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An Evaluation of Sorghum Syrup Processing Operations in Tennessee

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AN EVALUATION OF SORGHUM SYRUP PROCESSING OPERATIONS IN TENNESSEE

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INTRODUCTION

Sorghum has been grown for grain and animal feed for many centuries. However, production of sorghum for the purpose of making syrup is a relatively recent practice which did not begin in the United States until the late 1850's. The first seeds for this purpose were imported by way of France from China. Cultivation of sorghum for syrup spread rapidly across the nation in the years immediately following its introduction. In addition, considerable interest developed in exploring the possibility of obtaining sugar from sorghum. This was reflected in an 1882 appropriation by Congress which provided funds for "experiments in the manufacture of sugar from sorghum, beets, and other sugar producing plants." The resulting study by the National Academy of Sciences (1883) concluded that the processing of sorghum for sugar was possible but many problems remained to be solved.

The rapid development of the sugar cane and sugar beet industries soon made adequate sugar available to supply national needs, and research in sorghum sugar production was discontinued. However, recent research in this area has shown promise of making sorghum sugar competitive with other types (USDA, 1971).

Sorghum syrup production in the U. S. reached almost 7 million gallons per year by 1859. This increased to 28 million gallons per year in 1879. By World War I, this production had decreased by about 40%. The postwar shortage of sugar and syrup caused a syrup production jump to a high of 49 million gallons annually (Doggett, 1970) before production declined to a relatively stable level of 1 to 2 million gallons.
Tennessee has always been one of the major sorghum syrup producing states. Production has consistently averaged better than 10% of the national total, with sales of sorghum syrup at about the same percentage. The 1964 census of Agriculture (U. S. Bureau of the Census, 1968) ranked Tennessee second in production and sale of sorghum syrup. With the exception of Iowa, the top producer, all other major producing states (Kentucky, Alabama, Mississippi, Georgia, Arkansas, and North Carolina) adjoin Tennessee (Wall and Ross, 1970). Some sorghum is produced in almost every county in Tennessee. However, in most cases, production is very limited. While official records are no longer kept, available information indicates that well over half of the Tennessee production is in West Tennessee.

The past few years have brought a renewed interest in sorghum syrup processing. Several new growers and processors have emerged in Tennessee. Most of these are small operators who, individually, have little impact upon total syrup production. However, the production of syrup now appears to be increasing. Some processors who formerly sold all their production within days of the close of the season now require a few weeks to exhaust their stock. Processors who produce low quality syrup may require a much longer period.

To better evaluate current processing conditions in Tennessee, a study was made of several existing processing operations in the state. This study emphasized the processing aspects of sorghum syrup production; however, limited harvesting operation data were also obtained. Half the processors (8 of 16) visited during the study were located in Benton County. One was in an adjoining county, three were located in Middle Tennessee, and four were in other West Tennessee counties. During the visit,
mill and evaporator specifications were obtained. If the unit was operating, capacity data and processing temperature records were also collected.

**GROWING AND HARVESTING PRACTICES**

Growing practices vary widely across the state. A few growers continue to insist that sorghum can only be grown on poor soil. Therefore, their syrup yield is usually low. Other growers use good soil with suitable fertilization and consider yields of less than 100 gallons per acre to be poor. Several varieties are grown in the state. Most growers use varieties that they have grown for many years. A few growers are now experimenting with newer varieties; however, change to new varieties is slow. Freeman et al (1973) have summarized the characteristics of several varieties currently available.

Current harvesting methods vary widely among growers. A few growers still use a labor intensive operation in which they strip the leaves from the stalk, cut the stalk, and remove the seed head before processing. Other producers cut the unstripped cane, remove the seed head, and extract the juice in the field. The juice is then delivered to the plant for processing. Most processing operations fall somewhere between these two extremes. Cane is cut and transported to the mill without stripping. Corn binders are often used to cut the cane and tie it in small bundles. Binders are often ineffective when stalks are tall or severely lodged. The bundles are loaded crosswise on wagons, with all seed heads on the same side, and moved to the mill site. The seed heads are often removed at the mill by using a chain saw to remove the top several inches of stalk (Figure 1). This removes most of the heads, although a few heads are invariably left on shorter stalks.

