DOE/R4/10409--T1

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SMALL SCALE ETHANOL PRODUCTION DEMONSTRATION
COMPARISON OF PACKED VERSUS PLATE RECTIFYING COLUMN

DOE/R4/10409--T1

DE84 000438

Kenneth E. Johnson Environmental and Energy Center

The University
Of Alabama
In Huntsville

FB44-81R410409

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July 1982

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SMALL SCALE ETHANOL PRODUCTION DEMONSTRATION
COMPARISON OF PACKED VERSUS PLATE RECTIFYING COLUMN

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U.S. Department of Energy

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Grant Number: DE-FG4481R4 10409

July 1982

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ABSTRACT

The Johnson Environmental and Energy Center with assistance from the Madison County Farm Bureau Association received a grant in 1980 from the U.S. Department of Energy to design, fabricate, and evaluate a small scale continuous ethanol plant.

In 1981, the Center received a second DOE grant to compare the economics of replacing the plate rectifying column in the initial unit with a packed rectifying column.

The results of the study indicate that the distillation unit with the packed rectifying column is capable of producing 14 gallons per hour of 170 proof ethanol. The energy ratio for distillation was a positive 2:1. Cost of the packed column was considerably less than the plate column.

INTRODUCTION

The scope of this study was to satisfy four specific objectives. The first objective was to design a small scale continuous distillation unit capable of producing 10-15 gallons per hour of 170-190 proof ethanol. Additional design parameters were to minimize cost, incorporate features which would permit a farmer to easily replicate the unit, and have a positive energy balance. A second objective was to fabricate the distillation unit. Here again, cost and ease of fabrication were important factors. A third objective was to thoroughly evaluate the distillation unit. Special emphases were on production potential, operational considerations, and energy balance. Of special interest was to thoroughly evaluate the energy balance to determine if a net positive energy ratio can be achieved. A fourth objective of this study was to work with the Madison County Farm Bureau Association in identifying an organization that would place the unit into a production environment.

In 1980, The Johnson Environmental and Energy Center in cooperation with the Madison County Farm Bureau received a U.S. DOE ethanol production demonstration grant.

The results of this 1980 study are documented in the final UAH Report No. 291. In summary, the distillation unit was capable of producing an average of 9-14 gallons per hour (based on alcohol percent in beer) of 174 proof ethanol. The energy balance for distillation was a positive 3:1.

In 1981, the Johnson Center and the Farm Bureau received a U.S. DOE grant to compare the economics of a packed versus a plate rectifying column. The scope of this study was to replace the plate rectifying column in Reference 1 with a packed column and to evaluate the difference in performance and operation.

PLATE DISTILLATION UNIT DESIGN

The plate unit was designed to operate continuously and to produce between 10-15 gallons per hour of 170+ proof ethanol. The engineering drawings of the distillation unit are given in Figures 1 through 8. Table 1 contains a complete list of materials for the unit. The distillation columns are sieve tray columns which are probably the most common type of vessel for distillation. The unit consists of two columns: a beer or stripping column and a rectifying column. Both columns are made of SCH 20 steel, are 16 feet in length, and have a 12-inch inside diameter.

Stripping Column (See Figures 4 and 5)

The stripping column consists of 18 stripping plates which are made of one-fourth inch steel with approximately eight percent of surface area of each plate drilled out in a pattern of 30 one-half inch diameter holes. Each plate has a downcomer consisting of two inch steel tubing which extends from one and one-half inches above the plate, through the plate and down to within one inch of the plate below. At the opposite side of the plate from the downcomer is a four inch steel tubing cup which extends one and one-half inches above the plate. The cup of the lower plate is positioned below the downcomer of the above plate. Liquid will build up on the plate surface to the height of the downcomer and then flow to the plate below. The cup provides a liquid seal to assure vapors will rise through the holes in the plate and not up the downcomers.

The plates are assembled with two seven-sixteenth inch diameter steel rods which extend the length of the column. The plates are separated with two one-half inch diameter, steel tubing, each nine and one-half inches in length. Also several three-sixteenth inch by three-fourth inch flat steel bars are bent and welded to the spacer tubing for additional tray support. The plate spacing is nine and one-half inches.

Rectifying Column (See Figures 6 and 7)

The rectifying column consists of 27 rectifying plates which are made of one-fourth inch steel with approximately eight percent of surface area of each plate drilled out in a pattern of 966 $\frac{7}{64}$ inch diameter holes. Each plate has a one and one-half inch steel tubing downcomer and a three and one-half inch steel tubing cup similar to the stripping column. The plate assembly is identical to the stripping column.

Condenser

The condenser consists of 200 feet of three-fourth inch Type M copper tubing. The tubing is bent in a circular fashion and placed in an 18 inch diameter by five foot steel tank.

