THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
Department of Chemical and Metallurgical Engineering

Final Report

# SPRAY EVAPORATION OF STICKWATER FROM FISH RENDERING

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## SUMMARY

The objectives of the present study were to design, fabricate and install a parallel flow, spray concentrator for fish stickwater. If time and funds permitted, the operating characteristics of the equipment were to be tested. All these objectives were met. It was shown that a parallel flow concentrator, operating by direct contact between hot combustion products from a gas burner and a rain of falling water drops, had the following characteristics:

1. The equipment was easy to operate. It could be started in 30 min and stopped in 5 min.

2. Operating efficiencies of 60% were achieved, based upon the fraction of heat absorbed versus the amount of heat supplied in the gas fed to the burner.

3. The equipment, as presently installed, evaporated over 550 lb of water per hour.

4. With the precautions instituted, the equipment was safe to operate.

# INTRODUCTION

Fish-meal and fish oil continue to command adequate markets in the United States, although the business is not a large one. These products are obtained nationally from fish rendering plants located on seacoasts and along shores of the Great Lakes. Traditionally, the wet rendering process is used. A flow sheet for this process is shown in Figure 1 and the process is discussed in our previous report (R-1). Besides the saleable products, wet rendering of fish often produces strong, undesirable odors as well as solid and liquid wastes. In the past few years, disposal of these wastes has become a serious problem since the liquids have enormously high Biochemical Oxygen Demands (BOD) and the solids are putrescible fish flesh. Generally the strong stick-water, together with floor and boat washings, is collected in a tank or lagoon which overflows to an adjacent body of natural water. This is gradually becoming illegal so managers of fish rendering plants are being forced to dispose of these wastes without creating nuisances, or to close down the plants. Treatment of the wastes to destroy their BOD is a costly process that most fish rendering plants cannot justify economically. Fortunately the wastes contain valuable solids that can be added to the fish meal product. This can be done by first concentrating the stickwater along with the other liquid wastes and then introducing the concentrate into the kiln along with the press-cake. These liquid wastes are designated as (W-5), (W-1), and (W-2) in Figure 1. The concept of adding the concentrate to the product in the kiln is discussed in detail in our previous annual report (R-1).

Concentration of wastes that are normally discharged to a lagoon involves screening out large particles, acidulation, and centrifugation followed by evaporation (R-1, R-2). The screenings can usually be mixed directly with the press-cake before introduction into the kiln. Evaporation is not so simple. Large plants that operate most of the year on essentially a continuous basis can sometimes justify the capital investment required for multiple effect evaporation (R-1). Two- or three-stage evaporators of this kind utilize steam heat economically and produce a concentrate that is acceptable for introduction into the kiln along with the press-cake. However, multiple effect evaporators need to be large and operate continuously for long periods of time to financially justify acquisition and operating costs. Furthermore, it takes significant time to get such evaporators operating when they start empty; then, when waste production is interrupted, expert attention is needed in shutting them down. Lastly, multiple effect evaporators are sophisticated chemical engineering equipment that require engineering supervision and operation to produce effective results.

It seems evident that if evaporation of stickwater is to be feasible for small fish rendering plants, the evaporators must have both low capital investment and low operating costs. They must be rugged and simple to use and be