Labor requirements associated with harvesting the cane are a major
problem faced by processors who grow their own cane. Stripping the cane and cutting it by hand are very time consuming operations. Field measurements with one processor's operation indicated the following field capacities:

- Stripping (about 80% effective), 1 person 0.056 ac/hr (0.023 ha/hr)
- Cutting (1 cutting, 2 holding), 3 people 0.20 ac/hr (0.081 ha/hr)
- Removing heads of cut cane, 1 person 0.18 ac/hr (0.073 ha/hr).

Another study with a different processor showed capacities approximately 40 percent lower than the measurements shown above. From these measurements, about eight people would be needed for the stripping, cutting, and heading operations to supply a typical mill; thus, the labor expense is large.

One popular alternative is to leave cane unstripped and use more mechanization in the harvesting operation. This substantially reduces the labor requirement but causes some problems with juice (and syrup) quality because of added impurities in the raw juice. Research tests (Rea et al, 1977) and processor use have shown that such mechanization, using modified forage choppers, is feasible.

**JUICE EXTRACTION**

Juice is extracted from the cane by pressing the stalks between the iron rollers of a mill. Most mills in current use are units formerly used in the sugar industry. They consist of three rollers approximately 1.5 ft (0.38 m) in length. The largest roller is about 1 ft (0.30 m) in diameter and the two smaller rollers are about 8 in. (0.20 m). Operating speeds vary although a speed of about 8 rpm is desired for the larger roller. All the mills are old - many with patent dates prior to 1900. Replacement parts must often be specially made or cannibalized from other mills.
Additional mills of the types currently used are becoming scarce; consequently, mill repair and replacement will likely become more difficult in future years.

Mill operating speed and juice extraction rate were measured for several mills. The results are summarized in Table 1. Speeds ranged from 4.8 to 11.4 rpm, with most mills being near 8 rpm. Juice extraction rates depended upon mill speed, moisture content of the cane, mill adjustment, and feeding rate. However, the values in Table 1 are considered typical for the mill size given above.

The percentage juice extraction is an important factor in mill operation. The rollers must be adjusted to spacings sufficiently close to produce maximum extraction. Henrickson (1958) discussed the economic value of proper extraction and provided adjustment recommendations. As a general rule, juice is lost if the bagasse contains visible juice and is not broken at the joints as it comes from the mill.

After extraction, the juice flows through a coarse filter for removal of stalk pieces and other large solid particles. The liquid is then collected in a container sufficiently large to permit substantial settling of additional solid particles. From this container the juice usually flows directly into the evaporator pan where impurities are removed and the juice is concentrated into syrup.

FURNACE AND EVAPORATOR DESIGN

The early evaporators were either kettles (batch evaporators) or baffled pans (continuous flow evaporators) heated by a wood fire. Wood as a heat source has almost disappeared. Most processors use a baffled continuous flow pan heated directed by petroleum fuel. (The modified Stubbs
evaporator, used in some areas of the South, apparently is not used in Tennessee.) While several Tennessee processors use steam as the heat source for the evaporator pan, the evaporators evaluated in this study were, except for a single wood-fired unit, heated directly by propane fuel.

A sketch of a typical evaporator pan is shown in Figure 2. The pan is long, shallow, and relatively narrow. Raw juice enters one end and is heated as it flows toward the other end. Initial heating is slow to allow the "skimmings" to coagulate and rise to the top of the juice. Vigorous boiling occurs in the center of the pan. Foam produced by this boiling tends to push the skimmings back into the raw juice end of the pan. In addition, small particles of skimmings are pushed over the side of the pan into the skimming trough, where they drain back into the raw juice. This operation tends to concentrate all skimmings at the input (juice) end of the pan where they can be periodically removed from the surface of the juice by hand. Very little skimming is required in the vigorous boiling or finishing sections of the pan.

Concentration to the desired solids content occurs in the finish end of the pan. Here, the heat input is decreased to prevent overheating and scorching the syrup. Some processors install a "water jacket" in the final 6-in. section of the pan. The boiling water moderates the temperature and helps to prevent overheating of the syrup. This portion of the evaporator pan must be monitored carefully to insure that the syrup is drawn from the pan at the proper solids content.

While the evaporator described above is called a continuous-flow unit, the syrup is not always drawn off continuously. The drain is occasionally plugged to allow additional concentration of the syrup. Some
operators plug the drain occasionally when flow from the juice end of the pan has been too rapid to allow sufficient concentration. Other operators use essentially a batch operation in the finish end of the pan. They will remove almost all the syrup in the last 3 feet (1 m) of the pan, plug the drain, and cook the new batch of semi-syrup flowing into this section before removing it. In all cases, however, juice inflow is continuous, being adjusted as necessary to maintain proper cooking conditions.

