the wall would slowly increase until it reached the temperature at the center of the column.

Effect of the Mass Flux and Particle Size Distribution

The criteria for evaluation in this project was the amount of 99-wt% ethanol produced per gram of dried barley. This quantity was determined by mathematically mixing the samples obtained until a mixture of 99-wt% was obtained. The weight of this mixture was divided by the amount of dried barley present at the start of the run. This was done with the aid of a Fortran computer program shown in Appendix B. This program also printed the results shown in Appendix A.

Figures 6, 7, and 8 show the yield as a function of mass flux and particle size for the 1.5" X 14", 1.5" X 24", and the 2.5" X 23" adsorption columns respectively. The equations for the lines shown on the figures are listed in Table 3. The lines were obtained by linear regression. The yield was found to be linear in reciprocal mass flux in all cases. The yields for the 1/32" hammer-milled barley were highest at all conditions. The yields for the 1/8" and 1/16" hammer-milled barley were very close to each other in all cases. The results for the 1/8" and 1/16" hammer-milled barley were so similar for the 1.5" X 24" column that one equation was found to represent both particle size distributions.

This was due to how close the two particle size distributions were to each other. Figure 9 is a plot of percent of the total weight of barley screened versus pan number for the three particle size distributions. The screen sizes for the various pans are shown in Table 2.

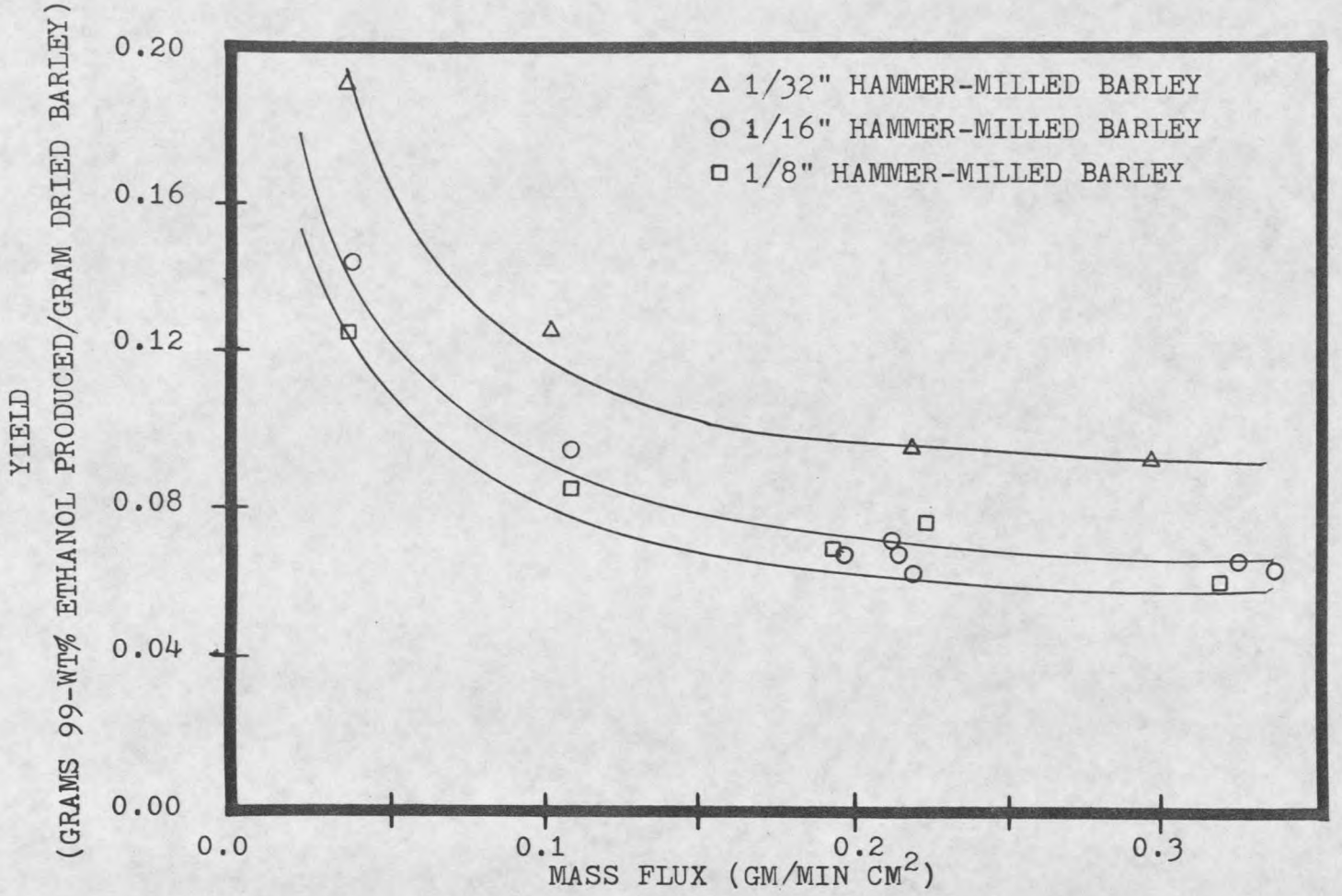

Figure 6. Yield as a function of mass flux for the 1.5" x 14" adsorption column.

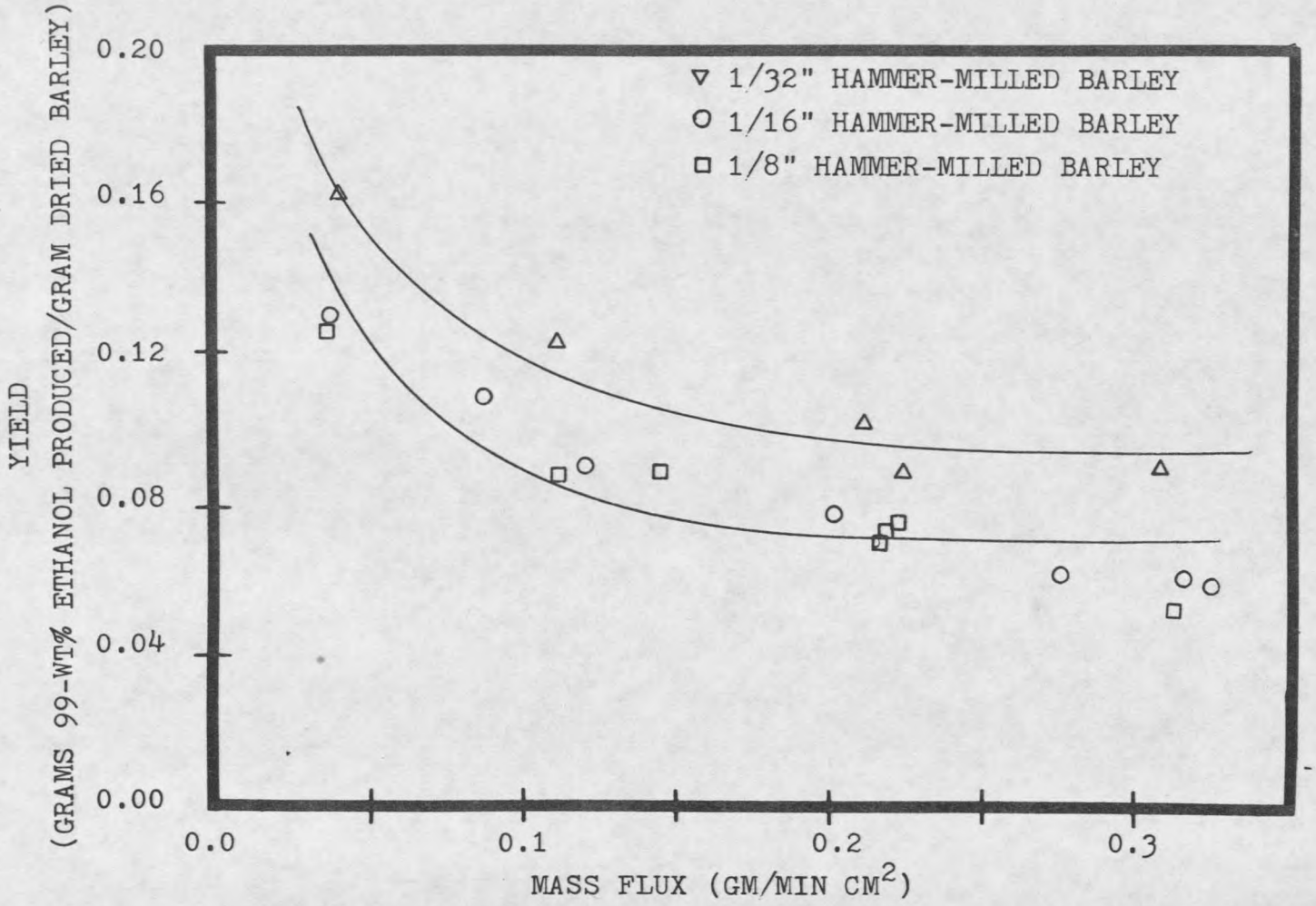

Figure 7. Yield as a function of mass flux for the 1.5" X 24" adsorption column.

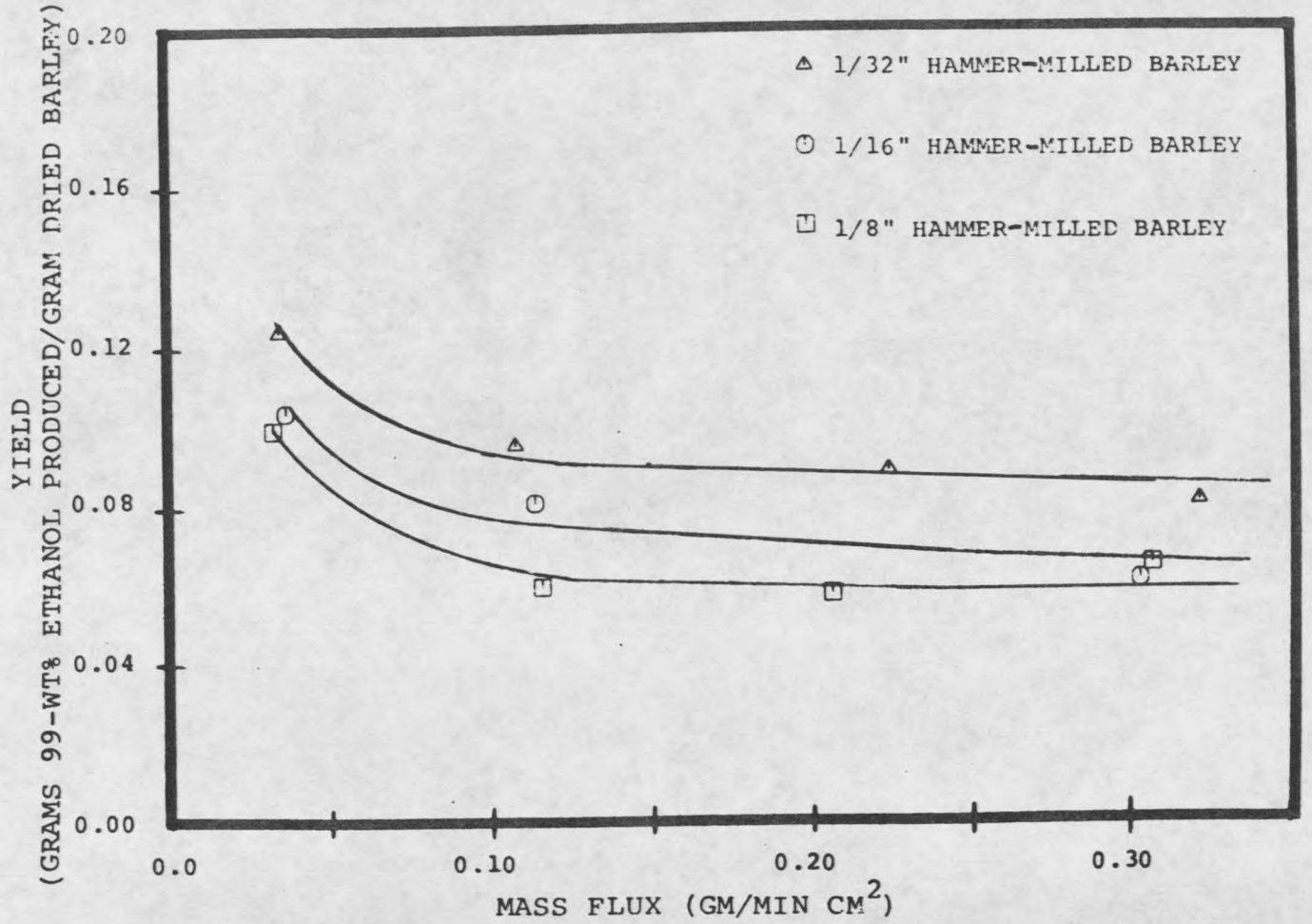

Figure 8. Yield as a function of mass flux for the 2.5" X 23" adsorption column.

Table 3. Equations for the Yield as a Function of Mass Flux for the Various Adsorber Columns and Grain Particle Size Distributions.