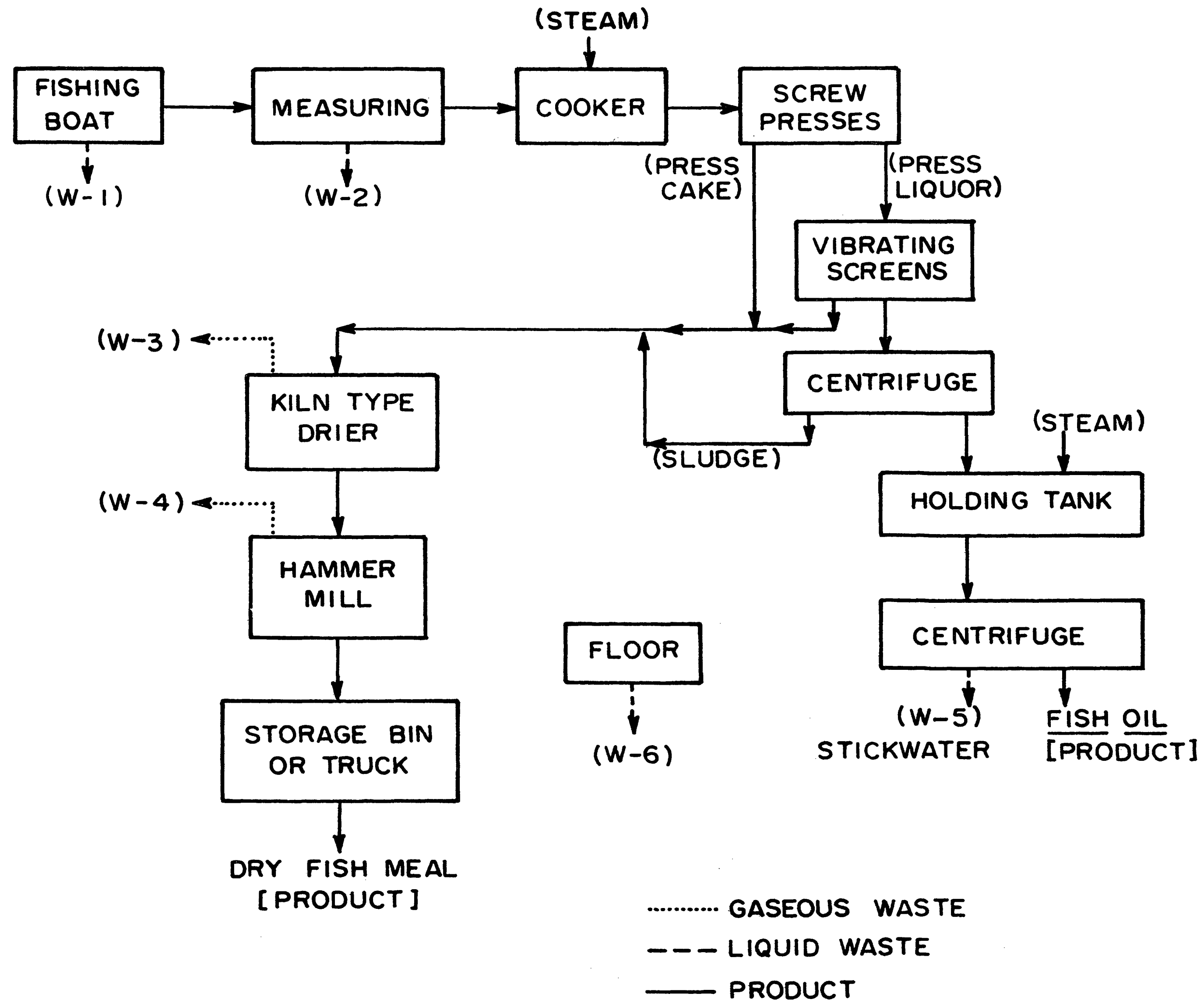



Figure 1. Flow diagram. Alewife rendering plant using the wet rendering process (R-1).

designed to start and stop in phase with other plant operations. In addition, the evaporation should retain the nutritional character of solids in the wastes, the apparatus should be safe to operate and should not cause air pollution. These are stringent requirements! Probably no apparatus will completely meet them all. A number of designs have been offered and tested. Some of them were discussed in our previous report (R-1). They include submerged combustion, the VINCENT evaporator (R-3), and the TRANSCHANGER. The latter is manufactured by the Selas Corporation of America (R-5). We have proposed another device for this service, a parallel-flow, spray-concentrator (R-1). It is designed to incorporate the desirable features of a suitable stickwater concentrator for a small rendering plant and to avoid the known bad features of other devices.

The VINCENT evaporator is a patented device for evaporating water from "solutions and/or suspensions of materials which when concentrated tend to form syrupy gel-like, or sticky concentrates of substances which decompose when heated" (R-3). The evaporation of fish stickwater is discussed in this patent which further states "The present invention has for one of its objects the control of evaporating conditions and the carrying out of evaporating of the undesired moisture under such conditions that moisture is efficiently and quickly removed while the concentrate is obtained without raising the temperature of the decomposable materials to temperatures much in excess of 165°F, even though the system is maintained under atmospheric pressure and materials being concentrated are subjected to direct heat of heating gases which may be as hot as 1400°F to 1900°F."

This patent (R-3) continues by stating that "Another object of the present invention is the carrying out of the herein described process in such a manner as to avoid permitting the concentrating or concentrated materials from collecting at any stage of treatment where they would be subject to overheating with attendant decomposition, charring, or carmelization." In other places this patent states (1) that "Temperatures somewhat lower, such as 800°F to 1300°F, may be employed and temperatures somewhat higher, such as 1600°F to 1900°F may be employed," and (2) "In its broader aspects, the invention involves passing a stream of liquid to be concentrated into a high velocity stream of highly heated gases flowing countercurrent thereto, passing the components of said streams through a zone of turbulence and at least partial vacuum, and then separating the gases and concentrated liquid."