Figure 2. Right Side View of Distillation Unit

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NOT TO SCALE

Figure 3. Left Side View of Distillation Unit

JUNE 1981

Figure 6. Rectifying Column (Typical)

JUNE 1981

Figure 7. Rectifying Plate Hole Configuration

JUNE 1981

VIEW B-B

VIEW C-C

NOT TO SCALE

Figure 8. Miscellaneous Plate Hole Patterns

JUNE 1981

TABLE I. LIST OF MATERIALS

ITEM	QUANTITY	DESCRIPTION	COST
1	32 ft.	12 in. dia. sch. 20 steel pipe	\$ 783
2	45	12 in. dia. $\frac{1}{4}$ steel plate (for trays)	405
3	30 ft.	4 in. dia. sch. 40 steel pipe	139
4	6	8 in. dia. rings	54
6	2	0-30 lb. steam gauge	6
7	2	15 lb. pop off valve	25
8	16 ft.	2 in. dia. steel tubing extra thin wall	80
9	3 ft.	4 in. dia. steel tubing sch. 40	29
10	15 ft.	1 $\frac{1}{2}$ in. dia. steel tubing sch. 20	75
11	4 ft.	3 $\frac{1}{2}$ in. dia. steel tubing sch. 20	30
12	5	4 in. 90° weld elbow (sch. 20)	73
13	2	Weld caps 12" to 4"	20
14	6	16 in. dia. rings	108
15	2	18 x 18 x $\frac{1}{2}$ in. steel plate	32
16	12 ft.	3/4 in. steel pipe	86
17	18	4 in. steel cap sch. 20	183
18	1	Steel platform	350
19	1	Steel platform	150
20	32 ft.	3/4 in. steel pipe	23
21	1	3/4 in. tee	1
22	64 ft.	1/2 in. dia. steel rod	37
23	64 ft.	$\frac{1}{2}$ in. steel sch. 40 pipe	48
26	2 ft.	1 $\frac{1}{4}$ in. steel pipe	3
27	2	1 $\frac{1}{4}$ in. steel elbow	4
28	4	3/4 in. steel elbow	2
29	2	3/4 in. to 1/2 in. copper elbow reducer	3
30	4 ft.	2 in. steel pipe	9
31	1	Bottom pump	470
		Teel 1 P898 rotary screw 9 gpm pump	
		Dayton $\frac{1}{2}$ hp. 5 x 994 adjustable drive	
		4 x 179 coupling body	
		1 x 408 spider	
		1 P 675 mounting base	
32	1	Reflux pump	174
		Jabsco 12510-0001	
		Neoprene impeller	
33	1	Feed pump (same as item 31)	470
34	2	Temperature gauges	250
35	6	Temperature gauges	186
36	3	3/4 in. gate valves	29
100	1	Steel tank 18 in. x 5 ft. plain steel	150
101	1	Steel collection drum	125
102	200	3/4 in. copper tubing (Type M)	94
		Misc. items	200
			<u>\$4906</u>

PACKED DISTILLATION UNIT DESIGN

The engineering drawings of the packed rectifying column are given in Figures 9 through 12. Table II contains a complete list of materials for the column. The column was designed to connect directly to the existing plate stripping column. (See Figure 1.)

Figure 10 is a drawing of the distributor plate. The installation of this plate is shown in Figure 11. The plate is located 8 inches from the top flange of the column.

Figure 12 is a drawing of the packing support ring. This ring consists of a wire mesh placed over several 1/2 inch support rods. This support is installed near the flanges (approximately 28 inches from the bottom of the column).

The packing for the column consisted of 8 ft³ of 5/8 inch polypropylene pall rings purchased from Norton Company in Atlanta. The detailed specifications of the packing material are given in Appendix A.

It should be noted that the 5/8 inch copper coil in the packed column was an added option and was not used during testing. Water could be circulated through this coil instead of the refluxing product to control the column temperature. Therefore, the cost of the copper tubing is not included in the cost estimate in Table II.

The material cost of the packed column is estimated to be \$821. The cost of the packing material was \$79.12 per ft³ for a total of \$633.

The cost of both plate columns (See Table I) was \$3,792 when the three pumps are subtracted from the total cost. If the assumption is made that the material costs are equal for both columns, the cost of the plate rectifying column was \$1,896. This compares with a packed rectifying cost of \$1,454.

However, it should be noted that the major cost of the rectifying column is the labor required to fabricate the 27 plates. Each plate required the drilling of 966 7/64 inch holes. The company which fabricated the column estimated that 48 man-hours were required to fabricate the 27 plates. A total of 100 man-hours were required to fabricate the plate rectifying column. The same company estimated that 20 man-hours were required to fabricate the packed column.

Figure 10 .. Packed Column-Distributor Plate

Figure 11. Packed Column-Distributor Plate Location

TABLE II. LIST OF MATERIALS FOR PACKED COLUMN

ITEM	QUANTITY	DESCRIPTION	COST
1	16 ft.	12 in. dia. sch 20 steel pipe	\$397
2	5	16 in. dia. rings	90
3	1	weld cap 12" to 4"	10
4	3	4" 90° weld elbows	54
5	10 ft.	4" dia. sch 20 steel pipe	43
6	2	8" dia. weld rings	18
7	1	15 lb. pop off valve	25
8	20 ft.	3/4 in. steel pipe	20
9	1	0-30 lb. steam gauge	6
10	1	10 1/2 in. dia. distributor plate	10
11	1	1 1/4 in. steel elbow	2
12	2	3/4 in. steel elbow	1
13		5/8 in. dia. copper tubing (Type M)	omitted
14	2 ft.	1 1/4 in. steel pipe	3
15	2	5/8 in. copper elbows	omitted
16	4	16" dia. gasket	8
17	2	8" dia. gasket	4
18		1/8 in. mild steel ring	10
19		wire cloth 3 mesh	10
20		1/2 in. dia. support rods	10
21		miscellaneous items	100
			<u>\$821</u>
22	8 ft. ³	5/8 in. pall rings (packed material)	633
		Total Cost	<u>\$ 1,454</u>