Column geometry	Grain size distribution	Yield as a function of mass flux (F)* (gm 99-wt% ethanol produced/gm dried barley)	Correlation coefficient
1.5" X 14"	1/8"	Y=0.00242/F + 0.0572	0.84
	1/16"	Y=0.00348/F + 0.0536	0.96
	1/32"	Y=0.00407/F + 0.0840	0.99
1.5" X 24"	1/8" & 1/16"	Y=0.00247/F + 0.00578	0.97
	1/32"	Y=0.00328/F + 0.081	0.92
2.5" X 23"	1/8"	Y=0.00144/F + 0.0523	0.92
	1/16"	Y=0.00162/F + 0.0599	0.93
	1/32"	Y=0.00155/F + 0.0786	0.98

*F = Mass flux (gm/min-sqcm).

In order to determine the approximate error in the values reported, several data points were repeated. Table 4 shows the repeated runs and the conditions used. Generally the repeatability was good—the maximum deviation was 15%.

Table 4. Results of Repeated Runs.

Column geometry	Grain size distribution	Mass flux (gm/min-sqcm)	Yield*
1.5" X 14"	1/16" H.M.	0.325	0.066
		0.337	0.063
1.5" X 14"	1/8" H.M.	0.212	0.071
		0.196	0.068
		0.219	0.062
		0.214	0.068
1.5" X 24"	1/8" H.M.	0.219	0.071
		0.219	0.074
		0.216	0.068
1.5" X 24"	1/16" H.M.	0.317	0.059
		0.327	0.057
1.5" X 24"	1/32" H.M.	0.225	0.087
		0.212	0.094

*Yield = Grams 99-wt% ethanol produced/gram dried barley.

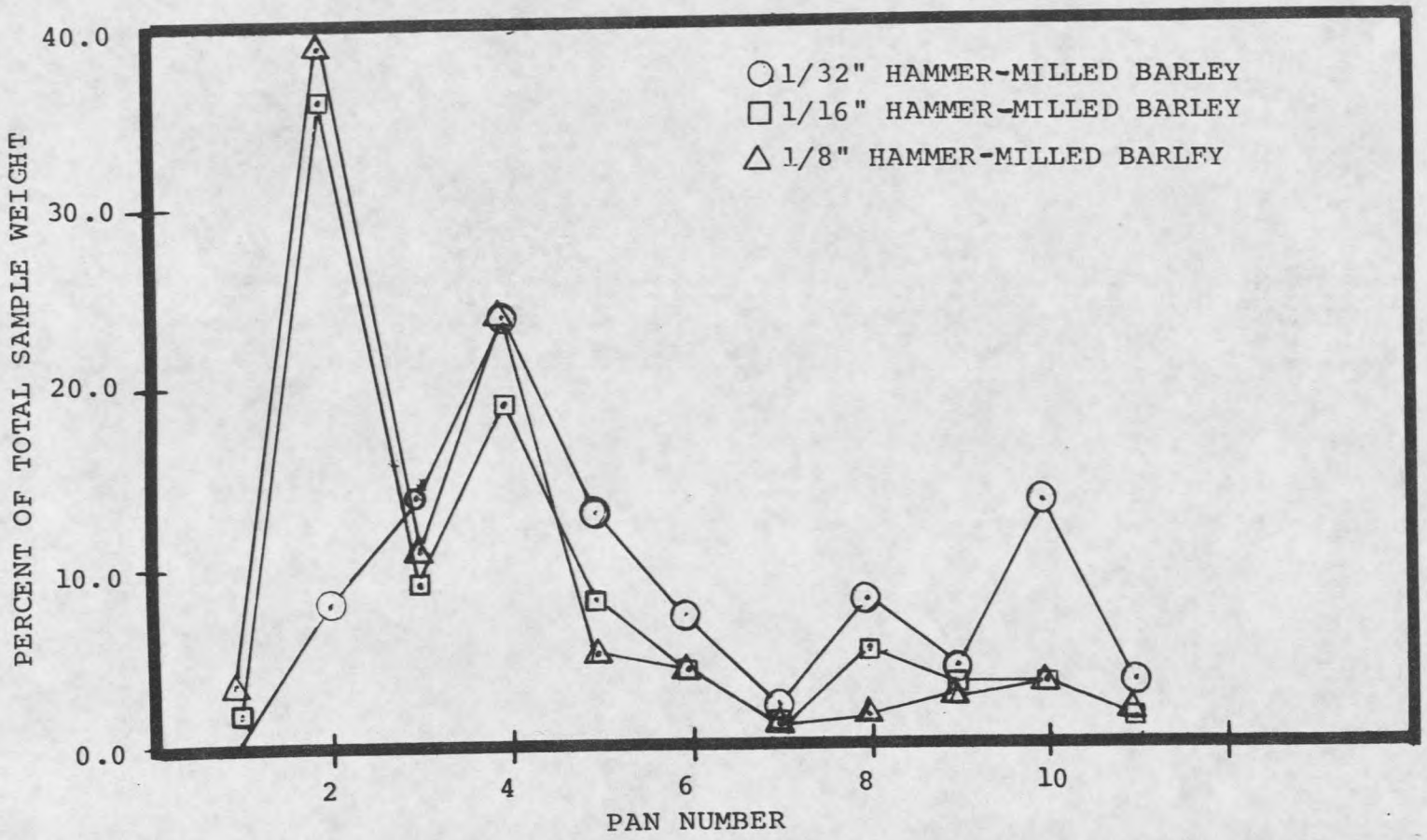

Figure 9. Graphical representation of the 1/8", 1/16", and 1/32" hammer-milled barley particle size distributions.

Effect of Column Geometry

Figures 10, 11, and 12 show yield as a function of mass flux and adsorption column geometry for the 1/32", 1/16", and the 1/8" hammer-milled barley respectively. The column geometry had an effect on the 1/32" and 1/16" hammer-milled barley at the lowest mass flux, but there was no effect at the higher mass fluxes. The 1.5" X 14" and the 1.5" X 24" adsorption columns showed about the same yields after 0.1 gm/min-sqcm. The 2.5" X 24" adsorption column showed lower yields until about 0.2 gm/min-sqcm; the column geometry had no apparent effect after that. The column geometry had less effect on the 1/8" hammer-milled barley; however, the 2.5" X 23" adsorption column was lower at the low values of the mass flux.

The increase in adsorption column length had little effect on the yield. The increase in adsorption column diameter decreased the yield by 20-30% at the low mass fluxes. This could be due to the increase in temperature in the larger diameter column.

The curve obtained by Graham [28] is plotted on Figure 11. He used a 0.75" X 12" adsorption column. The yields were considerably higher at the low mass fluxes, but the yield drops off very fast and is about the same as the other yields at the high mass fluxes.

Effect of Grain Regeneration

A total of five runs were made with the same 1/32" hammer-milled barley. All the runs were made with a mass flux of 0.32 gm/min-sqcm. This mass flux was chosen because a small variation in flow would not affect the yield. All the runs were made with the 1.5" X 24" adsorption column.

A plot of yield versus number of runs is shown in Figure 13. Initially the yield dropped 20%, then the yield stays at a constant 0.075 over the next four runs.

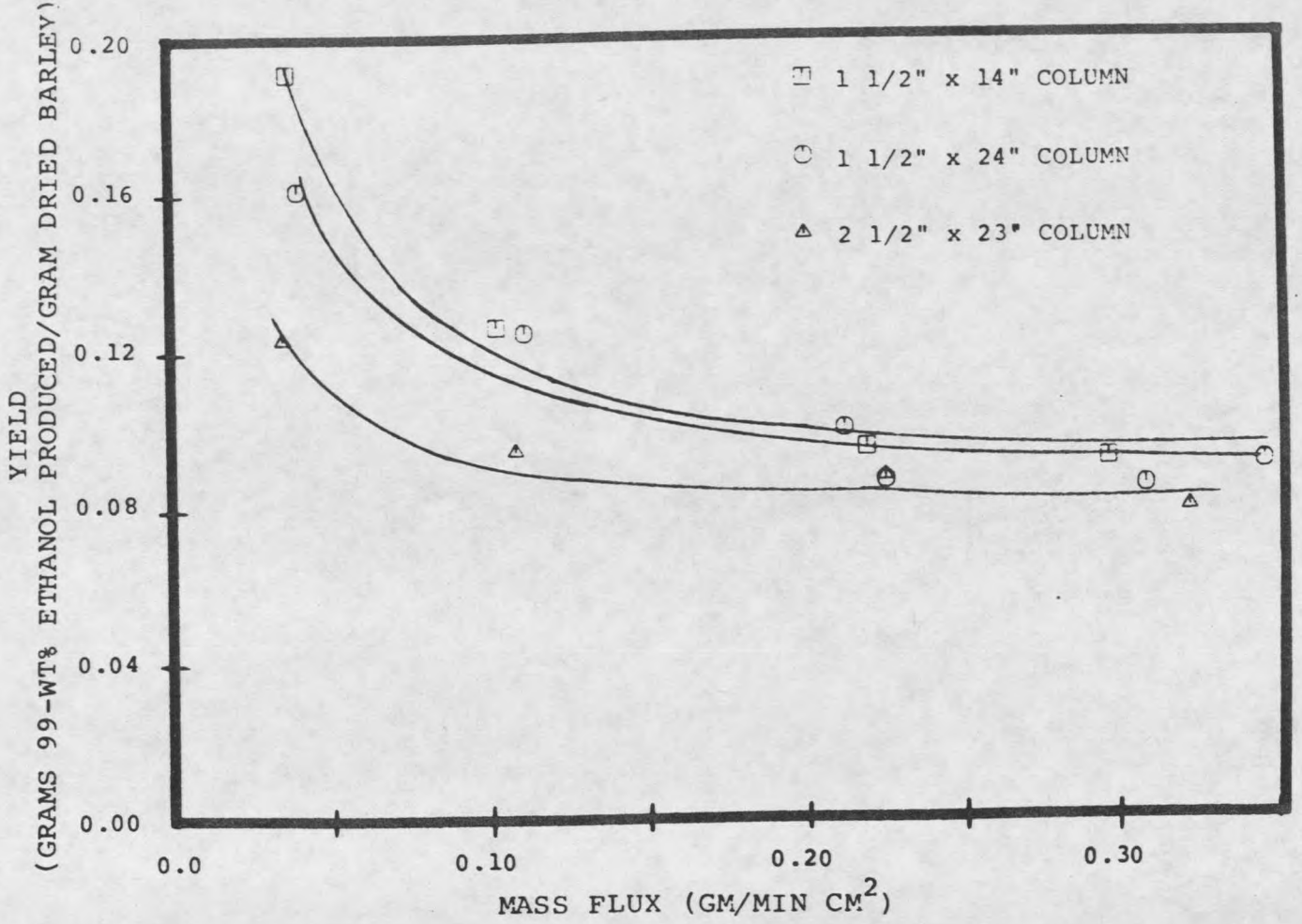

Figure 10. Yield as a function of mass flux for the 1/32" hammer-milled barley.

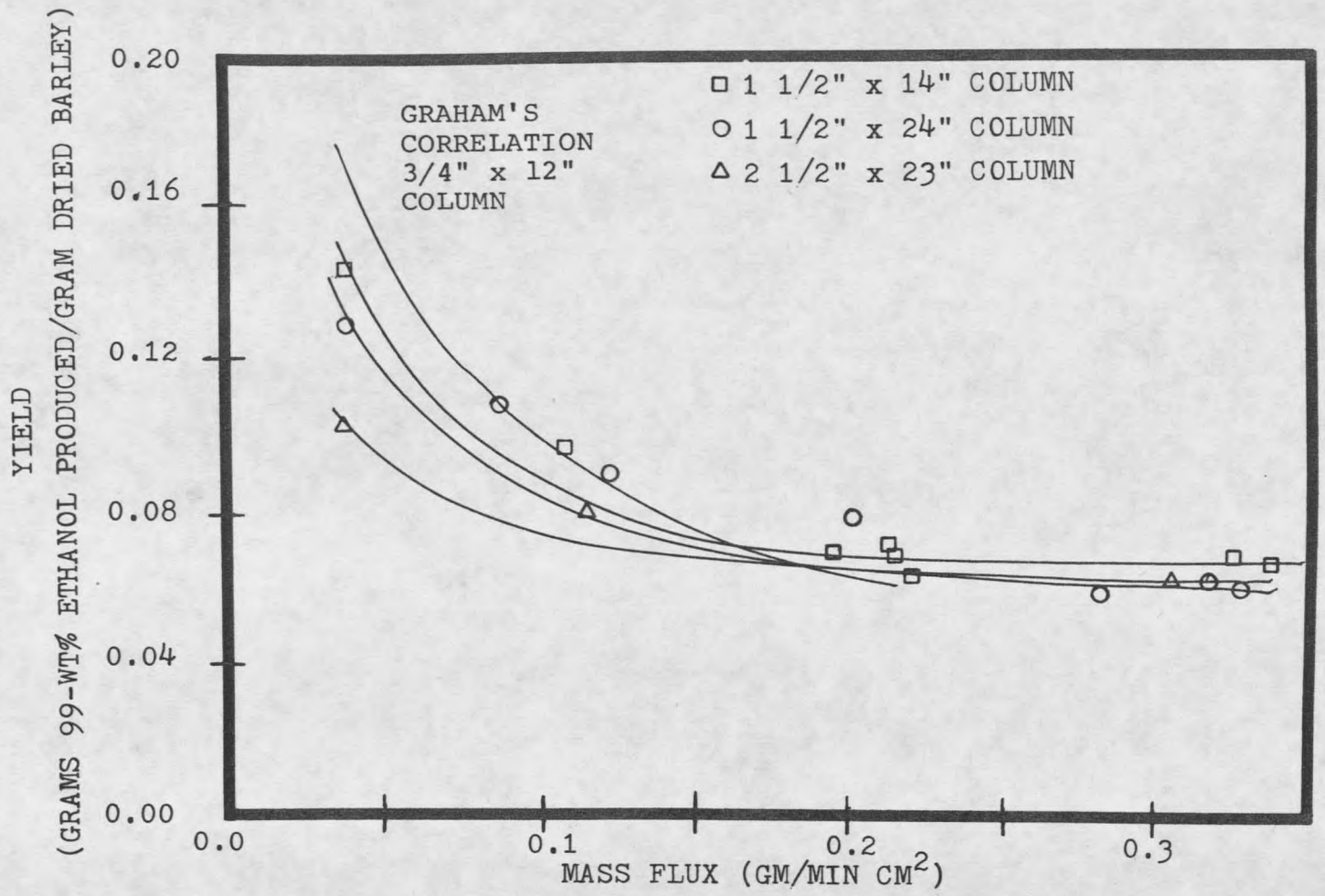

Figure 11. Yield as a function of mass flux for the 1/16" hammer-milled barley.