A few years ago the Selas Corporation of America reportedly had their TRANSCHANGER tested for concentration of stickwater by the University of Texas (R-4). The evaporator that we proposed in our earlier report (R-1) and which we are testing, has some features in common with the TRANSCHANGER. This latter device reportedly operates by completely burning fuel gas in a chamber, forcing the hot combustion products through a small exhaust port, injecting a stream of stickwater into the hot gases in the exhaust port and separating the concentrated liquid from cooled combustion gases and steam in a cyclonic separator (R-5). The concentrate can be recycled for further evaporation, or it becomes the product. Spent gases and steam are vented into the atmosphere. The operation of this unit appears to rely upon high velocity gases in both the exhaust port and in the separator. This should allow direct contact of the single stream of liquid with the hot, high-velocity combustion products in the former and provide centrifugal action in the separator. Turbulence in the gas-liquid contacting zone would be expected to break the liquid stream into various sized drops, thereby promoting good heat and mass transfer. The mechanism of contact seems different from the VINCENT evaporator in at least two ways. In the TRANSCHANGER the flow of hot combustion products and the liquid stream issuing from the pipe are cocurrent. This is also called parallel flow. It has advantages for concentrating foods or other heat labile materials because the hottest gases contact the most dilute solutions. This provides maximum initial thermal driving force for evaporation and tends to reduce burning. It also slows evaporation at the end of the process when the vapor pressure of water may be lower at the liquid surface. This is desirable in a device for concentrating stickwater because burning or charring of organic matter in partially evaporated drops is thus less likely to occur than in a countercurrent flow device. However, introduction of even dilute solutions of fish stickwater into very hot gases of 1000°F or above may lead to burning or charring.

Even though most of the stickwater should remain liquid, very small drops could flash-evaporate to dryness, since small drops evaporate faster than large ones (R-7, R-8, R-9, R-10). This could lead to scorching or charring of dry particles before they leave the very hot zone. A similar situation has been reported for submerged combustion evaporators when they are used for fish stickwater (R-1).

Besides this scorching problem, there are other recognized deficiencies to be considered for concentrators using direct contact between hot, gaseous combustion products and liquids. These include transfer of undesirable chemicals in the combustion products to the concentrate, and air pollution from the often noxious steam that is usually discharged directly into the atmosphere.

## EQUIPMENT AND OPERATING PROCEDURES

With these observations in mind we designed, built and have begun testing a device that should effectively concentrate fish stickwater discharged from small rendering plants. It should also eliminate or significantly reduce the deficiencies just discussed for other evaporators that also employ the principle of contacting bulk liquids, jet streams, or drops of water with hot combustion products. A number of preliminary experiments were necessary to provide data upon which to design the apparatus. These included (1) testing of numerous atomizing nozzles to determine their spray patterns for water, (2) assembling and testing the fluid storage and pumping system that is now incorporated in the apparatus, and (3) fabricating a small spray tower from sheet iron to test the assembled equipment, less the burner. This small sheet iron unit was discarded after serving its purpose.

In order to determine the required dimensions of the concentrating chamber and the size of the gas burner for design purposes, the expected evaporation rates of water from drops were calculated using an iterative procedure. This method predicted that 3.45 lb/min of water would be evaporated from 1.05 gal/min of feed using an inlet temperature of the combustion gas at 900°F and a drop size of 800 μ. Assuming an efficiency of 50% and a feed rate of 1 gal/min, the approximate heat requirement is 450,000 Btu/hr. This was the basis for the purchase of a 1,000,000 Btu/hr, gas-fired burner for this installation.

While evaluating various nozzles to be used for spraying water droplets into the concentrating chamber, we also kept in mind the problems that will likely develop when spraying stickwater. We anticipate that the stickwater will first be passed through a rotary screen. However small particles, together with burn-on, may tend to clog nozzles of the type that are otherwise satisfactory for water. Two alternative drop-producing systems were therefore considered, namely rotary atomizers (R-11) and pinless, spiral nozzles similar to the TF series of the Bete Fog Nozzle, Inc. (R-12). For experiments with water we have used only nozzles supplied by the Delavan Manufacturing Co (R-13).