TEST PLAN

The test plan consisted of the following runs:

- Run 1: Prepare 900 gallons of 10 percent water/alcohol beer and distill
- Run 2: Prepare 900 gallons of 10 percent water/alcohol beer and distill
- Run 3: Prepare 1000 gallons of 9 percent water/alcohol beer and distill
- Run 4: Prepare 1000 gallons of 9 percent water/alcohol beer and distill
- Run 5: Prepare 1500 gallons of 8 percent water/alcohol beer and distill
- Run 6: Prepare 1500 gallons of 9 percent water/alcohol beer and distill

By using a mash consisting of alcohol and water it was possible to more accurately control the percent alcohol in the beer. The percent alcohol was varied between 8 and 10 percent to test the still performance over a range of input. The alcohol/water mixture also permitted the more rapid testing of the unit rather than preparing mash and waiting three days for fermentation.

TEST CONFIGURATION

A schematic of the test configuration for the distillation unit is given in Figure 13. Figure 14 is a photograph of the test configuration. A detailed description of each element in the test configuration is given in Appendix B.

Figure 14. Distillation Unit

TEST RESULTS

Production Statistics

Table III summarizes the production statistics for the test runs using the packed rectifying column. A total of over 5000 gallons of mash was distilled during the test runs. The production ranged between 14 and 19 gallons per hour. The proof corrected for temperature ranged between 166-184. The detailed test results are given in Appendix C.

Table IV summarizes the production statistics for the test runs using the plate rectifying column. (See Reference 1.) A total of over 5000 gallons of mash was distilled during the test runs. The production ranged between 8-17 gallons per hour. The proof corrected for temperature ranged between 150-176.

The hourly production for Runs 1, 2, 4, 5, and 6 are given in Figures 15, 16, 17, 18, and 19, respectively, for the packed rectifying column. The test results indicate that product is produced approximately one-half hour after mash is fed into the system. Furthermore, the system reaches equilibrium approximately one hour after the start of the run. Once equilibrium is reached, product can be collected at a constant rate depending on the mash feed rate and the percent alcohol in the mash. With the plate rectifying column; product was produced one hour after mash was fed into the system, and the system reached equilibrium one hour after the start of the run.

A number of feed rates were tested ranging from a low of 133 gallons per hour to a high of 220 gallons per hour. The higher feed rates resulted in flooding of the rectifying column. The test results indicate that probably an optimum feed rate is 150 gallons per hour.

As with the plate column, the packed rectifying column also had a very high ethanol loss. The majority of this loss was in the stillage. For Run 2, the ethanol remaining in the stillage was 3.0 percent. Ideally, this percent should be between 0.1-0.2 percent.

TABLE III. PRODUCTION STATISTICS FOR PACKED COLUMN

Run	% Beer	MASH				STILLAGE			PRODUCT					Time Product Over	Time Before Product Over (hr-min)	Time Before Take Product (hr-min)	Time Take Off Product
		Vol Feed (gal)	Feed Time	Feed Rate (gph)	Theoretical Alcohol 200 Proof (gal)	Vol (gal)	Proof	Alcohol 200 Proof (gal)	Vol (gal)	Rate (gph)	Proof (corrected)	200 Proof (gal)	Rate 200 Proof (gal)				
1	10.0	892	8:30-2:00	162	89.2	1200	--	--	79	17.6	167	66	12	8:45	0-30	1-15	9:30-2:00
2	9.8	697	8:20-12:00	190	66.5	950	3.0	14.2	53	17.7	184	47.7	15.9	8:45	0-45	1-0	9:00-12:00
3	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	9.0	962	9:15-2:45	175	86.6	1250	--	--	87	16.6	170	74	14.1	9:30	0-30	1-30	9:30-2:45
5	8.0	1433	8:00-2:30	220	114.6	--	--	--	105	19.1	166	87.2	15.9	8:15	0-30	1-15	9:00-2:30
6	9.0	1211	7:45-4:50	133	109	--	--	--	120	14.1	167	99.9	11.8	7:50	0-05	1-0	8:20-4:50

TABLE IV. PRODUCTION STATISTICS FOR PLATE COLUMN

Run	% Beer	MASH				STILLAGE			PRODUCT					Time Product Over	Time Before Product Over (hr-min)	Time Before Take Product (hr-min)	Time Take Off Product
		Vol Feed (gal)	Feed Time	Feed Rate (gph)	Theoretical Alcohol 200 Proof (gal)	Vol (gal)	Proof	Alcohol 200 Proof (gal)	Vol (gal)	Rate (gph)	Proof (corrected)	200 Proof (gal)	Rate 200 Proof (gal)				
1	9.0	297	3:00-6:30	85	26.7	--	--	--	41	--	102	21	--	3:30	1-0	--	--
2	8.9	511	9:30-5:00	68	45.5	--	--	--	65	--	171	56-21 = 35	6.4	10:00	1-0	2-45	11:45-5:15
3	9.0	813	8:35-6:00	86	73.2	--	4.2	--	56	8	170	48	6.9	9:30	1-10	2-40	11:00-6:00
4	9.8	840	8:35-3:45	117	82.1	950	1.25	5.9	70	16.7	172	67	14.3	8:40	1-35	3-25	11:30-4:10
5																	
6	6.6	674	10:15-3:05	140	46.4	875	0.5	2.2	34	9.8	176	34	8.5	10:30	1-5	2-20	11:45-3:45
7	11.0	1001	9:40-4:30	147	110.0	1050	3.0	15.8	--	--	150	--	--	10:00	1-30	--	--
8	12.1	1025	10:15-5:15	146	124.0	1100	4.8	26.4	75	15.6	173	65	13.5	10:00	0-45	2-45	12:30-5:20
9	10.5	550	11:40-5:15	100	52.8	--	0.9	--	22	--	155	43	8.6	12:00	2-50	3-5	12:15-5:15