The evaporator pan is placed over a furnace similar to that shown in Figure 3. The combination of furnace design and heat source determine the heat flow rate to the pan bottom and, thus, are critical factors in proper evaporator operations. The heat source is usually a propane gas jet installed with the jet opening centered below the juice end of the pan. The jet is sometimes equipped with an air blower; however, blowers are not usually provided. A few processors use more than one burner (jet) to allow greater variation in heat input.

The furnace is designed with a long sloping surface near the juice end of the pan. The center section is typically flat and only a few inches [5 in. (0.13 m) to 6 in. (0.15 m)] below the bottom of the pan and from 24" (0.61 m) to 36" (0.91 m) in length. This center region concentrates the hot gas directly below the pan and produces the heat needed for the vigorous boiling to "roll" the skimmings into the trough draining to the juice end. Below the finish end, the furnace bottom drops sharply away from the pan to reduce heat input and to avoid overheating (scorching) the finished syrup. Design of this furnace is presently more of an art than a science. Even experienced operators often find they must reshape the bottom of a new furnace several times to obtain proper heat distribution. Once the furnace is operating properly, change is often
unnecessary for one or more operating seasons. Although some movement of
the material on the furnace bottom usually occurs, the operation of the
unit is not seriously affected.

A summary of several furnace evaporator systems currently in use is
shown in Table 2. Most new pans are made from stainless steel. Process-
sors using galvanized pans have indicated they plan to replace them with
stainless steel pans. Since the useful life of a galvanized pan is about
3 years, the great majority of evaporator pans in use will soon be made of
stainless steel.

PROCESSING SORGHUM SYRUP

Sorghum syrup is made from varieties of cane which have an abundance
of sweet juice. Sugar levels of the extracted juice of sweet sorghum
range from 7 to 20% (Walton et al, 1938), whereas forage varieties contain
only 3 to 5% sugar. Syrup is made by evaporating water from either the
raw or clarified plant juice. Quality of the syrup may be influenced by
cane variety, maturity, growing conditions, length of time cane has been
cut, and equipment and processes used in syrup production. Sugar levels
(percent soluble solids expressed as degrees Brix) measured in this study
ranged from 10 to 19%. Most varieties had Brix readings of 11 to 14%.

Juice extracted from the cane has many impurities which must be
removed to produce high quality syrup. Some impurities are solid particle-
es which may be removed by a coarse filter or the sedimentation process
mentioned above. Others are colloidal in nature and can only be removed
during the evaporation process.

Once the skimmings are removed, production of the sorghum syrup is
essentially an evaporation process. Water must be removed by boiling to
produce the desired sugar concentration. The rate at which the water can
be evaporated is essentially a function of the surface area over which the heat is added to the juice and semi-syrup. Thus, a larger evaporator would be expected to produce more syrup within a given time. Several of the processors studied were asked to estimate an average daily syrup production and an average daily time for evaporator operation. This information, along with the measured evaporator size, was used to determine the syrup production rate. These values, given in Table 2, ranged from 2.0 to 3.3 lb/ft$^2$.hr (10 to 16 kg/m$^2$.hr) and are in agreement with the range of 2.3 to 3.3 lb/ft$^2$.hr (11 to 16 kg/m$^2$.hr) measured by Wilhelm and Morgan (1973) for a steam heated evaporator. One operator maintained operating and production records for five days and found that production averaged 2.8 lb/ft$^2$.hr (13.7 kg/m$^2$.hr).

The actual production rate is also a function of other factors such as weather conditions (humidity) and quality of the cane. Dissolved solids in the juice represent an especially important factor in evaluating cane quality. The amount of water which must be removed increases rapidly as the solids content drops. Juice with a Brix reading of 18% would require the removal of 322 units (pounds or kilograms) of water to produce 100 units of syrup at 76% solids. If the Brix reading of the juice was 10%, the removal of 660 units of water would be necessary to produce the same amount of syrup. Thus water removal rate is the limiting factor in the capacity of sorghum evaporators.