### SPRAY CONCENTRATOR

The spray concentrator that we have assembled and are testing is shown in Figure 2. It has three major components, namely the:

(1) Air Heating System
(2) Fluid Pumping System
(3) Concentrating Chamber

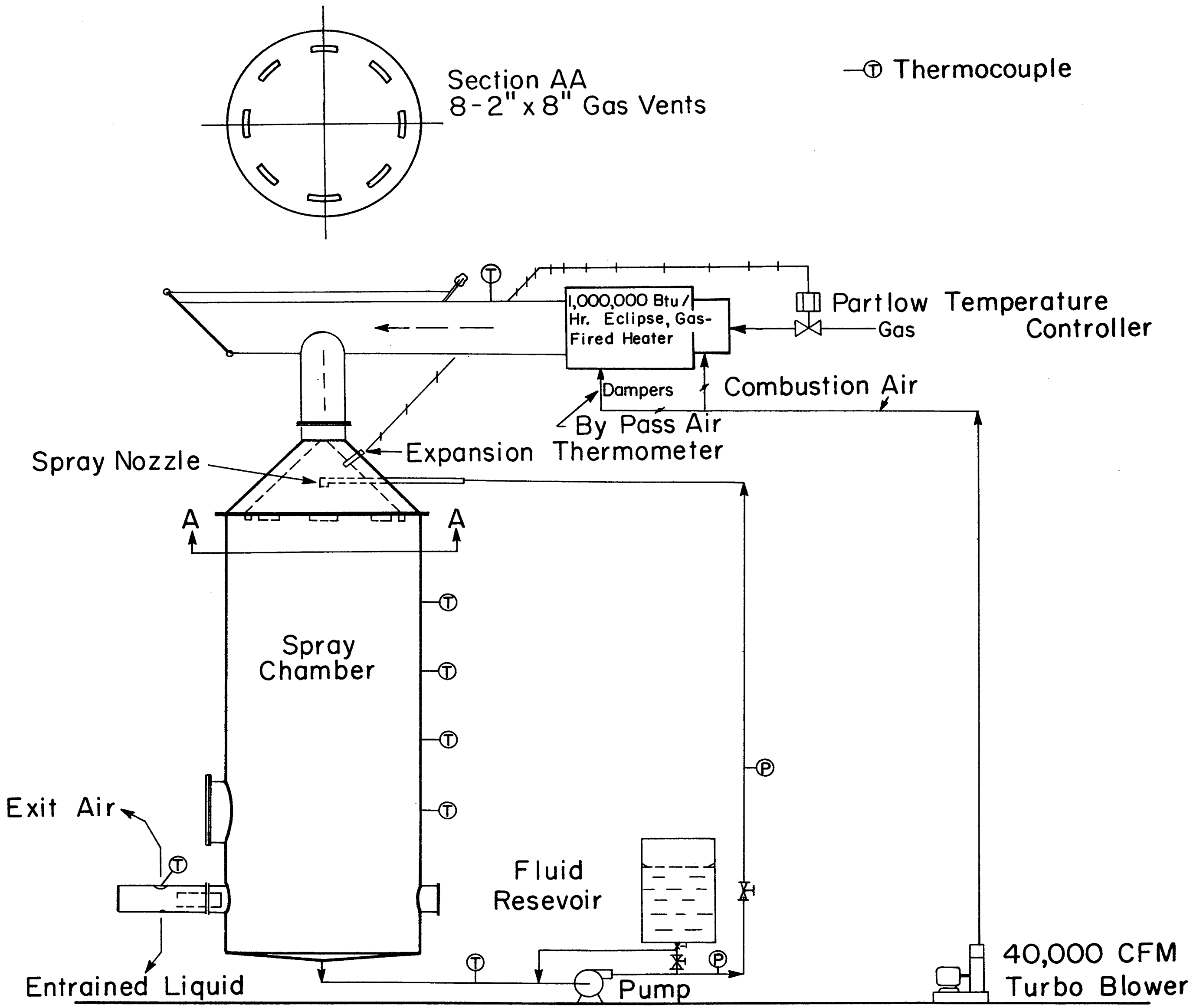



Figure 2. Diagram of spray concentrator for fish stickwater.

## Air Heating System

A 1,000,000 Btu/hr, gas-fired burner with a minimum turn-down ratio of 40 to 1 is used as the energy source. It was produced by the Industrial Burner Systems Inc., Detriot, Michigan (R-6). A picture of the burner attached to the spray concentrating chamber through the "T" connection is shown in Figure 3.

Included with the burner are a 40,000 standard cubic feet per hour (SCFH) turboblower and a cylindrical chamber in which the hot combustion gases are mixed with excess air. This chamber has a length of 3 ft and a diameter of 16 in. Safety devices, that are required by "Factory Mutual Insurance," have been included in both the gas chain and its accompanying control system. Most important among these safety devices is an electrically operated ECLIPSE, "Safety Shut-Off Valve" (R-6) which is linked with a protection control box that shuts down the system upon failure of the flame or of the blower, or upon loss of electrical power.