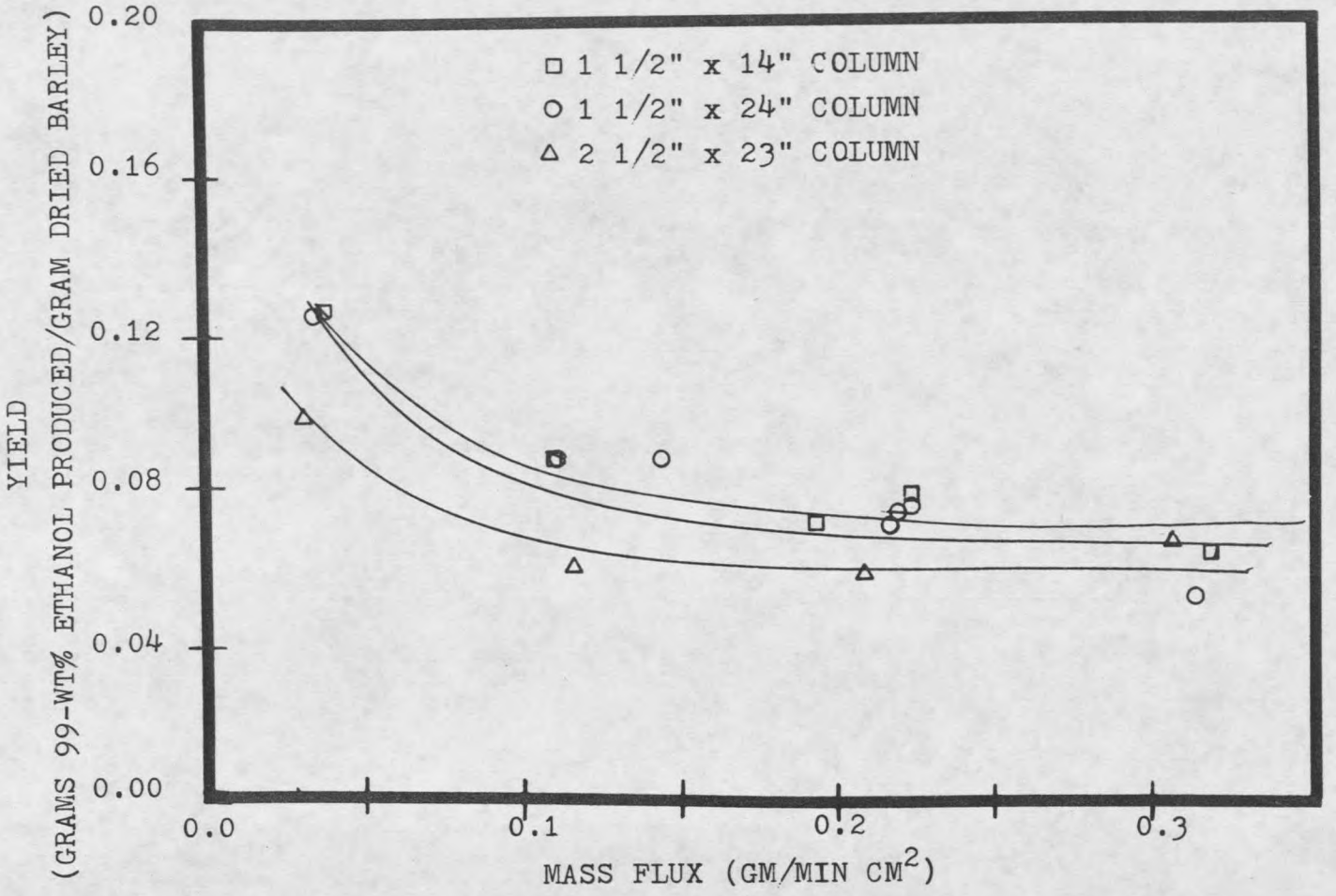

Figure 12. Yield as a function of mass flux for the 1/8" hammer-milled barley.

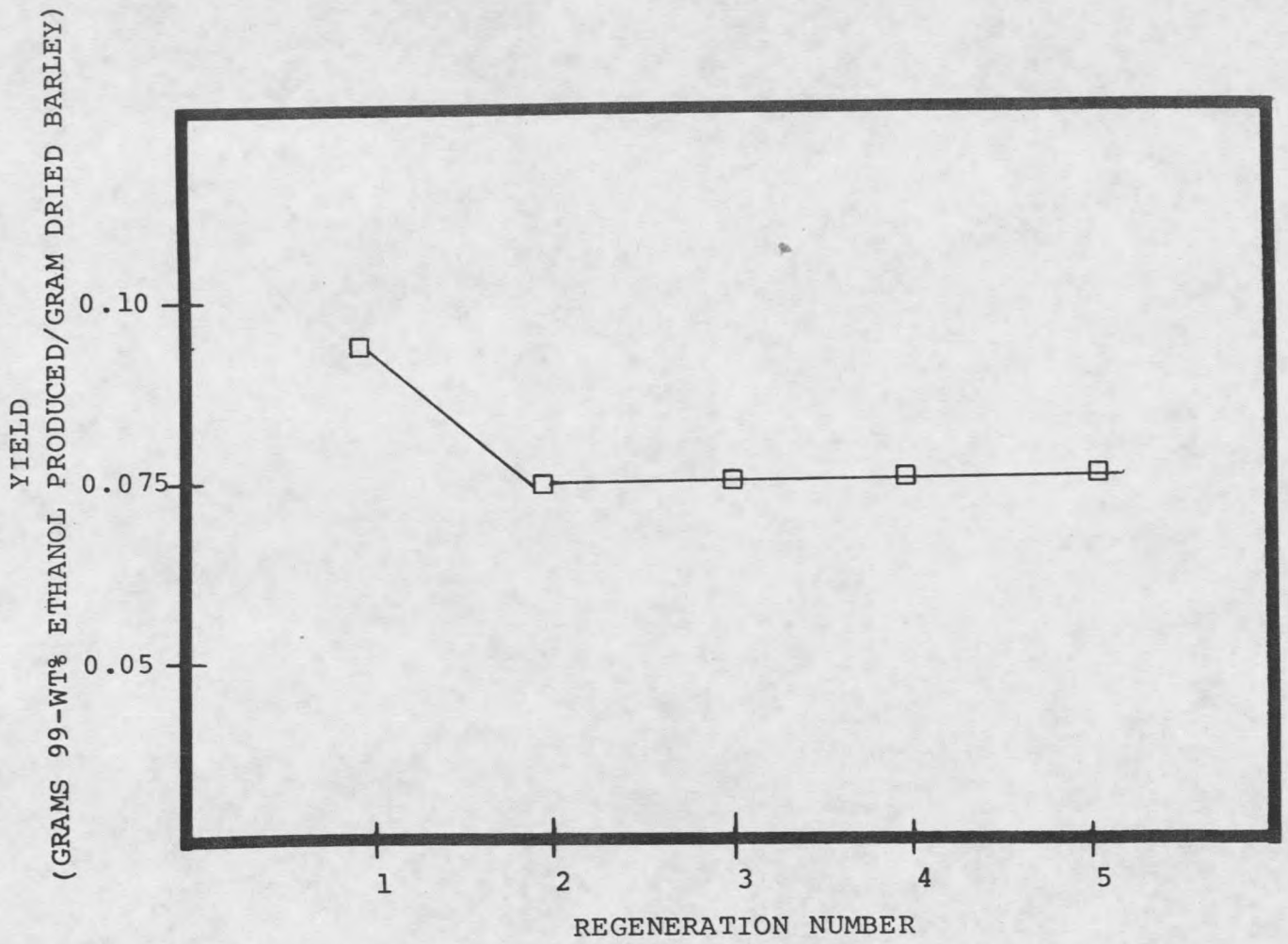

Figure 13. Yield as a function of the number of regenerations.

Run 45 was made with grain that was dried for a period of 500 hours in the oven at a temperature of 110 C. The results of this run were about 20% lower than the value obtained for run 52 where the barley was dried for 100 hours. It could be possible that the regeneration did not affect the sorptive capacity, but the time it spent in the oven was the cause of the decrease in sorptive capacity. Sair and Fetzer found that severe desiccation can reduce the ability of starches to adsorb water [29]. It has been proposed that the hydroxyl groups present in starches play an important role in water sorption. The high heat required to dry the barley could cause mutual bonding of the hydroxyl groups, thus reducing the sorptive capacity [30].

Possible Barley Sorption Process

In order for the barley sorption process to be economically feasible, regeneration of the grain would be necessary. Since the barley contains some ethanol, it should not be used for anything except fermentation to produce ethanol. As shown in Appendix C, four regenerations are required to dehydrate the ethanol created by fermenting one batch of barley.

The barley adsorption process would be tied directly to a conventional distillation column. The distillation column would output 75-wt% ethanol directly to the barley adsorption column. If one barley adsorption column was used, four regenerations would be required for each batch of fermentation ethanol. This would be very inefficient since the distillation column would have to be heated up four times for each batch of ethanol.

A more feasible alternative would be to have four columns in parallel. Then the entire batch could be distilled and concentrated at the same time. At the end of the run the barley from one column would be dumped and fermented. New barley would be put in its place, and the columns would be regenerated. As shown in Appendix C, the time required to regenerate the barley is about 7 hours. The fermentation requires 36-48 hours [31], so

a run could be made every other day. The time required for the distillation and adsorption is much less than the time required for regeneration.

It should be noted that for the barley adsorption system, the yield is not known for larger columns. More tests would be required in order to know how the yield varies in large columns. From the data in this report it can be concluded that the yield will not increase in a larger adsorption column.

This type of a process would undoubtedly be very expensive and difficult to run. At this point there are more attractive methods, such as molecular sieve adsorption, which would be easier and less costly to run.

SUMMARY

This investigation of the separation of an ethanol-water mixture by sorption using barley as the sorbent has produced the following results and conclusions:

1. The amount of 99-wt% ethanol produced per gram of dried barley is inversely proportional to the mass flux.

2. The smallest particle size distribution provided the greatest yield under all conditions.

3. An increase in adsorption column length has no effect on the yield, but an increase in column diameter decreases the yield at low values of mass flux.

4. Absorption in addition to adsorption of the water vapor occurs when barley is used as a sorbent.

5. Both ethanol vapor and water vapor are adsorbed by the barley.

6. Regeneration of the barley will decrease the sorptive capacity.

7. An increase in the adsorption column diameter will increase the temperature of the grain, thus lowering the yield.

8. Regeneration will be necessary if the process is to be used on a large scale.

9. The use of this process would be difficult because of grain regeneration and temperature control.

10. The repeatability of the data obtained was good.

RECOMMENDATIONS FOR FUTURE STUDY

1. Experiments with even more finely ground barley should be run.
2. The adsorption process should be tried at pressures greater than atmospheric.
3. A small scale distillation unit with a barley adsorption unit should be tested with each other to determine the best operating conditions.

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LITERATURE CITED

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APPENDICES

APPENDIX A

RESULTS OF RUNS

Table 5. List of Rejected Runs and the Reason for Rejection.