Many processors have recently become interested in determining their energy use during processing. Several operators who use propane as source have maintained records of fuel use and syrup production for one or more years. These records showed fuel use variation from 0.97 to 1.44 gal
propane/gal syrup\(^1\) with an average of 1.23 gal propane/gal syrup.\(^1\) Evaporator design and operator technique affect this fuel/syrup ratio. However, the raw juice sugar content is the major factor influencing the ratio. As noted above, the energy requirement for evaporation is doubled when the juice sugar content drops from 18\% to 10\%. The lowest fuel/syrup ratio (0.97) noted in the above range was obtained in a dry season when juice sugar content was high. All other measurements were greater than the 1 gal propane/gal syrup\(^1\) used as a "rule of thumb" by many processors. A value of 1.25 gal propane/gal syrup\(^1\) appears more realistic. This estimate can be expected to vary as much as 25\%, depending upon the factors previously noted.

The continuous-flow evaporator, used almost exclusively in Tennessee, provides a continually increasing solids content from the juice end of the pan to the syrup end. If the pan is operated so that the skimmings are properly concentrated and removed, the major function of the operator is to insure that the syrup is drawn from the pan when the proper density is obtained. The preferred density of finished syrup produced in Tennessee is about 78 degrees Brix (at room temperature). This is equivalent to a soluble solids content of 78 percent. Cooling the syrup and measuring the density is obviously not practical because of the time involved. In fact, most operators rely upon the appearance of the boiling syrup and check the texture by pulling a skimmer or syrup "rake" through the boiling syrup, holding it up, and observing how the cooling syrup "flakes off." Even an experienced operator is not always consistent with this

\(^1\)The "8-pound gallon" (two 4-pound buckets) commonly used by producers. A U. S. gallon of sorghum syrup weighs about 11.5 lbs.
subjective method. To evaluate operator consistency and differences among operators, temperature records were made at different locations along the evaporator pans of six processors. Thermocouples were installed along the length of the evaporator pans and temperatures were recorded for at least one hour of continuous operation. Although other temperatures were recorded, the temperature of the finished syrup was of primary interest. Figure 4 shows typical temperature profiles along the evaporator pan length for six processors. The most rapid temperature increase occurred near the juice end of the pan. The temperature then increased slowly with the change in boiling point as the syrup became more concentrated.

A syrup with 78 percent solids can be produced by concentration until the boiling point of the syrup is 226°F (108°C). This relationship permits the density of the syrup to be readily determined by simply observing the syrup temperature during boiling. Table 3 shows that differences in the boiling points of finished syrup ranged from a low of 5°F (3°C) to a high of 12°F (7°C) when processors used subjective methods to determine finished syrup density. Thus, even experienced operators obviously could produce a more consistent product by using a temperature monitor.

After cooking is complete, the syrup is drained into an "accumulation box" where mixing reduces density variation and the syrup cools a few degrees. The finished product is then placed into containers for sale.

DISTRIBUTION AND MARKETING

None of the processors visited in this study used an established distribution and marketing system. Most of them sold their product to customers at the mill. Sales were usually in 2 lb or 4 lb containers
commonly called "quarts" and "half-gallons." The remainder of their product was either sold through supermarkets in their area or was purchased in bulk by sorghum brokers in the area. Brokers then packaged the syrup in smaller containers and sold it as pure sorghum or as a blend of sorghum and corn syrup. Low quality syrup was usually blended to produce a more palatable product.

Marketing appears to be a growing concern of the larger processors, since the demand has been stable for some time as production dropped slowly. With more producers entering the field, concern is expressed about possible oversupply. Swope (1975) has presented the current marketing problems in some detail and suggests several steps which could be taken in an effort to improve the sale of sorghum syrup. These include (1) developing additional uses in industries such as baking, (2) developing specialized outlets such as health food stores and outlets catering to travelers, and (3) improving the farmer-producer marketing structure.

SUMMARY AND CONCLUSIONS

Sixteen sorghum syrup processing operations in Tennessee were studied to evaluate current operating conditions. All systems for which operating data were obtained used conventional, continuous-flow evaporators with propane burners as the heat source. Production rates for all processors were similar. The overall average was about 2.5 lb/ft$^2$.hr (12 kg/m$^2$.hr).

All processors used visual indicators, based upon experience, to determine when the finished syrup should be drawn from the evaporator. Temperature records indicated substantial variations in concentration of the syrup for each processor. Substantial variation among processors are also evident.
The skimming trough, now used by most processors, aids substantially in removing the skimmings from the syrup - provided the evaporator is properly heated. Proper furnace construction to provide the necessary heat distribution is sometimes a problem for the processor.