Vol (gal)	15	15	15	15	19
Proof (corrected)	180	167	163	172	167

Figure 15. Ethanol Production for Run 1

Vol	15	15	22
Proof (corrected)	183	184	184

Figure 16. Ethanol Production for Run 2

Figure 17. Ethanol Production for Run 4

Figure 18. Ethanol Production for Run 5

Figure 19. Ethanol Production for Run 6

Energy Consumption

Table V summarizes the energy consumption during distillation for the packed column. Fuel usage for the boiler ranged from 2.9 to 4.5 gallons of No. 2 oil per hour or 406,000 to 630,000 Btu's per hour. The electrical consumption ranged from 4310 to 7714 Btu's per hour.

Table VI summarizes the energy consumption during distillation for the plate column.

The product production ranged from 11.8 to 15.9 gallons of 200 proof ethanol per hour or 995,920 to 1,341,940 Btu's per hour. It should be noted that the product production is based on only the time elapsed after product began to be removed from the system. This is a valid assumption since the still is designed to operate continuously. Consequently, the time for the system to reach equilibrium should be relatively short as compared to the theoretical time the system would operate during continuous distillation.

Given the above assumption the following energy balance equation can be stated:

$$\begin{aligned}\text{Energy balance} &= \frac{\text{Btu's produced/hr}}{\text{Btu's used/hr}} \\ &= \frac{\text{Gallons 200 proof/hr} \times 84,400 \text{ Btu's/gal}}{\text{Gallons \#2 fuel/hr} \times 140,000 \text{ Btu's/gal} + \text{KW/hr} \times 3414 \text{ Btu's/KW}}\end{aligned}$$

Using this equation a positive energy balance during distillation was achieved for all test runs of the packed column. The energy balance ranged between 1.46 and 2.96. For example, 1.46 Btu's were produced for every 1 Btu's used.

TABLE V. ENERGY BALANCE DURING DISTILLATION FOR PACKED COLUMN

Run	Time	Fuel Used (gal)	Fuel Used (gph)	Fuel Used (BTU's/hr)	KWH Used	Elect Used (BTU's/hr)	Ethanol Product				BTU Prod/ BTU Used
							Time	200 Proof (gal)	200 Proof (gph)	200 Proof (BTU's/hr)	
1	8:15- 2:00	24	4.1	574,000	13	7714	8:30- 2:00	66	12	1,012,800	1.46
2	8:00- 12:00	18	4.5	630,000	8	6824	9:00- 12:00	47.7	15.9	1,341,940	2.11
3	--	--	--	--	--	--	--	--	--	--	--
4	9:00- 2:45	20	3.5	490,000	9	5340	9:30- 2:45	74	14.1	1,190,040	2.4
5	7:45- 9:15	43	3.2	448,000	21	5308	9:00- 2:30	87.2	15.9	1,341,940	2.96
6	7:20- 4:50	28	2.9	406,000	12	4310	8:20- 4:50	99.9	11.8	995,920	2.45

TABLE VI. ENERGY BALANCE DURING DISTILLATION FOR PLATE COLUMN

Run	Time (hrs)	Fuel Used (gal)	Fuel Used (gph)	Fuel Used (BTU's/hr)	KWH Used	Elect Used (BTU's/hr)	Ethanol Product				BTU Prod/ BTU Used
							Time Hr	200 Proof (gal)	200 Proof (gph)	200 Proof (BTU's/hr)	
1	4.0	11	2.75	385,000	--	--	--	21	--	--	--
2	8.25	21	2.5	350,000	--	--	5.5	35	6.4	540,160	1.54
3	9.5	24.5	2.6	364,000	--	--	7	48	6.9	582,360	1.60
4	8.0	19	2.4	336,000	--	--	4.7	67	14.3	1,206,920	3.59
5	2.5	--	--	--	--	--	--	--	--	--	--
6	6.25	14	2.2	308,000	--	--	4	34	8.5	717,400	2.33
7	8.5	--	--	--	--	--	--	--	--	--	--
8	8.0	17.6	2.2	308,000	5.8	2474	4.8	65	13.5	1,139,400	3.67
9	8.0	17	2.1	294,000	--	--	5	43	8.6	725,840	2.47

Water Consumption

Table VII summarizes the water consumption during distillation for the packed column. Table VIII summarizes the water consumption during distillation for the plate column.

Since live steam was injected into the column, the boiler required 100 percent make-up in water. The boiler water make-up for the packed column ranged from 36-67 gallons per hour.

The usage in water for the condenser for the packed column ranged from 248 to 313 gallons per hour. Again, the water consumption generally decreased during each run. Possibly the lines begin to clog with usage and reduce water flow.