Run number	Reason for rejection
1-12	Start up
25	Bad mass balance
26	Valve was left open
34	Bad mass balance
37	Powerstat blew a fuse
40	Leak detected after start
43	Bad mass balance
46	Hose burst
49	Feed concentration too low
61	Feed concentration too low
69	Valve was left open

RESULTS RUN NUMBER 13

1.5" X 14" COLUMN
MASS FLUX .224 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	4.58	.0198	.994
1- 2	8.13	.0352	.995
1- 3	10.26	.0444	.996
1- 4	12.82	.0555	.996
1- 5	15.28	.0662	.996
1- 6	20.34	.0881	.984
1- 7	24.93	.1079	.960
1- 8	29.55	.1279	.943
1- 9	32.34	.1400	.933
1-10	36.96	.1600	.919
1-11	41.61	.1801	.909
1-12	49.19	.2129	.896

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .07678

FINAL GRAIN TEMPERATURE 90.0 C

FEED ADDITIONS 62.64 GRAMS

TOTAL SAMPLE WEIGHT 49.19 GRAMS

BARLEY MOISTURE CONTENT 6.80 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 16.85 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 105.43 PERCENT

AMOUNT OF ETHANOL IN FEED 49.53 GRAMS

AMOUNT OF WATER IN FEED 16.51 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 44.06 GRAMS

AMOUNT OF WATER IN PRODUCT 5.13 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 5.47 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 11.05 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 32.48 PERCENT

RESULTS RUN NUMBER 14

1.5" X 14" COLUMN
MASS FLUX .325 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	6.20	.0268	.998
1- 2	10.35	.0448	.998
1- 3	12.51	.0542	.997
1- 4	15.24	.0660	.990
1- 5	17.42	.0754	.983
1- 6	19.73	.0854	.971
1- 7	22.18	.0960	.960
1- 8	24.95	.1080	.948
1- 9	29.10	.1260	.931
1-10	33.73	.1460	.915
1-11	38.57	.1670	.902
1-12	44.86	.1942	.889

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .06643

FINAL GRAIN TEMPERATURE 89.0 C

FEED ADDITIONS 56.76 GRAMS

TOTAL SAMPLE WEIGHT 44.86 GRAMS

BARLEY MOISTURE CONTENT 5.50 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 13.44 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 102.71 PERCENT

AMOUNT OF ETHANOL IN FEED 43.73 GRAMS

AMOUNT OF WATER IN FEED 14.58 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 39.88 GRAMS

AMOUNT OF WATER IN PRODUCT 4.98 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 3.85 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 8.80 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 28.63 PERCENT

RESULTS RUN NUMBER 15

1.5" X 14" COLUMN
MASS FLUX .037 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	4.68	.0203	.996
1- 2	9.77	.0423	.997
1- 3	14.96	.0648	.997
1- 4	19.58	.0848	.997
1- 5	24.58	.1064	.996
1- 6	27.77	.1202	.993
1- 7	32.62	.1412	.984
1- 8	37.10	.1606	.974
1- 9	40.63	.1759	.967
1-10	45.25	.1959	.959

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .12653

FINAL GRAIN TEMPERATURE 88.0 C

FEED ADDITIONS 70.85 GRAMS

TOTAL SAMPLE WEIGHT 45.25 GRAMS

BARLEY MOISTURE CONTENT 7.60 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 19.00 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 90.69 PERCENT

AMOUNT OF ETHANOL IN FEED 48.19 GRAMS

AMOUNT OF WATER IN FEED 16.06 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 43.39 GRAMS

AMOUNT OF WATER IN PRODUCT 1.86 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 4.80 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 9.95 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 25.25 PERCENT

RESULTS RUN NUMBER 16

1.5" X 14" COLUMN
MASS FLUX .108 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	7.13	.0309	.997
1- 2	10.36	.0449	.997
1- 3	13.26	.0574	.998
1- 4	15.27	.0661	.998
1- 5	17.90	.0775	.998
1- 6	19.79	.0857	.996
1- 7	22.76	.0985	.989
1- 8	26.04	.1127	.979
1- 9	29.11	.1260	.968
1-10	32.61	.1412	.958

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .09729

FINAL GRAIN TEMPERATURE 91.0 C

FEED ADDITIONS 50.11 GRAMS

TOTAL SAMPLE WEIGHT 32.61 GRAMS

BARLEY MOISTURE CONTENT 5.80 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 14.22 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 93.46 PERCENT

AMOUNT OF ETHANOL IN FEED 35.12 GRAMS

AMOUNT OF WATER IN FEED 11.71 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 31.22 GRAMS

AMOUNT OF WATER IN PRODUCT 1.39 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 3.90 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 11.10 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 27.42 PERCENT

RESULTS RUN NUMBER 17

1.5" X 14" COLUMN
MASS FLUX .037 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	4.80	.0208	.996
1- 2	9.39	.0407	.998
1- 3	14.37	.0622	.998
1- 4	17.97	.0778	.998
1- 5	22.04	.0954	.998
1- 6	25.88	.1120	.998
1- 7	29.51	.1277	.997
1- 8	29.51	.1278	.997
1- 9	32.30	.1398	.993
1-10	36.93	.1599	.983
1-11	42.14	.1824	.975
1-12	47.83	.2071	.967

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .14544

FINAL GRAIN TEMPERATURE 89.0 C

FEED ADDITIONS 80.78 GRAMS

TOTAL SAMPLE WEIGHT 47.83 GRAMS

BARLEY MOISTURE CONTENT 8.10 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 20.36 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 84.41 PERCENT

AMOUNT OF ETHANOL IN FEED 51.14 GRAMS

AMOUNT OF WATER IN FEED 17.05 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 46.24 GRAMS

AMOUNT OF WATER IN PRODUCT 1.59 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 4.90 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 9.59 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 24.08 PERCENT

RESULTS RUN NUMBER 18

1.5" X 14" COLUMN
MASS FLUX .110 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	7.59	.0329	.999
1- 2	11.16	.0483	.999
1- 3	13.78	.0597	.999
1- 4	15.98	.0692	.999
1- 5	18.92	.0819	.994
1- 6	22.36	.0968	.983
1- 7	26.72	.1157	.967
1- 8	31.90	.1381	.953
1- 9	37.19	.1610	.939
1-10	43.28	.1874	.928

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .08699

FINAL GRAIN TEMPERATURE 87.0 C

FEED ADDITIONS 60.05 GRAMS

TOTAL SAMPLE WEIGHT 43.28 GRAMS

BARLEY MOISTURE CONTENT 6.10 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 15.01 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 97.07 PERCENT

AMOUNT OF ETHANOL IN FEED 43.71 GRAMS

AMOUNT OF WATER IN FEED 14.57 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 40.14 GRAMS

AMOUNT OF WATER IN PRODUCT 3.14 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 3.57 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 8.17 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 23.79 PERCENT

RESULTS RUN NUMBER 19

1.5" X 14" COLUMN
MASS FLUX .219 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	5.52	.0239	.998
1- 2	8.80	.0381	.998
1- 3	10.95	.0474	.999
1- 4	14.01	.0607	.999
1- 5	16.37	.0709	.999
1- 6	19.48	.0843	.997
1- 7	22.63	.0980	.989
1- 8	25.58	.1107	.976
1- 9	29.25	.1266	.962
1-10	33.36	.1444	.949
1-11	39.92	.1728	.932

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .09560

FINAL GRAIN TEMPERATURE 89.0 C

FEED ADDITIONS 56.16 GRAMS

TOTAL SAMPLE WEIGHT 39.92 GRAMS

BARLEY MOISTURE CONTENT 5.50 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 13.44 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 95.02 PERCENT

AMOUNT OF ETHANOL IN FEED 40.02 GRAMS

AMOUNT OF WATER IN FEED 13.34 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 37.20 GRAMS

AMOUNT OF WATER IN PRODUCT 2.72 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 2.82 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 7.06 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 21.00 PERCENT

RESULTS RUN NUMBER 20

1.5" X 14" COLUMN
MASS FLUX .320 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	5.05	.0219	.999
1- 2	7.73	.0335	.999
1- 3	10.42	.0451	.999
1- 4	13.35	.0578	.994
1- 5	16.39	.0710	.980
1- 6	19.22	.0832	.964
1- 7	22.06	.0955	.949
1- 8	26.94	.1166	.927
1- 9	31.44	.1361	.911
1-10	39.23	.1698	.892

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .06139

FINAL GRAIN TEMPERATURE 90.0 C

FEED ADDITIONS 50.28 GRAMS

TOTAL SAMPLE WEIGHT 39.23 GRAMS

BARLEY MOISTURE CONTENT 5.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 12.16 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 102.19 PERCENT

AMOUNT OF ETHANOL IN FEED 38.54 GRAMS

AMOUNT OF WATER IN FEED 12.85 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 34.98 GRAMS

AMOUNT OF WATER IN PRODUCT 4.25 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 3.56 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 9.23 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 29.25 PERCENT

RESULTS RUN NUMBER 21

1.5" X 14" COLUMN
MASS FLUX .297 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	7.15	.0310	.998
1- 2	9.94	.0430	.998
1- 3	11.86	.0513	.998
1- 4	14.26	.0617	.998
1- 5	16.88	.0731	.998
1- 6	20.34	.0881	.992
1- 7	25.32	.1096	.982
1- 8	29.29	.1268	.964
1- 9	33.30	.1442	.949
1-10	40.69	.1761	.927

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .09252

FINAL GRAIN TEMPERATURE 90.0 C

FEED ADDITIONS 55.30 GRAMS

TOTAL SAMPLE WEIGHT 40.69 GRAMS

BARLEY MOISTURE CONTENT 5.40 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 13.19 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 97.43 PERCENT

AMOUNT OF ETHANOL IN FEED 40.41 GRAMS

AMOUNT OF WATER IN FEED 13.47 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 37.72 GRAMS

AMOUNT OF WATER IN PRODUCT 2.97 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 2.69 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 6.66 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 20.41 PERCENT

RESULTS RUN NUMBER 22

1.5" X 14" COLUMN
MASS FLUX .036 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	6.92	.0300	.998
1- 2	15.10	.0654	.999
1- 3	22.05	.0955	.999
1- 4	27.48	.1190	.999
1- 5	32.67	.1414	.999
1- 6	38.32	.1659	.998
1- 7	43.16	.1868	.992
1- 8	47.44	.2054	.985
1- 9	52.94	.2292	.976
1-10	60.48	.2618	.963
1-11	62.72	.2715	.958

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .19193

FINAL GRAIN TEMPERATURE 87.0 C

FEED ADDITIONS 93.31 GRAMS

TOTAL SAMPLE WEIGHT 62.72 GRAMS

BARLEY MOISTURE CONTENT 9.30 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 23.69 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 92.60 PERCENT

AMOUNT OF ETHANOL IN FEED 64.80 GRAMS

AMOUNT OF WATER IN FEED 21.60 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 60.11 GRAMS

AMOUNT OF WATER IN PRODUCT 2.61 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 4.69 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 7.24 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 19.82 PERCENT

RESULTS RUN NUMBER 23

1.5" X 14" COLUMN
MASS FLUX .212 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	5.55	.0240	.999
1- 2	13.46	.0583	.998
1- 3	18.22	.0789	.985
1- 4	23.94	.1036	.960
1- 5	27.58	.1194	.946
1- 6	32.15	.1392	.930
1- 7	37.33	.1616	.917
1- 8	44.48	.1926	.904

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .07143

FINAL GRAIN TEMPERATURE 90.0 C

FEED ADDITIONS 61.78 GRAMS

TOTAL SAMPLE WEIGHT 44.48 GRAMS

BARLEY MOISTURE CONTENT 5.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 12.16 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 91.68 PERCENT

AMOUNT OF ETHANOL IN FEED 42.48 GRAMS

AMOUNT OF WATER IN FEED 14.16 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 40.20 GRAMS

AMOUNT OF WATER IN PRODUCT 4.28 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 2.28 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 5.36 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 18.72 PERCENT

RESULTS RUN NUMBER 24

1.5" X 14" COLUMN
MASS FLUX .102 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	8.02	.0347	.995
1- 2	11.52	.0499	.996
1- 3	14.36	.0622	.997
1- 4	17.57	.0761	.997
1- 5	20.05	.0868	.997
1- 6	22.64	.0980	.997
1- 7	24.98	.1081	.997
1- 8	27.51	.1191	.994
1- 9	30.00	.1299	.989
1-10	34.46	.1492	.977

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .12695

FINAL GRAIN TEMPERATURE 88.0 C

FEED ADDITIONS 53.40 GRAMS

TOTAL SAMPLE WEIGHT 34.46 GRAMS

BARLEY MOISTURE CONTENT 7.30 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 18.19 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 98.61 PERCENT

AMOUNT OF ETHANOL IN FEED 39.49 GRAMS

AMOUNT OF WATER IN FEED 13.16 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 33.67 GRAMS

AMOUNT OF WATER IN PRODUCT .79 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 5.81 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 14.72 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 31.96 PERCENT

RESULTS RUN NUMBER 27

1.5" X 14" COLUMN
MASS FLUX .196 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	5.01	.0217	.997
1- 2	11.54	.0500	.997
1- 3	16.73	.0724	.988
1- 4	20.20	.0875	.973
1- 5	23.64	.1023	.957
1- 6	27.83	.1205	.940
1- 7	30.91	.1338	.931
1- 8	34.17	.1479	.921
1- 9	41.19	.1783	.905