For the small processor, the processing technique evaluated in this study appeared to work well. The major problems facing the processors appeared to be with the mills used to extract the juice and with harvesting operations. All mills in the study are old and worn. Replacement parts are unavailable, and few replacement mills are available. The labor involved in harvesting is great if the cane is stripped. If stripping is not done, the juice quality is degraded. Mechanization in this area is perhaps one of the greatest needs at this time.


Table 1. Sorghum Mill Operating Data for Selected Tennessee Processors

<table>
<thead>
<tr>
<th>Processor</th>
<th>Mill Speed (rpm)$^2$</th>
<th>Size of Power Unit (Horsepower)</th>
<th>Juice Flow$^1$ gal/min</th>
<th>Juice Flow$^1$ L/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.4</td>
<td>Tractor with belt drive</td>
<td>3.3</td>
<td>12.5</td>
</tr>
<tr>
<td>2</td>
<td>8.3</td>
<td>Electric (7.5)</td>
<td>3.6</td>
<td>13.6</td>
</tr>
<tr>
<td>3</td>
<td>7.6</td>
<td>Electric (5)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>4</td>
<td>---</td>
<td>Tractor with belt drive</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>9.5</td>
<td>Stationary gasoline engine with belt drive</td>
<td>2.7</td>
<td>10.2</td>
</tr>
<tr>
<td>6</td>
<td>6.4</td>
<td>Electric (5)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>7</td>
<td>7.7</td>
<td>Electric (7.5)</td>
<td>2.8</td>
<td>10.6</td>
</tr>
<tr>
<td>8</td>
<td>6.3</td>
<td>Electric (5)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>9</td>
<td>4.8</td>
<td>Electric (5)</td>
<td>2.4</td>
<td>9.1</td>
</tr>
<tr>
<td>10</td>
<td>---</td>
<td>Tractor PTO$^3$</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>11</td>
<td>---</td>
<td>-------------------------------</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>12</td>
<td>---</td>
<td>Tractor PTO$^3$</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>13</td>
<td>8.0</td>
<td>Electric (5)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>14</td>
<td>---</td>
<td>Electric (5)</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>15</td>
<td>---</td>
<td>Tractor PTO</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>16</td>
<td>---</td>
<td>Tractor with belt drive</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

$^1$Average of at least three measurements.

$^2$Speed of large roller.

$^3$Mill is mounted on trailer. Juice is extracted in field and delivered to processing area in 300-gallon tanks (1100 L).
Table 2. Syrup Production Rates and Evaporator Data for Selected Tennessee Processors