TABLE VII. WATER USAGE FOR PACKED COLUMN

Run	Time Water On	Time Water On (hrs)	Boiler Feed Water		Condenser Cooling Water		Boiler Operating Press	Use of Heat Exchanger
			gal	(gph)	gal	(gph)		
1	2:30-6:30	4	130	33	1635	409	30	No
2	9:00-5:15	8.25	257	31	3894	472	30	No
3	8:20-6:00	9.5	235	25	2810	296	30	No
4	8:05-4:10	8	245	31	2344	293	30	No
5	8:15-10:40	2.5	75	30	--	--	30	No
6	9:25-3:45	6.25	--	--	1767	283	30	No
7	8:30-5:00	8.5	190	22	2141	253	30	Yes
8	9:15-5:15	8.0	236	30	2055	257	75	Yes
9	11:40-5:00	5.3	129	24	1508	282	75	No

TABLE VIII. WATER USAGE FOR PLATE COLUMN

Run	Time Water On	Time Water On (hrs)	Boiler Feed Water		Condenser Cooling Water		Boiler Operating Press	Use of Heat Exchanger
			gal	(gph)	gal	(gph)		
1	8:30-2:00	5.5	365	66	1724	313	75	No
2	8:20-12:00	3.7	247	67	934	252	75	No
3	--	--	--	--	--	--	--	--
4	9:00-2:45	5.75	342	60	1586	276	75	No
5	7:45-9:15	13.5	671	50	3361	249	75	No
6	7:20-4:50	9.5	344	36	2361	248	75	No

Boiler Efficiency

The boiler efficiency has been checked three times during the last two years. The summary of the tests is given in Table IX. Test #3 was made during the testing of the packed column. (See Appendix D.) The boiler is still operating at an acceptable efficiency of 82 percent.

TABLE IX. BOILER EFFICIENCY TESTS

	<u>Efficiency Test</u>		
	July 7, 1981	August 5, 1981	May 19, 1982
CO ₂	10%	11%	9%
O ₂	6%	10.5%	10.5%
Stack temperature	450°F	400°F	445°F
Efficiency	83.5%	85.6%	82%

TECHNOLOGY TRANSFER

The primary purpose of any demonstration is the transfer of information to interested individuals and organizations. The activities of this demonstration were distributed by a number of sources. News releases were prepared for the news media and several interviews were conducted with the radio and television networks.

The primary source of transferring information was through an in-State hotline operated by the Alabama Department of Energy in Montgomery. A second source of disseminating information was through the Alabama Solar Energy Center.

Progress reports were presented orally to the monthly meetings of the Madison County Farm Bureau board of directors.

A one-day workshop was also scheduled toward the end of the testing program. This workshop was co-sponsored by the Madison County Farm Bureau and the Alabama Department of Energy.

The Madison County Farm Bureau established an advisory board to determine a method for placing the unit into a production environment. This advisory board consisted of the following members: Sam J. Darwin, James E. Patterson, Joe Lasseter, Grady Abernathy, and R.D. Watts. No decision has been made at the writing of this report.

OBSERVATIONS

Stripping Column Plates

The column plates were made of 1/4 inch steels. The thickness could possibly be reduced to 1/8 inch and thus reduce labor costs. Also, the clearance between the plates and the column wall is very critical. It appears that there may be an excess clearance which is resulting in the loss of ethanol through the bottom. Some types of gasket around the plates would possibly prevent the "weeping" down the column walls and increase plate efficiency.

Rectifying Column Flooding

The rectifying column flooded during several of the runs. The flooding significantly affected product flow and quality. It appears that the beer feed rate and column temperature may be the major factors which caused the flooding.

Reflux

Reflux is used to control the temperature at the top of the rectifying column and thus prevent low proof alcohol vapor from entering the condenser. While this effect was achieved with the packed column the result was not as dramatic as in the plate column. Reflux into the plate column resulted in a sudden slowing of the product stream while in the packed column this effect was not immediate. The probable explanation has to do with the physical construction at the column top. When the reflux stream enters the top tray in the plate column not only is cooler liquid entering but it is raising the liquid level on the tray. This results in a greater pressure gradient across the top tray slowing or stopping vapor passage for a short time. In the packed column only the cooling effect is evident which causes less pressure drop.

CONCLUSIONS

The conclusions resulting from this study are:

- o The packed rectifying column performed as well as the plate rectifying column and costs considerably less to fabricate.
- o The distillation unit with the packed rectifying column is capable of continuously producing 14 gallons per hour of 170 proof ethanol. Greater production was achieved; however, column flooding occurred.
- o The optimum beer feed rate is between 130-150 gallons per hour.
- o The unit required only one-half hour to reach steady state before product was withdrawn (as compared to one hour with the plate rectifying column).
- o Once the unit reached steady state, very little operator attention is required with the exception of maintaining temperature at the top of the rectifying column. By valving down the reflux, it is possible to maintain small continuous reflux.
- o The energy ratio for distillation average a positive 2:1. That is, one Btu in fuel was required to produce two Btu's of ethanol. This compares to an energy ratio of 3:1 for the plate column.
- o Water consumption averaged 270 gallons per hour through the condenser. An average of 55 gallons per hour was used as make-up water to the boiler.
- o The boiler operated at an average efficiency of 82% as compared to 85% for the first study.

REFERENCES

1. Small Scale Ethanol Production Demonstration, UAH Report 291, Johnson Environmental and Energy Center, University of Alabama in Huntsville, September 1981.