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .06806

FINAL GRAIN TEMPERATURE 90.0 C

FEED ADDITIONS 57.02 GRAMS

TOTAL SAMPLE WEIGHT 41.19 GRAMS

BARLEY MOISTURE CONTENT 6.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 14.74 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 98.09 PERCENT

AMOUNT OF ETHANOL IN FEED 41.95 GRAMS

AMOUNT OF WATER IN FEED 13.98 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 37.26 GRAMS

AMOUNT OF WATER IN PRODUCT 3.93 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 4.69 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 11.17 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 31.79 PERCENT

RESULTS RUN NUMBER 28

1.5" X 14" COLUMN
MASS FLUX .219 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	4.39	.0190	.998
1- 2	11.59	.0502	.997
1- 3	14.24	.0617	.990
1- 4	16.44	.0712	.982
1- 5	20.08	.0869	.968
1- 6	23.97	.1038	.952
1- 7	28.98	.1255	.934
1- 8	32.08	.1389	.925
1- 9	35.83	.1551	.916
1-10	41.70	.1805	.904

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .06210

FINAL GRAIN TEMPERATURE 89.0 C

FEED ADDITIONS 58.75 GRAMS

TOTAL SAMPLE WEIGHT 41.70 GRAMS

BARLEY MOISTURE CONTENT 6.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 14.74 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 96.07 PERCENT

AMOUNT OF ETHANOL IN FEED 42.33 GRAMS

AMOUNT OF WATER IN FEED 14.11 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 37.71 GRAMS

AMOUNT OF WATER IN PRODUCT 3.99 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 4.62 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 10.92 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 31.34 PERCENT

RESULTS RUN NUMBER 29

1.5" X 14" COLUMN
MASS FLUX .214 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	6.14	.0266	.993
1- 2	10.30	.0446	.995
1- 3	14.26	.0617	.994
1- 4	18.36	.0795	.983
1- 5	22.23	.0962	.970
1- 6	27.11	.1174	.953
1- 7	30.93	.1339	.940
1- 8	35.96	.1557	.927

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .06776

FINAL GRAIN TEMPERATURE 88.0 C

FEED ADDITIONS 52.27 GRAMS

TOTAL SAMPLE WEIGHT 35.96 GRAMS

BARLEY MOISTURE CONTENT 7.10 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 17.65 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 102.57 PERCENT

AMOUNT OF ETHANOL IN FEED 40.21 GRAMS

AMOUNT OF WATER IN FEED 13.40 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 33.32 GRAMS

AMOUNT OF WATER IN PRODUCT 2.64 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 6.90 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 17.15 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 39.06 PERCENT

RESULTS RUN NUMBER 30

1.5" X 14" COLUMN
MASS FLUX .337 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	5.48	.0237	.997
1- 2	10.08	.0436	.998
1- 3	12.76	.0552	.997
1- 4	17.55	.0760	.980
1- 5	22.25	.0963	.955
1- 6	28.11	.1217	.929
1- 7	38.93	.1685	.897

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .06362

FINAL GRAIN TEMPERATURE 92.0 C

FEED ADDITIONS 50.98 GRAMS

TOTAL SAMPLE WEIGHT 38.93 GRAMS

BARLEY MOISTURE CONTENT 5.70 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 13.96 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 103.76 PERCENT

AMOUNT OF ETHANOL IN FEED 39.67 GRAMS

AMOUNT OF WATER IN FEED 13.22 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 34.90 GRAMS

AMOUNT OF WATER IN PRODUCT 4.03 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 4.77 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 12.03 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 34.16 PERCENT

RESULTS RUN NUMBER 31

1.5" X 14" COLUMN
MASS FLUX .193 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	4.30	.0186	.997
1- 2	8.86	.0384	.998
1- 3	11.82	.0512	.998
1- 4	14.43	.0625	.996
1- 5	16.71	.0723	.988
1- 6	19.01	.0823	.977
1- 7	22.04	.0954	.962
1- 8	27.96	.1210	.937

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .06976
FINAL GRAIN TEMPERATURE 90.0 C
FEED ADDITIONS 44.93 GRAMS
TOTAL SAMPLE WEIGHT 27.96 GRAMS
BARLEY MOISTURE CONTENT 6.00 PERCENT
AMOUNT OF LIQUID ADSORBED INTO BARLEY 14.74 GRAMS
AMOUNT OF FEED ACCOUNTED FOR 95.05 PERCENT
AMOUNT OF ETHANOL IN FEED 32.03 GRAMS
AMOUNT OF WATER IN FEED 10.68 GRAMS
AMOUNT OF ETHANOL IN PRODUCT 26.21 GRAMS
AMOUNT OF WATER IN PRODUCT 1.75 GRAMS
AMOUNT OF ETHANOL ADSORBED INTO BARLEY 5.82 GRAMS
FRACTION OF ETHANOL ADSORBED INTO BARLEY 18.18 PERCENT
FRACTION OF ETHANOL IN ADSORBED LIQUID 39.49 PERCENT

RESULTS RUN NUMBER 32

1.5" X 24" COLUMN
MASS FLUX .111 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	6.37	.0159	.998
1- 2	15.95	.0399	.998
1- 3	22.52	.0563	.998
1- 4	25.42	.0636	.998
1- 5	28.74	.0719	.998
1- 6	32.75	.0819	.994
1- 7	36.05	.0901	.988
1- 8	41.20	.1030	.979

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .08754

FINAL GRAIN TEMPERATURE 94.0 C

FEED ADDITIONS 77.33 GRAMS

TOTAL SAMPLE WEIGHT 41.20 GRAMS

BARLEY MOISTURE CONTENT 5.30 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 22.39 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 82.23 PERCENT

AMOUNT OF ETHANOL IN FEED 47.69 GRAMS

AMOUNT OF WATER IN FEED 15.90 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 40.34 GRAMS

AMOUNT OF WATER IN PRODUCT .86 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 7.35 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 15.41 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 32.83 PERCENT

RESULTS RUN NUMBER 33

1.5" X 24" COLUMN
MASS FLUX .121 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	6.07	.0152	.998
1- 2	12.72	.0318	.998
1- 3	17.97	.0449	.998
1- 4	21.21	.0530	.998
1- 5	25.10	.0628	.998
1- 6	28.14	.0704	.998
1- 7	30.87	.0772	.997
1- 8	33.38	.0835	.995
1- 9	38.21	.0955	.986

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .09003

FINAL GRAIN TEMPERATURE 96.0 C

FEED ADDITIONS 62.21 GRAMS

TOTAL SAMPLE WEIGHT 38.21 GRAMS

BARLEY MOISTURE CONTENT 4.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 16.67 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 88.21 PERCENT

AMOUNT OF ETHANOL IN FEED 41.16 GRAMS

AMOUNT OF WATER IN FEED 13.72 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 37.67 GRAMS

AMOUNT OF WATER IN PRODUCT .54 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 3.49 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 8.49 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 20.96 PERCENT

RESULTS RUN NUMBER 35

1.5" X 24" COLUMN
MASS FLUX .144 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	5.87	.0147	.995
1- 2	12.26	.0307	.996
1- 3	16.58	.0415	.996
1- 4	23.00	.0575	.996
1- 5	27.32	.0683	.996
1- 6	29.40	.0735	.996
1- 7	32.51	.0813	.994
1- 8	35.67	.0892	.989
1- 9	39.00	.0975	.983
1-10	44.37	.1109	.972
1-11	48.96	.1224	.964
1-12	55.36	.1384	.956

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .08764

FINAL GRAIN TEMPERATURE 94.0 C

FEED ADDITIONS 87.26 GRAMS

TOTAL SAMPLE WEIGHT 55.36 GRAMS

BARLEY MOISTURE CONTENT 5.40 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 22.83 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 89.61 PERCENT

AMOUNT OF ETHANOL IN FEED 58.64 GRAMS

AMOUNT OF WATER IN FEED 19.55 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 52.92 GRAMS

AMOUNT OF WATER IN PRODUCT 2.44 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 5.72 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 9.76 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 25.06 PERCENT

RESULTS RUN NUMBER 36

1.5" X 24" COLUMN
MASS FLUX .309 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	5.68	.0142	.998
1- 2	11.08	.0277	.999
1- 3	18.14	.0454	.999
1- 4	22.51	.0563	.999
1- 5	24.93	.0623	.999
1- 6	28.03	.0701	.999
1- 7	31.01	.0775	.998
1- 8	32.72	.0818	.994
1- 9	37.75	.0944	.980
1-10	42.71	.1068	.966
1-11	48.51	.1213	.952

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .08551

FINAL GRAIN TEMPERATURE 98.0 C

FEED ADDITIONS 79.06 GRAMS

TOTAL SAMPLE WEIGHT 48.51 GRAMS

BARLEY MOISTURE CONTENT 5.30 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 22.39 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 89.68 PERCENT

AMOUNT OF ETHANOL IN FEED 53.17 GRAMS

AMOUNT OF WATER IN FEED 17.72 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 46.17 GRAMS

AMOUNT OF WATER IN PRODUCT 2.34 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 7.00 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 13.17 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 31.28 PERCENT

RESULTS RUN NUMBER 38

1.5" X 24" COLUMN
MASS FLUX .202 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	7.97	.0199	.994
1- 2	16.13	.0403	.995
1- 3	22.63	.0566	.995
1- 4	27.04	.0676	.995
1- 5	34.59	.0865	.985
1- 6	38.50	.0963	.977
1- 7	42.34	.1058	.970
1- 8	46.89	.1172	.961
1- 9	55.38	.1384	.947

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .07694

FINAL GRAIN TEMPERATURE 95.0 C

FEED ADDITIONS 84.67 GRAMS

TOTAL SAMPLE WEIGHT 55.38 GRAMS

BARLEY MOISTURE CONTENT 5.70 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 24.18 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 93.96 PERCENT

AMOUNT OF ETHANOL IN FEED 59.67 GRAMS

AMOUNT OF WATER IN FEED 19.89 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 52.46 GRAMS

AMOUNT OF WATER IN PRODUCT 2.92 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 7.21 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 12.08 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 29.81 PERCENT

RESULTS RUN NUMBER 41

1.5" X 24" COLUMN
MASS FLUX .111 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	8.79	.0220	.997
1- 2	15.82	.0396	.997
1- 3	22.42	.0561	.997
1- 4	29.97	.0749	.996
1- 5	38.56	.0964	.995
1- 6	46.75	.1169	.994
1- 7	51.22	.1280	.989
1- 8	53.91	.1348	.984
1- 9	58.36	.1459	.975
1-10	62.89	.1572	.965

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .12529

FINAL GRAIN TEMPERATURE 94.0 C

FEED ADDITIONS 116.21 GRAMS

TOTAL SAMPLE WEIGHT 62.89 GRAMS

BARLEY MOISTURE CONTENT 7.20 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 31.03 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 80.82 PERCENT

AMOUNT OF ETHANOL IN FEED 70.44 GRAMS

AMOUNT OF WATER IN FEED 23.48 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 60.66 GRAMS

AMOUNT OF WATER IN PRODUCT 2.23 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 9.78 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 13.89 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 31.52 PERCENT

RESULTS RUN NUMBER 42

1.5" X 24" COLUMN
MASS FLUX .087 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	7.76	.0194	.997
1- 2	15.29	.0382	.998
1- 3	22.88	.0572	.998
1- 4	30.58	.0765	.998
1- 5	34.15	.0854	.998
1- 6	37.89	.0947	.997
1- 7	41.49	.1037	.993
1- 8	44.61	.1115	.988
1- 9	50.33	.1258	.980

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .10895

FINAL GRAIN TEMPERATURE 93.0 C

FEED ADDITIONS 76.03 GRAMS

TOTAL SAMPLE WEIGHT 50.33 GRAMS

BARLEY MOISTURE CONTENT 5.60 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 23.73 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 97.40 PERCENT

AMOUNT OF ETHANOL IN FEED 55.54 GRAMS

AMOUNT OF WATER IN FEED 18.51 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 49.31 GRAMS

AMOUNT OF WATER IN PRODUCT 1.02 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 6.23 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 11.22 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 26.27 PERCENT

RESULTS RUN NUMBER 44

1.5" X 24" COLUMN
MASS FLUX .286 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	9.37	.0234	.993
1- 2	17.21	.0430	.983
1- 3	22.43	.0561	.971
1- 4	29.01	.0725	.954
1- 5	33.04	.0826	.941
1- 6	36.83	.0921	.929
1- 7	40.79	.1020	.918
1- 8	45.06	.1126	.908
1- 9	55.47	.1387	.889