<table>
<thead>
<tr>
<th>Processor</th>
<th>Pan Dimensions</th>
<th>Syrup Production Estimate</th>
<th>Burner Type</th>
<th>Evaporator Pan Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length (ft)</td>
<td>Width (ft)</td>
<td>1b/ft²/hr</td>
<td>Galv. SkT</td>
</tr>
<tr>
<td>1</td>
<td>15.42 (4.70)</td>
<td>3.42 (1.04)</td>
<td>2.9 (14)</td>
<td>#3 Maxon Forced air</td>
</tr>
<tr>
<td>2</td>
<td>12.25 (3.73)</td>
<td>3.65 (1.11)</td>
<td>2.4 (12)</td>
<td>#2 Maxon Forced air</td>
</tr>
<tr>
<td>3</td>
<td>18.0 (5.49)</td>
<td>2.63 (0.80)</td>
<td>2.0 (10)</td>
<td>Special design</td>
</tr>
<tr>
<td>4</td>
<td>12.58 (3.83)</td>
<td>3.65 (1.11)</td>
<td>---</td>
<td>Wood fired</td>
</tr>
<tr>
<td>5</td>
<td>12.23 (3.73)</td>
<td>3.60 (1.10)</td>
<td>2.1 (10)</td>
<td>Maxon 4&quot;</td>
</tr>
<tr>
<td>6</td>
<td>14.75 (4.50)</td>
<td>3.65 (1.11)</td>
<td>3.0 (15)</td>
<td>SS, SkT, WB</td>
</tr>
<tr>
<td>7</td>
<td>14.75 (4.50)</td>
<td>3.65 (1.11)</td>
<td>2.8 (14)</td>
<td>Maxon 4&quot;</td>
</tr>
<tr>
<td>8</td>
<td>14.5 (4.42)</td>
<td>3.65 (1.11)</td>
<td>---</td>
<td>Maxon 4&quot;</td>
</tr>
<tr>
<td>9</td>
<td>14.5 (4.42)</td>
<td>3.65 (1.11)</td>
<td>2.0 (10)</td>
<td>Maxon 4&quot;</td>
</tr>
<tr>
<td>10</td>
<td>13.96 (4.25)</td>
<td>3.50 (1.07)</td>
<td>3.3 (16)</td>
<td>Ransom (2 burners)</td>
</tr>
<tr>
<td>11</td>
<td>15.75 (4.80)</td>
<td>4.00 (1.22)</td>
<td>3.3 (16)</td>
<td>Steel³, SkT</td>
</tr>
<tr>
<td>12</td>
<td>16.00 (4.88)</td>
<td>3.38 (1.03)</td>
<td>---</td>
<td>Steel³, SkT</td>
</tr>
<tr>
<td>13</td>
<td>14.75 (4.50)</td>
<td>3.62 (1.10)</td>
<td>2.4 (12)</td>
<td>Maxon 4&quot;</td>
</tr>
<tr>
<td>14</td>
<td>14.75 (4.50)</td>
<td>3.62 (1.10)</td>
<td>---</td>
<td>Maxon 4&quot;</td>
</tr>
<tr>
<td>15</td>
<td>14.75 (4.50)</td>
<td>3.62 (1.10)</td>
<td>---</td>
<td>Maxon 4&quot;</td>
</tr>
<tr>
<td>16</td>
<td>15.17 (4.62)</td>
<td>3.33 (1.02)</td>
<td>2.3 (11)</td>
<td>Galv.</td>
</tr>
</tbody>
</table>

1Based upon operator's estimate of total daily production and operating time of the evaporator.

2Abbreviations in the comments are as follows:
- Galv - galvanized evaporator pan
- SS - stainless steel evaporator pan
- SkT - skimming trough along sides
- WB - water bath at finish end of pan

3Baffled pan is made from welded steel.

4The pan is divided into four sections. Material is manually dipped from section to section as cooking progresses.

Mention of a commercial product is to provide specific information and should not be construed as a product endorsement.
Table 3. Summary of Finished Syrup Temperature for Six Processors

<table>
<thead>
<tr>
<th>Processor Number</th>
<th>Average Temperature °F</th>
<th>Average Temperature °C</th>
<th>Temperature Range °F</th>
<th>Temperature Range °C</th>
<th>Observation Period (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>229</td>
<td>110</td>
<td>224-236</td>
<td>107-113</td>
<td>1.93</td>
</tr>
<tr>
<td>2</td>
<td>222</td>
<td>106</td>
<td>220-224</td>
<td>104-107</td>
<td>1.05</td>
</tr>
<tr>
<td>5</td>
<td>236</td>
<td>113</td>
<td>232-240</td>
<td>111-116</td>
<td>1.40</td>
</tr>
<tr>
<td>6</td>
<td>229</td>
<td>110</td>
<td>224-234</td>
<td>107-112</td>
<td>1.09</td>
</tr>
<tr>
<td>7</td>
<td>224</td>
<td>107</td>
<td>218-227</td>
<td>103-108</td>
<td>4.42</td>
</tr>
<tr>
<td>9</td>
<td>229</td>
<td>110</td>
<td>224-236</td>
<td>107-113</td>
<td>2.32</td>
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</tbody>
</table>

1 All temperatures were measured to the nearest 0.1°F. Temperatures were then converted to °C and all numbers were rounded to the nearest degree. As a result, some temperatures shown are not consistent with direct conversion from °F to °C using the whole degree values listed.
Figure 1. Cane heads are often removed using a chain saw.
Figure 2. Sketch of a typical continuous flow evaporator pan with skimming troughs and "water bath." Inside dimensions of the pan are 14.75 ft (4.50 m) by 3.56 ft (1.11 m).
Figure 3. Typical configuration for propane burner heat source. Dimension A, B, and C are typically 18 in. (0.46 m), 5 in. (0.13 m), and 18 in. (0.46 m), respectively.
Figure 4. Temperature in evaporator pan as a function of location. Distances are measured as the percentage of total length from the juice end of the pan. The large variation in temperature at the zero end may be due in part to variation in positioning the sensor.