APPENDIX A
PACKING MATERIAL SPECIFICATIONS

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APPENDIX B

Test Configuration Details

TEST CONFIGURATION DETAILS

This section briefly describes each element in the test configuration. A more detailed description of the hardware specifications is given in Appendices in Reference 1.

Distillation Columns

The incoming mash is pumped from the fermentation tank through the shell and tube heat exchanger to the top of the stripping column by a variable speed rotary screw pump. (See Figure 1.) Steam enters at the bottom of the stripping column. The stillage falls to the bottom of the stripping column and is removed by a centrifugal pump. (See Figure 2.) A small 10 gallon sump tank was installed in the stillage line to keep a prime on the stillage pump. (See Figure 2.) The bottoms collected in the rectifying column are removed and returned to the top of the stripping column by a variable speed rotary screw pump. (See Figure 3.) A gate valve is also installed in the line to further control the bottoms flow.

Figure 1. Variable Speed Rotary Screw Feed Pump

Figure 2. Stillage Pump and 10 Gallon Sump

Figure 3. Variable Speed Rotary Screw Bottoms Pump
B-3

Figure 4. Column Temperature Gauges

The stripping and rectifying columns are each instrumented with six dial temperature gauges evenly spaced to monitor the temperature in the columns (See Figure 4). The steam input is adjusted by a hand gate valve to maintain the temperature at the bottom of the stripping column above 212°F . A temperature below 212°F will result in a loss of product in the stillage. Likewise a temperature in excess of 212°F requires additional energy.

The temperature at the top of the rectifying column is monitored by a dial temperature gauge. (See Figure 5.) A neoprene impeller reflux pump (See Figure 6) is used to transfer product back to the top of the rectifying column. A strainer is installed in-line to minimize the foreign particles entering the pump.

As the temperature rises on the rectifying column, the operator turns on the reflux pump for several seconds. This sequence is continued throughout the run to control the column temperature.

Figure 5. Temperature Gauges for Top of Columns

Figure 6. Reflux Pump

Boiler

A 30 bhp industrial tubeless boiler was purchased from Industrial Boiler Company, Thomasville, Georgia. The boiler is fired with No. 2 oil (140,000 Btu's/gal) and has the capacity of producing 1035 lbs. of steam (212°F) per hour which is equivalent to 1,005,000 Btu's/hr.

A photograph of the boiler installation is given in Figure 7. A 280 gallon fuel tank was installed underground approximately eight feet from the boiler. A stack thermometer was installed to measure exhaust temperature. (See Figure 8.) Figure 9 contains a photograph of the steam distribution system from the boiler to the cooker and column.

Figure 7. 30 Hp Boiler

Figure 8. Stack Thermometer and Water Meter Installation

Figure 9. Steam Distribution

A chemical feeder system was installed to treat the boiler water. A BT-20 feeder system and B-42 boiler chemicals were purchased from Culligan. In addition two 7 inch portable exchanger softener tanks from Culligan were also installed for heating the boiler feed water. A photograph of the chemical feed system is given in Figure 10.

Figure 10. Chemical Feed System

All boiler feed water is first fed through the water softener. (See Figure 11.) If the system is distilling ethanol the treated water is routed through the ethanol condenser and preheated before being fed into the boiler. A feed water overflow connected to a drain is used for the excess boiler feed water.

Figure 11. Water Softener Installation

Figure 12. Water Meter Installation

Two water meters are installed to measure water usage. One 5/8 inch water meter is installed on the outlet side of the water softeners (See Figure 12). A second 5/8 inch water meter is installed on the boiler feed water line to measure the boiler water usage (See Figure 8).

Mash Cookers

A 1000 gallon pressure cooker (See Figure 13) from Industrial Innovators Inc., Ashford, Alabama, was used for all mash preparation. The cooker uses live steam for cooking and can operate at pressures up to 70 psig. Steam enters the boiler from the top and is distributed through a three inch pipe approximately two feet from the bottom of the cooker. The steam input is controlled using a two inch gate valve.

Figure 13. 1000 Gallon Pressure Cooker

Heat Exchangers

A 60 foot shell and tube heat exchanger was fabricated by Industrial Innovators for both cooling the mash during cooking and preheating the mash prior to distillation. Figure 14 is a photograph of the heat exchanger. Three clamp-on dial thermometers are used to monitor inlet and outlet temperatures of the heat exchangers. (See Figure 15.)

Figure 14. Heat Exchanger

Figure 15. Heat Exchanger Temperature Gauges

Fermentation Tank

A 1250 gallon steel fermentation tank was purchased from Industrial Innovators, Inc. Figure 16 is a photograph of the tank. An in-line strainer was installed to protect the in-line flow meter. (See Figure 17.)

Figure 16. 1250 Gallon Fermentation Tank

Figure 17. Feed Flow Meter and Strainer Installation

Stillage Tank

A 1250 gallon polyolifin tank was used for the spent stillage. The tank is a one piece polyolifin molding and is 84 inches in diameter, 60 inches in height, and has 1/4 inch walls. A photograph of the tank is given in Figure 18.

Figure 18. 1250 Gallon Stillage Tank

Product Tank

A 200 gallon polyolifin tank is used for product storage (See Figure 19).