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .02929
FINAL GRAIN TEMPERATURE 93.0 C
FEED ADDITIONS 76.46 GRAMS
TOTAL SAMPLE WEIGHT 55.47 GRAMS
BARLEY MOISTURE CONTENT 5.30 PERCENT
AMOUNT OF LIQUID ADSORBED INTO BARLEY 22.39 GRAMS
AMOUNT OF FEED ACCOUNTED FOR 101.82 PERCENT
AMOUNT OF ETHANOL IN FEED 58.39 GRAMS
AMOUNT OF WATER IN FEED 19.46 GRAMS
AMOUNT OF ETHANOL IN PRODUCT 49.29 GRAMS
AMOUNT OF WATER IN PRODUCT 6.18 GRAMS
AMOUNT OF ETHANOL ADSORBED INTO BARLEY 9.10 GRAMS
FRACTION OF ETHANOL ADSORBED INTO BARLEY 15.58 PERCENT
FRACTION OF ETHANOL IN ADSORBED LIQUID 40.64 PERCENT

RESULTS RUN NUMBER 45

1.5" X 24" COLUMN
MASS FLUX .317 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	10.40	.0260	.999
1- 2	16.84	.0421	.998
1- 3	23.11	.0578	.991
1- 4	28.65	.0716	.982
1- 5	34.74	.0869	.959
1- 6	40.79	.1020	.938
1- 7	47.60	.1190	.920

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .05910

FINAL GRAIN TEMPERATURE 94.0 C

FEED ADDITIONS 62.64 GRAMS

TOTAL SAMPLE WEIGHT 47.60 GRAMS

BARLEY MOISTURE CONTENT 4.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 16.67 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 102.60 PERCENT

AMOUNT OF ETHANOL IN FEED 48.20 GRAMS

AMOUNT OF WATER IN FEED 16.07 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 43.80 GRAMS

AMOUNT OF WATER IN PRODUCT 3.80 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 4.40 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 9.12 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 26.38 PERCENT

RESULTS RUN NUMBER 47

1.5" X 24" COLUMN
MASS FLUX .223 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	9.27	.0232	.996
1- 2	15.26	.0382	.996
1- 3	20.82	.0521	.997
1- 4	24.95	.0624	.996
1- 5	28.61	.0715	.992
1- 6	32.68	.0817	.984
1- 7	37.07	.0927	.970
1- 8	43.69	.1092	.951
1- 9	50.62	.1265	.935
1-10	57.87	.1447	.922

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .07385

FINAL GRAIN TEMPERATURE 94.0 C

FEED ADDITIONS 77.76 GRAMS

TOTAL SAMPLE WEIGHT 57.87 GRAMS

BARLEY MOISTURE CONTENT 4.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 16.67 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 95.85 PERCENT

AMOUNT OF ETHANOL IN FEED 55.90 GRAMS

AMOUNT OF WATER IN FEED 18.63 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 53.33 GRAMS

AMOUNT OF WATER IN PRODUCT 4.54 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 2.58 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 4.61 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 15.46 PERCENT

RESULTS RUN NUMBER 48

1.5" X 24" COLUMN
MASS FLUX .277 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	12.35	.0309	.997
1- 2	17.54	.0439	.997
1- 3	23.18	.0580	.992
1- 4	27.71	.0693	.983
1- 5	32.28	.0807	.972
1- 6	38.08	.0952	.957

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .06023

FINAL GRAIN TEMPERATURE 93.0 C

FEED ADDITIONS 48.38 GRAMS

TOTAL SAMPLE WEIGHT 38.08 GRAMS

BARLEY MOISTURE CONTENT 3.50 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 14.51 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 108.69 PERCENT

AMOUNT OF ETHANOL IN FEED 39.44 GRAMS

AMOUNT OF WATER IN FEED 13.15 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 36.43 GRAMS

AMOUNT OF WATER IN PRODUCT 1.65 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 3.01 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 7.64 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 20.78 PERCENT

RESULTS RUN NUMBER 50

1.5" X 24" COLUMN
MASS FLUX .225 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	9.60	.0240	.996
1- 2	15.61	.0390	.996
1- 3	21.29	.0532	.996
1- 4	27.19	.0680	.996
1- 5	31.16	.0779	.995
1- 6	35.29	.0882	.989
1- 7	39.61	.0990	.978
1- 8	43.69	.1092	.966
1- 9	49.97	.1249	.950
1-10	57.14	.1428	.934

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .08708

FINAL GRAIN TEMPERATURE 96.0 C

FEED ADDITIONS 78.62 GRAMS

TOTAL SAMPLE WEIGHT 57.14 GRAMS

BARLEY MOISTURE CONTENT 5.20 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 21.94 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 100.58 PERCENT

AMOUNT OF ETHANOL IN FEED 59.31 GRAMS

AMOUNT OF WATER IN FEED 19.77 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 53.34 GRAMS

AMOUNT OF WATER IN PRODUCT 3.80 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 5.97 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 10.06 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 27.21 PERCENT

RESULTS RUN NUMBER 51

1.5" X 24" COLUMN
MASS FLUX .327 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	12.99	.0325	.998
1- 2	18.95	.0474	.996
1- 3	21.96	.0549	.992
1- 4	25.33	.0633	.985
1- 5	29.05	.0726	.975
1- 6	33.82	.0846	.961
1- 7	40.19	.1005	.944
1- 8	49.63	.1241	.923

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .05729

FINAL GRAIN TEMPERATURE 93.0 C

FEED ADDITIONS 64.80 GRAMS

TOTAL SAMPLE WEIGHT 49.63 GRAMS

BARLEY MOISTURE CONTENT 3.80 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 15.80 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 100.97 PERCENT

AMOUNT OF ETHANOL IN FEED 49.07 GRAMS

AMOUNT OF WATER IN FEED 16.36 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 45.81 GRAMS

AMOUNT OF WATER IN PRODUCT 3.82 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 3.26 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 6.64 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 20.63 PERCENT

RESULTS RUN NUMBER 52

1.5" X 24" COLUMN
MASS FLUX .314 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	10.66	.0267	.996
1- 2	16.86	.0422	.994
1- 3	19.52	.0488	.991
1- 4	22.89	.0572	.985
1- 5	27.51	.0688	.974
1- 6	31.74	.0794	.962
1- 7	37.25	.0931	.946
1- 8	46.69	.1167	.925

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .04974

FINAL GRAIN TEMPERATURE 94.0 C

FEED ADDITIONS 62.21 GRAMS

TOTAL SAMPLE WEIGHT 46.69 GRAMS

BARLEY MOISTURE CONTENT 4.30 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 17.97 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 103.95 PERCENT

AMOUNT OF ETHANOL IN FEED 48.50 GRAMS

AMOUNT OF WATER IN FEED 16.17 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 43.17 GRAMS

AMOUNT OF WATER IN PRODUCT 3.52 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 5.33 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 10.99 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 29.65 PERCENT

RESULTS RUN NUMBER 53

1.5" X 24" COLUMN
MASS FLUX .039 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	10.50	.0263	.996
1- 2	23.09	.0577	.996
1- 3	35.74	.0894	.996
1- 4	43.22	.1080	.996
1- 5	52.71	.1318	.995
1- 6	58.56	.1464	.994
1- 7	63.20	.1580	.992
1- 8	70.33	.1758	.985

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .16196

FINAL GRAIN TEMPERATURE 87.0 C

FEED ADDITIONS 115.34 GRAMS

TOTAL SAMPLE WEIGHT 70.33 GRAMS

BARLEY MOISTURE CONTENT 8.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 34.78 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 91.13 PERCENT

AMOUNT OF ETHANOL IN FEED 78.83 GRAMS

AMOUNT OF WATER IN FEED 26.28 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 69.25 GRAMS

AMOUNT OF WATER IN PRODUCT 1.08 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 9.58 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 12.15 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 27.55 PERCENT

RESULTS RUN NUMBER 54

1.5" X 24" COLUMN
MASS FLUX .216 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	7.12	.0178	.996
1- 2	14.62	.0366	.997
1- 3	18.29	.0457	.997
1- 4	21.94	.0549	.997
1- 5	23.67	.0592	.996
1- 6	25.53	.0638	.995
1- 7	29.09	.0727	.986
1- 8	34.85	.0871	.967
1- 9	41.02	.1025	.948

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .06883
FINAL GRAIN TEMPERATURE 93.0 C
FEED ADDITIONS 60.48 GRAMS
TOTAL SAMPLE WEIGHT 41.02 GRAMS
BARLEY MOISTURE CONTENT 5.30 PERCENT
AMOUNT OF LIQUID ADSORBED INTO BARLEY 22.39 GRAMS
AMOUNT OF FEED ACCOUNTED FOR 104.84 PERCENT
AMOUNT OF ETHANOL IN FEED 47.55 GRAMS
AMOUNT OF WATER IN FEED 15.85 GRAMS
AMOUNT OF ETHANOL IN PRODUCT 38.88 GRAMS
AMOUNT OF WATER IN PRODUCT 2.14 GRAMS
AMOUNT OF ETHANOL ADSORBED INTO BARLEY 8.67 GRAMS
FRACTION OF ETHANOL ADSORBED INTO BARLEY 18.24 PERCENT
FRACTION OF ETHANOL IN ADSORBED LIQUID 38.74 PERCENT

RESULTS RUN NUMBER 55

1.5" X 24" COLUMN
MASS FLUX .347 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	7.83	.0196	.996
1- 2	16.33	.0408	.997
1- 3	22.20	.0555	.997
1- 4	26.51	.0663	.997
1- 5	30.41	.0760	.997
1- 6	33.31	.0833	.996
1- 7	39.04	.0976	.985
1- 8	47.55	.1189	.958

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .09139

FINAL GRAIN TEMPERATURE 97.0 C

FEED ADDITIONS 68.69 GRAMS

TOTAL SAMPLE WEIGHT 47.55 GRAMS

BARLEY MOISTURE CONTENT 4.80 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 20.17 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 98.59 PERCENT

AMOUNT OF ETHANOL IN FEED 50.79 GRAMS

AMOUNT OF WATER IN FEED 16.93 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 45.53 GRAMS

AMOUNT OF WATER IN PRODUCT 2.02 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 5.26 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 10.36 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 26.08 PERCENT

RESULTS RUN NUMBER 56

1.5" X 24" COLUMN
MASS FLUX .037 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	12.20	.0305	.996
1- 2	24.69	.0617	.997
1- 3	32.64	.0816	.997
1- 4	40.52	.1013	.996
1- 5	45.14	.1128	.994
1- 6	49.53	.1238	.992
1- 7	54.20	.1355	.989
1- 8	58.10	.1452	.986

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .13083

FINAL GRAIN TEMPERATURE 86.0 C

FEED ADDITIONS 93.74 GRAMS

TOTAL SAMPLE WEIGHT 58.10 GRAMS

BARLEY MOISTURE CONTENT 7.80 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 33.84 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 98.08 PERCENT

AMOUNT OF ETHANOL IN FEED 68.95 GRAMS

AMOUNT OF WATER IN FEED 22.98 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 57.29 GRAMS

AMOUNT OF WATER IN PRODUCT .81 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 11.67 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 16.92 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 34.48 PERCENT

RESULTS RUN NUMBER 57

1.5" X 24" COLUMN
MASS FLUX .212 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED
REGENERATION NUMBER 1

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	11.59	.0273	.995
1- 2	16.26	.0383	.995
1- 3	21.59	.0508	.995
1- 4	26.32	.0619	.995
1- 5	29.29	.0689	.995
1- 6	32.18	.0757	.995
1- 7	40.58	.0955	.990

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .09454

FINAL GRAIN TEMPERATURE 95.0 C

FEED ADDITIONS 61.78 GRAMS

TOTAL SAMPLE WEIGHT 40.58 GRAMS

BARLEY MOISTURE CONTENT 4.40 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 19.56 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 97.35 PERCENT

AMOUNT OF ETHANOL IN FEED 45.11 GRAMS

AMOUNT OF WATER IN FEED 15.04 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 40.16 GRAMS

AMOUNT OF WATER IN PRODUCT .42 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 4.94 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 10.96 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 25.26 PERCENT

RESULTS RUN NUMBER 58

1.5" X 24" COLUMN
MASS FLUX .035 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	12.76	.0319	.997
1- 2	22.77	.0569	.997
1- 3	30.85	.0771	.997
1- 4	38.63	.0966	.996
1- 5	42.03	.1051	.995
1- 6	46.26	.1156	.993
1- 7	50.22	.1255	.990
1- 8	53.28	.1332	.988

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .12585

FINAL GRAIN TEMPERATURE 88.0 C

FEED ADDITIONS 82.08 GRAMS

TOTAL SAMPLE WEIGHT 53.28 GRAMS

BARLEY MOISTURE CONTENT 7.90 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 34.31 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 106.71 PERCENT

AMOUNT OF ETHANOL IN FEED 65.69 GRAMS

AMOUNT OF WATER IN FEED 21.90 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 52.63 GRAMS

AMOUNT OF WATER IN PRODUCT .65 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 13.06 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 19.89 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 38.07 PERCENT

RESULTS RUN NUMBER 59

1.5" X 24" COLUMN
MASS FLUX .209 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED
REGENERATION RUN NUMBER 2

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	6.75	.0169	.995
1- 2	11.83	.0296	.995
1- 3	16.73	.0418	.995
1- 4	21.32	.0533	.995
1- 5	25.92	.0648	.994
1- 6	28.84	.0721	.994
1- 7	31.96	.0799	.988
1- 8	36.82	.0921	.971
1- 9	47.30	.1182	.941