Figure 19. 200 Gallon Product Tank

Electricity Monitoring

A number of KWH meters (See Figure 20) were installed to measure electric consumption of each of the pump motors. The consumption was measured on the following meters:

1. Mash feed pump motor
2. Bottoms pump motor
3. Reflux pump motor
4. Stillage pump motor

Two KWH meters were also installed to monitor the boiler fuel pump motor, boiler motor and chemical feeder motor (See Figure 21).

Each KWH meter was calibrated by the Huntsville Utilities and had an error of less than 2 percent.

Figure 20. KWH Meter Installation

Figure 21. KWH Meters for Monitoring Boiler

APPENDIX C
TEST RESULTS

ME STALLED 9:1
MASH TEMP: 64°

MASH % BEER: _____

DATE: 4/25/82

TIME	(°F) STMP. TEMP		(°F) RECT. TEMP		(°F) STILL- AGE TEMP	CON- DENSER WATER TEMP (°F)	PRODUCT				FEED PUMP		REFLUX PUMP	BOT. PUMP	
	BOT	TOP	BOT	TOP	TEMP		RATE (ml/min)	OUT (gal)	PROOF	TEMP (°F)	METER	RATE			
8:30											29414				Start feed Produce over
8:45	216	198	208	156	194	104	2640		186	116					
9:00	220	196	203	150					195	116					
9:30	220	197	203	150	194	117	2680	15 180p	188	120					}
10:00	218	197	203	153	178	108	2840		192	119					
10:30	218	194	196	164	182	112	2800		182	100					
11:00	220	197	202	156	190	102	2040	15 167p	182	104					
11:30	221	197	202	178	186	94									
12:00	222	189	192	158					178	70					
12:30	220	189	192	163	174	82	980	15 163p	178	71					
1:00	219	188	190	162	186	102	1620		184	99					
1:30	219	198	200	166					184	108					
1:45	219	196	199	152			3100	19 167p							
2:00	219	197	200	178					178	106	30305				
2:05															
															out of feed

TIME STARTED: 8:00

RUN: 2

MASH TEMP: 73°

MASH % BEER: _____

DATE: 5/19/82

TIME	(°F) STIR TEMP		(°F) RECT. TEMP		(°F) STILL AGE TEMP	CON- DENSER WATER TEMP (°F)	PRODUCT			FEED PUMP		REFLUX PUMP	BOT. PUMP	
	BOT	TOP	BOT	TOP			RATE (ml/min)	OUT (gal)	PROOF	TEMP (°F)	METER	RATE		
8:20											31019			start feed
8:30	204	183	184	174	206									
8:45	218	190	189	169										Prod over
9:00	217	192	190	164		136	3140		201	128				
9:15	218	195	194	168		133	3320	15						
9:30	219	198	196	170			1580	183p	199	128				
9:45	220	199	196	170			2960		195	134				
10:07	220	196	190	163		124	3180		204	132				
10:17	222	190	182	164			3200	15	205	135				
10:30	222	191	190	166				184p						
10:45	221	191	187	164		127	3240		204	142				
11:00	220	192	185	170		125	3160							
11:15	222	193	189	161		133	2660	22	202	138				
11:30	222	196	191	170			3040	184p	200	134				
11:45	225	200	194	172			2720							
12:00	214	194	186	175										
12:05											31716			feed off

TIME STARTED: 7:00MASH TEMP: 78°FMASH % BEER: 9.0DATE: 5/24/82

TIME	(°F) STRIP TEMP		(°F) RECT. TEMP		(°F) STILL- AGE TEMP	CON- DENSER WATER TEMP (°F)	PRODUCT				FEED PUMP		REFLUX PUMP	BOT. PUMP	
	BOT	TOP	BOT	TOP			RATE (ml/min)	OUT (gal)	PROOF	TEMP (°F)	METER	RATE			
9:00															Boiler
9:10															on
9:15	208	190	160	76							33231				Steam
9:30	220	200	198	170											to col
9:45	224	200	190	166											Fired
10:00	220	200	194	166											on
10:15	215	190	190	160											Produ
10:30															over
10:45	208	190	190	170			1400	22	189	121					
11:00	210	188	190	164							33510				
11:15	216	190	190	176											
11:30	214	190	188	170											
11:45	216	190	188	169											
12:00	218	190	188	174			1300	23	182	108					
12:15	220	190	190	169											
12:30	220	190	190	170							33785				

MASIH TEMP : _____

MASH % BEER : _____

RUN: 4

DATE: 5/24/82

[illegible]

TIME STARTED: 7:15RUN: 5MASH TEMP: 76 MASH % BEER: 8.0DATE: 5/25/82

TIME	(°F) STRIP TEMP		(°F) RECT. TEMP		(°F) STILL- AGE TEMP	CON- DENSER WATER TEMP (°F)	PRODUCT			FEED PUMP		REFLUX PUMP	BOT. PUMP	
	BOT	TOP	BOT	TOP			RATE (ml/min)	OUT (gal)	PROOF	TEMP (°F)	METER	RATE		
7:45														B. 14. 05 Produ. over
8:00	Furn										34649			
8:15														
8:45	222	193	193	162										
9:00	214	192	192	167										
9:30	217	192	193	168										
9:45	215	192	189	177										
10:00	210	193	192	174										
10:30	218	193	192	174										
11:00	216	191	193	173										
11:30	216	191	193	172										
12:00	218	188	189	167										
12:30														Resin stg-t
1:00	220	192	192	172										
1:30	212	192	193	173										
2:00	210	190	192	170										
2:30	216	194	193	174							36080			