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .07671

FINAL GRAIN TEMPERATURE 96.0 C

FEED ADDITIONS 68.26 GRAMS

TOTAL SAMPLE WEIGHT 47.30 GRAMS

BARLEY MOISTURE CONTENT 5.10 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 21.50 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 100.79 PERCENT

AMOUNT OF ETHANOL IN FEED 51.60 GRAMS

AMOUNT OF WATER IN FEED 17.20 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 44.50 GRAMS

AMOUNT OF WATER IN PRODUCT 2.80 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 7.09 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 13.75 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 33.00 PERCENT

RESULTS RUN NUMBER 60

1.5" X 24" COLUMN
MASS FLUX .236 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED
REGENERATION RUN NUMBER 3

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	7.21	.0180	.994
1- 2	13.81	.0345	.995
1- 3	17.58	.0440	.995
1- 4	21.20	.0530	.995
1- 5	24.48	.0612	.996
1- 6	28.48	.0712	.995
1- 7	38.38	.0960	.966

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .07552

FINAL GRAIN TEMPERATURE 94.0 C

FEED ADDITIONS 60.48 GRAMS

TOTAL SAMPLE WEIGHT 38.38 GRAMS

BARLEY MOISTURE CONTENT 4.70 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 19.73 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 96.08 PERCENT

AMOUNT OF ETHANOL IN FEED 43.58 GRAMS

AMOUNT OF WATER IN FEED 14.53 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 37.06 GRAMS

AMOUNT OF WATER IN PRODUCT 1.32 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 6.52 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 14.95 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 33.04 PERCENT

RESULTS RUN NUMBER 61

2.5" X 23" COLUMN
MASS FLUX .113 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	15.18	.0169	.993
1- 2	30.77	.0342	.995
1- 3	46.48	.0516	.988
1- 4	54.68	.0608	.973
1- 5	59.71	.0663	.963
1- 6	65.00	.0722	.952
1- 7	71.34	.0793	.939
1- 8	81.69	.0908	.921
1- 9	89.82	.0998	.909
1-10	99.19	.1102	.897

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .04615

FINAL GRAIN TEMPERATURE 95.0 C

FEED ADDITIONS 135.65 GRAMS

TOTAL SAMPLE WEIGHT 99.19 GRAMS

BARLEY MOISTURE CONTENT 7.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 67.74 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 123.06 PERCENT

AMOUNT OF ETHANOL IN FEED 125.20 GRAMS

AMOUNT OF WATER IN FEED 41.73 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 88.92 GRAMS

AMOUNT OF WATER IN PRODUCT 10.27 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 36.27 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 28.97 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 53.55 PERCENT

RESULTS RUN NUMBER 62

2.5" X 23" COLUMN
MASS FLUX .116 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	16.92	.0188	.996
1- 2	30.27	.0336	.996
1- 3	45.61	.0507	.996
1- 4	55.12	.0612	.988
1- 5	62.31	.0692	.985
1- 6	69.18	.0769	.976
1- 7	76.35	.0848	.965
1- 8	82.98	.0922	.956
1- 9	93.12	.1035	.943

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .05875

FINAL GRAIN TEMPERATURE 94.0 C

FEED ADDITIONS 127.87 GRAMS

TOTAL SAMPLE WEIGHT 93.12 GRAMS

BARLEY MOISTURE CONTENT 5.10 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 48.37 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 110.65 PERCENT

AMOUNT OF ETHANOL IN FEED 106.12 GRAMS

AMOUNT OF WATER IN FEED 35.37 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 87.84 GRAMS

AMOUNT OF WATER IN PRODUCT 5.28 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 18.28 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 17.22 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 37.79 PERCENT

RESULTS RUN NUMBER 63

2.5" X 23" COLUMN
MASS FLUX .225 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	17.20	.0191	.998
1- 2	32.66	.0363	.998
1- 3	43.15	.0479	.998
1- 4	57.52	.0639	.998
1- 5	64.75	.0719	.998
1- 6	70.47	.0783	.998
1- 7	76.40	.0849	.995
1- 8	83.53	.0928	.983
1- 9	93.71	.1041	.967
1-10	112.04	.1245	.943
1-11	113.59	.1262	.941

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .08804

FINAL GRAIN TEMPERATURE 101.0 C

FEED ADDITIONS 152.93 GRAMS

TOTAL SAMPLE WEIGHT 113.59 GRAMS

BARLEY MOISTURE CONTENT 5.90 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 56.43 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 111.18 PERCENT

AMOUNT OF ETHANOL IN FEED 127.51 GRAMS

AMOUNT OF WATER IN FEED 42.50 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 106.93 GRAMS

AMOUNT OF WATER IN PRODUCT 6.67 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 20.59 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 16.15 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 36.49 PERCENT

RESULTS RUN NUMBER 64

1.5" X 24" COLUMN
MASS FLUX .225 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED
REGENERATION RUN NUMBER 4

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	10.39	.0260	.995
1- 2	16.64	.0416	.996
1- 3	20.39	.0510	.996
1- 4	26.58	.0665	.995
1- 5	30.21	.0755	.991
1- 6	34.02	.0851	.985
1- 7	38.97	.0974	.973
1- 8	43.98	.1099	.960
1- 9	48.94	.1223	.949
1-10	53.93	.1348	.939

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .07734

FINAL GRAIN TEMPERATURE 93.0 C

FEED ADDITIONS 73.44 GRAMS

TOTAL SAMPLE WEIGHT 53.93 GRAMS

BARLEY MOISTURE CONTENT 5.40 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 22.83 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 104.53 PERCENT

AMOUNT OF ETHANOL IN FEED 57.57 GRAMS

AMOUNT OF WATER IN FEED 19.19 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 50.64 GRAMS

AMOUNT OF WATER IN PRODUCT 3.29 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 6.94 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 12.05 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 30.38 PERCENT

RESULTS RUN NUMBER 65

2.5" X 23" COLUMN
MASS FLUX .032 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	13.80	.0153	.997
1- 2	28.41	.0316	.998
1- 3	43.53	.0484	.998
1- 4	58.87	.0654	.998
1- 5	69.87	.0776	.997
1- 6	78.19	.0869	.995
1- 7	86.20	.0958	.991
1- 8	94.47	.1050	.987
1- 9	102.30	.1137	.983

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .09873

FINAL GRAIN TEMPERATURE 90.0 C

FEED ADDITIONS 155.52 GRAMS

TOTAL SAMPLE WEIGHT 102.30 GRAMS

BARLEY MOISTURE CONTENT 6.30 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 60.51 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 104.69 PERCENT

AMOUNT OF ETHANOL IN FEED 122.11 GRAMS

AMOUNT OF WATER IN FEED 40.70 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 100.55 GRAMS

AMOUNT OF WATER IN PRODUCT 1.75 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 21.56 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 17.66 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 35.63 PERCENT

RESULTS RUN NUMBER 66

2.5° X 23° COLUMN
MASS FLUX .304 GM/MIN SQCM
GRAIN SIZE 1/16° HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	13.52	.0150	.997
1- 2	31.24	.0347	.997
1- 3	39.55	.0439	.996
1- 4	49.60	.0551	.993
1- 5	58.83	.0654	.987
1- 6	67.30	.0748	.977
1- 7	74.20	.0824	.966
1- 8	82.51	.0917	.953
1- 9	95.74	.1064	.931

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .06040

FINAL GRAIN TEMPERATURE 100.0 C

FEED ADDITIONS 127.87 GRAMS

TOTAL SAMPLE WEIGHT 95.74 GRAMS

BARLEY MOISTURE CONTENT 5.20 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 49.37 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 113.48 PERCENT

AMOUNT OF ETHANOL IN FEED 108.83 GRAMS

AMOUNT OF WATER IN FEED 36.28 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 89.14 GRAMS

AMOUNT OF WATER IN PRODUCT 6.60 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 19.69 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 18.09 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 39.88 PERCENT

RESULTS RUN NUMBER 67

2.5" X 23" COLUMN
MASS FLUX .034 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	14.37	.0160	.998
1- 2	30.57	.0340	.999
1- 3	48.56	.0540	.999
1- 4	64.86	.0721	.999
1- 5	76.82	.0854	.999
1- 6	88.14	.0979	.997
1- 7	96.58	.1073	.995
1- 8	105.49	.1172	.992
1- 9	114.06	.1267	.989
1-10	121.97	.1355	.986

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .12371

FINAL GRAIN TEMPERATURE 92.0 C

FEED ADDITIONS 177.55 GRAMS

TOTAL SAMPLE WEIGHT 121.97 GRAMS

BARLEY MOISTURE CONTENT 8.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 78.26 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 112.77 PERCENT

AMOUNT OF ETHANOL IN FEED 150.17 GRAMS

AMOUNT OF WATER IN FEED 50.06 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 120.21 GRAMS

AMOUNT OF WATER IN PRODUCT 1.77 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 29.97 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 19.96 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 38.29 PERCENT

RESULTS RUN NUMBER 68

2.5" X 23" COLUMN
MASS FLUX .308 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	17.18	.0191	.999
1- 2	28.99	.0322	.999
1- 3	40.76	.0453	.999
1- 4	50.16	.0557	.998
1- 5	58.03	.0645	.990
1- 6	65.52	.0728	.978
1- 7	73.79	.0820	.962
1- 8	82.22	.0914	.947
1- 9	95.61	.1062	.927

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .06413

FINAL GRAIN TEMPERATURE 96.0 C

FEED ADDITIONS 129.60 GRAMS

TOTAL SAMPLE WEIGHT 95.61 GRAMS

BARLEY MOISTURE CONTENT 5.40 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 51.37 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 113.41 PERCENT

AMOUNT OF ETHANOL IN FEED 110.24 GRAMS

AMOUNT OF WATER IN FEED 36.75 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 88.61 GRAMS

AMOUNT OF WATER IN PRODUCT 7.00 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 21.63 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 19.62 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 42.11 PERCENT

RESULTS RUN NUMBER 70

2.5" X 23" COLUMN
MASS FLUX .114 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	12.82	.0142	.998
1- 2	27.99	.0311	.999
1- 3	39.07	.0434	.998
1- 4	50.58	.0562	.998
1- 5	58.43	.0649	.998
1- 6	64.51	.0717	.996
1- 7	70.02	.0778	.992
1- 8	78.84	.0876	.983
1- 9	87.90	.0977	.972
1-10	104.18	.1158	.950

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .08026

FINAL GRAIN TEMPERATURE 95.0 C

FEED ADDITIONS 146.88 GRAMS

TOTAL SAMPLE WEIGHT 104.18 GRAMS

BARLEY MOISTURE CONTENT 5.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 47.37 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 103.18 PERCENT

AMOUNT OF ETHANOL IN FEED 113.66 GRAMS

AMOUNT OF WATER IN FEED 37.89 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 98.96 GRAMS

AMOUNT OF WATER IN PRODUCT 5.22 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 14.70 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 12.93 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 31.03 PERCENT

RESULTS RUN NUMBER 71

2.5" X 23" COLUMN
MASS FLUX .108 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	15.47	.0172	.997
1- 2	33.36	.0371	.998
1- 3	51.48	.0572	.998
1- 4	62.74	.0697	.998
1- 5	71.27	.0792	.998
1- 6	79.38	.0882	.996
1- 7	88.10	.0979	.987
1- 8	93.89	.1043	.980
1- 9	105.25	.1169	.966
1-10	116.64	.1296	.953
1-11	129.15	.1435	.942

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .09481

FINAL GRAIN TEMPERATURE 96.0 C

FEED ADDITIONS 178.85 GRAMS

TOTAL SAMPLE WEIGHT 129.15 GRAMS

BARLEY MOISTURE CONTENT 5.90 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 56.43 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 103.76 PERCENT

AMOUNT OF ETHANOL IN FEED 139.18 GRAMS

AMOUNT OF WATER IN FEED 46.39 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 121.61 GRAMS

AMOUNT OF WATER IN PRODUCT 7.54 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 17.57 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 12.62 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 31.14 PERCENT

RESULTS RUN NUMBER 72

2.5" X 23" COLUMN
MASS FLUX .207 GM/MIN SQCM
GRAIN SIZE 1/ 8" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	16.77	.0186	.998
1- 2	31.76	.0353	.998
1- 3	45.12	.0501	.995
1- 4	56.84	.0632	.985
1- 5	64.86	.0721	.974
1- 6	81.21	.0902	.947

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .05706

FINAL GRAIN TEMPERATURE 95.0 C

FEED ADDITIONS 114.05 GRAMS

TOTAL SAMPLE WEIGHT 81.21 GRAMS

BARLEY MOISTURE CONTENT 6.20 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 59.49 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 123.37 PERCENT

AMOUNT OF ETHANOL IN FEED 105.52 GRAMS

AMOUNT OF WATER IN FEED 35.17 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 76.89 GRAMS

AMOUNT OF WATER IN PRODUCT 4.32 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 28.63 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 27.13 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 48.13 PERCENT