MASIH TEMP : _____

MASH % BEER : _____

KUN: 3

DATE: 5/25/82

[illegible]

TIME STARTED: 7:20MASH TEMP: 79MASH % BEER: 9RUN: RDATE: 6/1/82

TIME	(°F) STRIP TEMP		(°F) RECT. TEMP		(°F) STILL- AGE TEMP	CON- DENSER WATER TEMP (°F)	PRODUCT				FEED PUMP		REFLUX PUMP	BOT. PUMP	
	BOT	TOP	BOT	TOP	TEMP	TEMP	RATE (ml/min)	OUT (gal)	PROOF	TEMP (°F)	METER	RATE			
7:20															Boiler On
7:45											37642				Feed on
7:50	212	198	200	185					158	73					Produce over
8:15	220	195	194	170					170	76					
8:20															
8:30	220	192	193	162			1200	15	172	81					
9:00	217	187	188	163			1000								
9:20	213	186	187	165				15	178	85					
10:00	214	188	188	164			1600								
10:15	214	190	190	168				15	180	80					
11:00	215	192	191	166											
11:15	215	190	190	165				15	176	81					
12:00	217	193	191	176											
12:20	218	194	192	173			950								
1:20	218	190	189	173				15	172	82					
1:30	218	190	190	172											

TIME STARTED: _____

MASIH TEMP: _____

MASH % BEER : _____

KUN: 6

DATE: 6/1/82

[illegible]

APPENDIX D
BOILER EFFICIENCY DATA SHEETS

DATE: May 19, 1982

DATA SHEET FOR BOILER EFFICIENCY TEST

PLANT NAME UAH/IEEC
LOCATION Huntsville, Alabama
TEST NO. 3 BOILER NO. 30355 BURNER NO. R-208412
TEST CONDUCTED BY Bernard Levine
BOILER, MAKE & TYPE Industrial Boiler Company "Plaza Pack" 1980
RATED CAPACITY 1035 lb/hr. 30 hp. FUEL USED #2 Fuel Oil
80 square feet of heating surface

EFFICIENCY Measured: 82% 90-100% Excess Air
Recommendation: Adjust for 30% Excess Air (5% Oxygen)

		LOAD / FIRING					COMMENTS
PRODUCTS OF COMBUSTION							
CO ₂	%	9.0					
O ₂	%	10.5					
CO	%	0.*	* Less than 0.2% (2000 ppm)				
T _{Exh.}	F	445					
T _{Comb. Air}	F	88					
T _{Fuel}	F	60					
T _{db}	F	79					
T _{wb}	F	69					

61% Relative Humidity

COMBUSTION EFFICIENCY CURVES

CO₂ - O₂ RATIO CURVES FOR FUEL OILS, GASES & WOOD

CURVE	FUEL	MAX. CO ₂ %
A	NATURAL GAS	11.7
B	"	12.1
C	PROPANE	13.7
D	BUTANE	14.0
E	#2 FUEL OIL	15.2
F	#5 " "	16.0
W	WOOD	19.5
G	EXCESS AIR vs OXYGEN

1-76
REPLACES 1-73

PERCENT EXCESS AIR

P.O. Box 650 Winfield, Kansas, 67156....
Manufacturers Of Combustion Equipment

D-3

B.18

TABLE B.2 COMBUSTION EFFICIENCY TABLE FOR #2 OIL (Cont)

TFLUE=400.0

EXCESS AIR	PERCENT O2	PERCENT CO2	EFFICIENCY
0.0	0.0	15.6	87.55
4.7	1.0	14.9	87.28
9.9	2.0	14.1	86.97
15.6	3.0	13.4	86.64
22.0	4.0	12.6	86.26
29.2	5.0	11.9	85.84
37.4	6.0	11.1	85.36
46.8	7.0	10.4	84.81
57.6	8.0	9.7	84.18
70.2	9.0	8.9	83.45
85.0	10.0	8.2	82.58
102.9	11.0	7.4	81.53
124.7	12.0	6.7	80.25
152.0	13.0	6.0	78.66
187.0	14.0	5.2	76.61

TFLUE=450.0

0.0	0.0	15.6	86.53
4.7	1.0	14.9	86.21
9.9	2.0	14.1	85.86
15.6	3.0	13.4	85.47
22.0	4.0	12.6	85.04
29.2	5.0	11.9	84.55
37.4	6.0	11.1	84.00
46.8	7.0	10.4	83.37
57.6	8.0	9.7	82.64
70.2	9.0	8.9	81.79
85.0	10.0	8.2	80.78
102.9	11.0	7.4	79.53
124.7	12.0	6.7	78.10
152.0	13.0	6.0	76.25
187.0	14.0	5.2	73.89

TFLUE=500.0

0.0	0.0	15.6	85.50
4.7	1.0	14.9	85.14
9.9	2.0	14.1	84.75
15.6	3.0	13.4	84.31
22.0	4.0	12.6	83.81
29.2	5.0	11.9	83.25
37.4	6.0	11.1	82.63
46.8	7.0	10.4	81.92
57.6	8.0	9.7	81.09
70.2	9.0	8.9	80.13
85.0	10.0	8.2	78.99
102.9	11.0	7.4	77.62
124.7	12.0	6.7	75.95
152.0	13.0	6.0	73.85
187.0	14.0	5.2	71.15