RESULTS RUN NUMBER 73

2.5" X 23" COLUMN
MASS FLUX .323 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	18.38	.0204	.998
1- 2	34.32	.0381	.999
1- 3	47.46	.0527	.999
1- 4	57.13	.0635	.999
1- 5	66.49	.0739	.997
1- 6	74.62	.0829	.986
1- 7	89.70	.0997	.962

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY = .07973

FINAL GRAIN TEMPERATURE 98.0 C

FEED ADDITIONS 146.02 GRAMS

TOTAL SAMPLE WEIGHT 89.70 GRAMS

BARLEY MOISTURE CONTENT 6.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 57.45 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 100.77 PERCENT

AMOUNT OF ETHANOL IN FEED 110.36 GRAMS

AMOUNT OF WATER IN FEED 36.79 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 86.30 GRAMS

AMOUNT OF WATER IN PRODUCT 3.40 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 24.06 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 21.80 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 41.88 PERCENT

RESULTS RUN NUMBER 74

2.5" X 23" COLUMN
MASS FLUX .036 GM/MIN SQCM
GRAIN SIZE 1/16" HAMMER MILLED

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	18.14	.0202	.996
1- 2	35.60	.0396	.997
1- 3	53.33	.0593	.997
1- 4	69.17	.0769	.997
1- 5	80.37	.0893	.995
1- 6	87.32	.0970	.993
1- 7	100.29	.1114	.986

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .10348

FINAL GRAIN TEMPERATURE 92.0 C

FEED ADDITIONS 144.29 GRAMS

TOTAL SAMPLE WEIGHT 100.29 GRAMS

BARLEY MOISTURE CONTENT 6.00 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 57.45 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 109.32 PERCENT

AMOUNT OF ETHANOL IN FEED 118.30 GRAMS

AMOUNT OF WATER IN FEED 39.43 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 98.89 GRAMS

AMOUNT OF WATER IN PRODUCT 1.40 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 19.41 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 16.41 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 33.79 PERCENT

RESULTS RUN NUMBER 75

1.5" X 24" COLUMN
MASS FLUX .236 GM/MIN SQCM
GRAIN SIZE 1/32" HAMMER MILLED
REGENERATION RUN NUMBER 5

SAMPLE NUMBERS	CUMULATIVE WEIGHT (GRAMS)	WEIGHT OF PRODUCT PER GRAM BARLEY	CUMULATIVE WEIGHT PERCENT ETHANOL
1- 1	11.40	.0285	.996
1- 2	17.66	.0442	.996
1- 3	22.14	.0554	.995
1- 4	28.29	.0707	.992
1- 5	34.31	.0858	.985
1- 6	38.89	.0972	.979
1- 7	42.81	.1070	.971
1- 8	46.31	.1158	.963
1- 9	52.17	.1304	.950

GRAMS 99 WT.% ETHANOL PRODUCED PER GRAM DRIED BARLEY .07515

FINAL GRAIN TEMPERATURE 93.0 C

FEED ADDITIONS 76.90 GRAMS

TOTAL SAMPLE WEIGHT 52.17 GRAMS

BARLEY MOISTURE CONTENT 6.10 PERCENT

AMOUNT OF LIQUID ADSORBED INTO BARLEY 25.99 GRAMS

AMOUNT OF FEED ACCOUNTED FOR 101.64 PERCENT

AMOUNT OF ETHANOL IN FEED 58.62 GRAMS

AMOUNT OF WATER IN FEED 19.54 GRAMS

AMOUNT OF ETHANOL IN PRODUCT 49.55 GRAMS

AMOUNT OF WATER IN PRODUCT 2.62 GRAMS

AMOUNT OF ETHANOL ADSORBED INTO BARLEY 9.07 GRAMS

FRACTION OF ETHANOL ADSORBED INTO BARLEY 15.47 PERCENT

FRACTION OF ETHANOL IN ADSORBED LIQUID 34.90 PERCENT

APPENDIX B

FORTRAN COMPUTER PROGRAM USED TO CALCULATE YIELD AND PRINT RESULTS

```
      DIMENSION X(20),ETOH(20),CUMPER(20),TOTALW(20),TOTALF(20)
     &,IG(3),AREA(3),DIA(3),IHEIGHT(3),GRWT(3)
      REAL MOIST
  556 K=1
      TOTAL=0
      TETOH=0
      READ(10,5)NRUN,N,FEED,MOIST,TIME,ICOL,IGRAIN,GTEMP
    5 FORMAT(8F.4)
      IF (NRUN.EQ.99) GOTO 558
      IG(1)=8;IG(2)=16;IG(3)=32;DIA(1)=1.5;DIA(2)=1.5
      DIA(3)=2.5;IHEIGHT(1)=14;IHEIGHT(2)=24;IHEIGHT(3)=23
      AREA(1)=11.4;AREA(2)=11.4;AREA(3)=31.67
      GRWT(1)=231.;GRWT(2)=400.
      DO 55,I=1,N
      READ(10,6)X(I),ETOH(I)
    6 FORMAT(2F.3)
      ETOH(I)=ETOH(I)*X(I)
      TETOH=TETOH+ETOH(I)
      TOTAL=TOTAL+X(I)
      TOTALW(I)=TOTAL
      TOTALF(I)=TOTAL/GRWT(ICOL)
      CUMPER(I)=TETOH/TOTAL
      IF(CUMPER(I).LT..99.AND.K.EQ.1)  GOTO 100
      GOTO 55
  100 K=0
      YEILD=(.99-CUMPER(I-1))/((CUMPER(I)-CUMPER(I-1))/X(I))
     &+TOTAL-X(I)
      YEILD=YEILD/GRWT(ICOL)
   55 CONTINUE
      WRITE(108,2) NRUN
    2 FORMAT(///,20X,'RESULTS RUN NUMBER',I3,/)
      WRITE (108,41) DIA(ICOL),IHEIGHT(ICOL)
   41 FORMAT(/,22X,F3.1,'" X ',I2,'" COLUMN')
      SPACE=(FEED*.846/TIME)/AREA(ICOL)
      WRITE (108,42) SPACE
   42 FORMAT(17X,'MASS FLUX ',F5.3,' GM/MIN SQCM')
      WRITE(108,43) IG(IGRAIN)
   43 FORMAT(16X,'GRAIN SIZE 1/',I2,'" HAMMER MILLED')
      WRITE (108,3)
    3 FORMAT (///,12X,'CUMULATIVE',5X,'WEIGHT OF')
```

```
      WRITE (108,13)
13    FORMAT(X,'SAMPLE',7X,'WEIGHT',6X,'PRODUCT PER'5X,'CUMULATIVE'
     &,' WEIGHT')
      WRITE (108,14)
14    FORMAT(X,'NUMBERS',5X,'(GRAMS)',6X,'GRAM BARLEY',6X,'PERCENT '
     &,'ETHANOL',/)
      WRITE(108,20) (I,TOTALW(I),TOTALF(I),CUM
     &PER(I)),I=1,N
20    FORMAT(X,'1-',I2,8X,F6.2,10X,F5.4,13X,F5.3)
      WRITE(108,19)
19    FORMAT(///)
      WRITE (108,25) YEILD
25    FORMAT(/,X,'GRAMS 99 WT.% ETHANOL PRODUCED',
     &' PER GRAM DRIED BARLEY',4X,F7.5)
      WRITE (108,943) GTEMP
943   FORMAT(/,X,'FINAL GRAIN TEMPERATURE ',F6.1,'  C')
      FEED=FEED*.864
      WRITE (108,35) FEED
35    FORMAT(/,X,'FEED ADDITIONS',5X,F7.2,2X,'GRAMS')
      WRITE(108,45) TOTAL
45    FORMAT(/,X,'TOTAL SAMPLE WEIGHT',5X,F7.2,2X,'GRAMS')
      ADS=(MOIST/(1-MOIST))*GRWT(ICOL)
      XMOIST=MOIST*100
      WRITE(108,36) XMOIST
   36 FORMAT(/,X,'BARLEY MOISTURE CONTENT',F7.2,'   PERCENT')
      WRITE(108,65) ADS
65    FORMAT(/,X,'AMOUNT OF LIQUID ADSORBED INTO BARLEY',
     &5X,F7.2,2X,'GRAMS')
      ACC=((TOTAL+ADS)/FEED)*100
      WRITE(108,75) ACC
75    FORMAT(/,X,'AMOUNT OF FEED ACCOUNTED FOR',5X,F7.2,'  PERCENT')
      FEED=FEED*ACC/100
      ETOHI=FEED*.75
      H2O=FEED*.25
      H2OO=TOTAL-TETOH
      WRITE(108,85) ETOHI
85    FORMAT(/,X,'AMOUNT OF ETHANOL IN FEED',5X,F7.2,2X,'GRAMS')
      WRITE(108,95) H2O
95    FORMAT(/,X,'AMOUNT OF WATER IN FEED',5X,F7.2,2X,'GRAMS')
      WRITE (108,96) TETOH
```

```
 96    FORMAT(/,X,'AMOUNT OF ETHANOL IN PRODUCT',5X,F7.2,2X,'GRAMS')
       WRITE (108,105) H2OO
105    FORMAT(/,X,'AMOUNT OF WATER IN PRODUCT',5X,F7.2,2X,'GRAMS')
       ADSB=ETOHI-TETOH
       WRITE(108,125) ADSB
125    FORMAT(/,X,'AMOUNT OF ETHANOL ADSORBED INTO BARLEY',
      &5X,F7.2,2X,'GRAMS')
       FRAC=ADSB/ETOHI*100
       WRITE(108,135) FRAC
135    FORMAT(/,X,'FRACTION OF ETHANOL ADSORBED INTO BARLEY',
      &5X,F7.2,'  PERCENT')
       PER=(ADSB/(ADSB+H2O-H2OO))*100
       WRITE(108,145) PER
145    FORMAT(/,X,'FRACTION OF ETHANOL IN ADSORBED LIQUID',
      &5X,F7.2,'  PERCENT')
       WRITE (108,555)
555    FORMAT (/////////)
       GOTO 556
  558 END
```

APPENDIX C

CALCULATIONS

CALCULATIONS

A. Calculation of the number of regenerations required to dehydrate the ethanol produced from fermenting the barley:

Amount of ethanol produced by fermenting barley:

0.3 grams 99-wt% ethanol produced/gram barley fermented [32]

Yield for the first run:

0.094 grams 99-wt% ethanol produced/gram dried barley

Yield for each additional run:

0.075 grams 99-wt% ethanol produced/gram dried barley

Number of runs required to consume barley produced by fermentation:

$$1 + \frac{0.30 - 0.094}{0.075} = 3.7 \approx 4 \text{ regenerations}$$

B. Calculation of the approximate time required to regenerate the barley.

The method of regeneration is to blow hot air (120 C) in the top of the adsorption column to drive off the liquid from the barley.

Assumptions:

1. All the liquid is on the surface—none has been absorbed into the interior of the barley. This assumption is made because absorption is important only when the concentration of water in the effluent is 15-20 wt%. Under actual operating conditions, the process would be shut down when the concentration of the effluent dropped below 99-wt%.
2. All the adsorbed liquid has the properties of liquid water.
3. There is no heat loss in the adsorption column during regeneration.

This example uses run number 57 as an example; 425 grams of barley were charged to the adsorber.

From the results on page 87:

mass of liquid adsorbed into barley = 19.5 grams

Since the final grain temperature is nearly at the boiling point of water, the only energy required to remove the water is the latent heat.

$$q = m\lambda$$

$$q = 0.0195\text{kg} \times 2256 \frac{\text{KJ}}{\text{kg}} = 44\text{KJ}$$

The energy required to heat the grain from 95 to 120 C is:

$$q = C_p m \Delta T \qquad C_p = 1.4 \frac{\text{KJ}}{\text{kg C}}$$

$$q = 1.4 \frac{\text{KJ}}{\text{kg C}} \times 0.425\text{kg} \times (120\text{-}95)\,\text{C} = 14\text{KJ}$$

The total energy required for regeneration is the sum of the two previous quantities:

$$44\text{KJ} + 14\text{KJ} = 58\text{KJ}$$

The hot air is blown through the adsorption column at the same velocity the run was made (2.4 grams/min). Using the ideal gas law:

$$V = \frac{nRT}{P}$$

$$V = \frac{2.4}{29} \frac{\text{moles}}{\text{min}} \times 62400 \frac{\text{cm}^3\,\text{mmHg}}{\text{mole K}} \times 393\,\text{K} \times \frac{1}{640\,\text{mmHg}} = 3171 \frac{\text{cm}^3}{\text{min}}$$

The heat given off by the air:

$$q = V \rho C_p \Delta T$$

$$q = 3171 \frac{\text{cm}^3}{\text{min}} \times 8.95 \times 10^{-7} \frac{\text{kg}}{\text{cm}^3} \times 1.1 \frac{\text{KJ}}{\text{kg C}} \times (120\text{-}95)\,\text{C}$$

$$= 0.078\ \text{KJ/min}$$

The total regeneration time is:

$$58\text{KJ}/0.078 \frac{\text{KJ}}{\text{min}} = 743\ \text{min} = 12.4\ \text{hours}$$