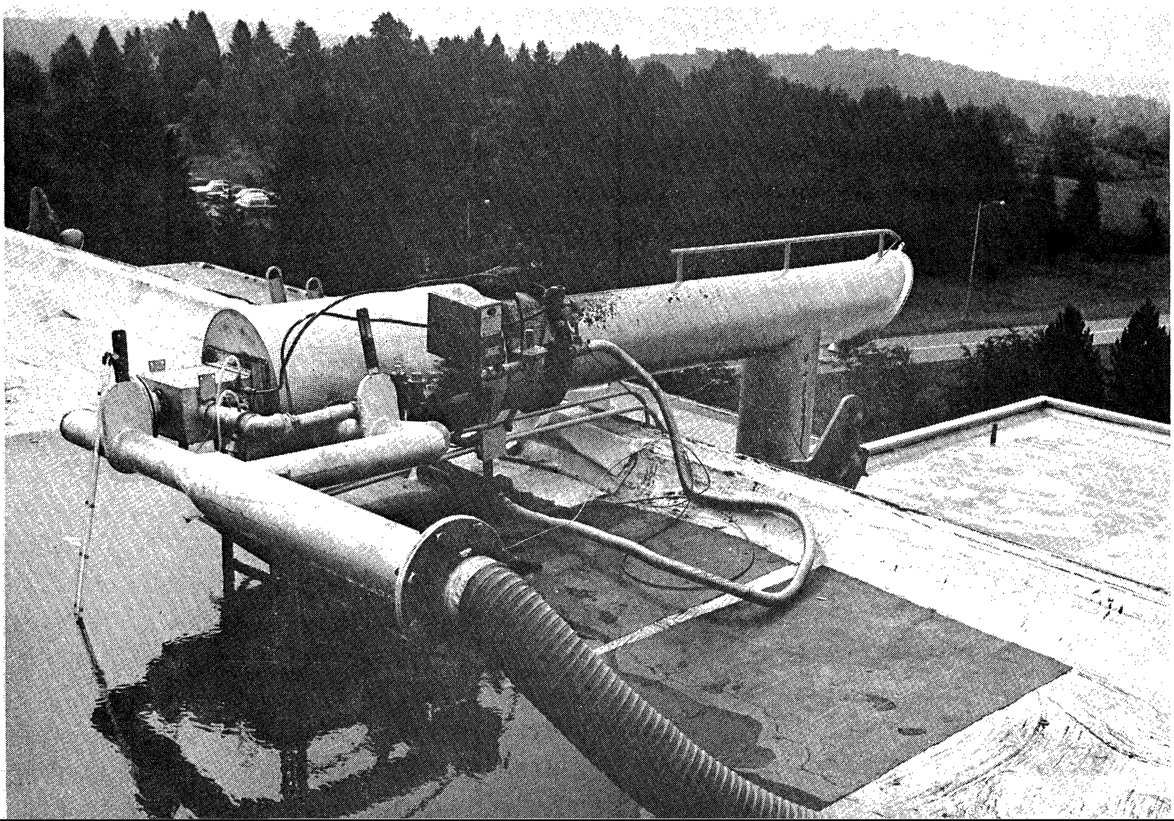
The gas chain and safety control systems are shown in Figure 4. It will be noted that a portion of the air is used for initial combustion and enters through the rear of the burner while the remaining fraction enters tangentially into the cylindrical mixing chamber. This chamber is 3 ft long, 16 in. in diameter and is covered with a 2-in. layer of insulation. Dampers are present in both lines to regulate air flows. Diluted combustion gases pass from the mixing chamber to a "T" connection between the concentrating chamber and the burner. Here the hot gases can either be vented to the atmosphere or diverted into the chamber by opening or closing the flap-valve at the straight end of the "T." This was installed as a safety device. The "T" is kept open until the burner is operating satisfactorily at start up, then the valve is closed.

A number of component parts are associated with the gas supply for the burner. From upstream to downstream these components are a Nordstrom, manually operated gas cock, a pilot gas cock, an Eclipse model 204 T-3, electrically operated, main-gas, safety shutoff value, and a Partlow indicating temperature controller. The desired temperature at the exit of the cones is monitored by a vapor expansion thermometer. The gas flow is correspondingly adjusted by a controller. There is also an automatic solenoid valve in the pilot gas line.

A "Unified Control Panel," made by Protection Controls Inc. Skokie, Illinois, controls the ignition and maintenance of the flame. Failure of the blower or of the flame results in automatic closure of the pilot gas valve and of the main-gas, safety shutoff valve.

## Fluid Pumping System

The fluid to be concentrated is retained in a 55-gal drum (Figure 5).



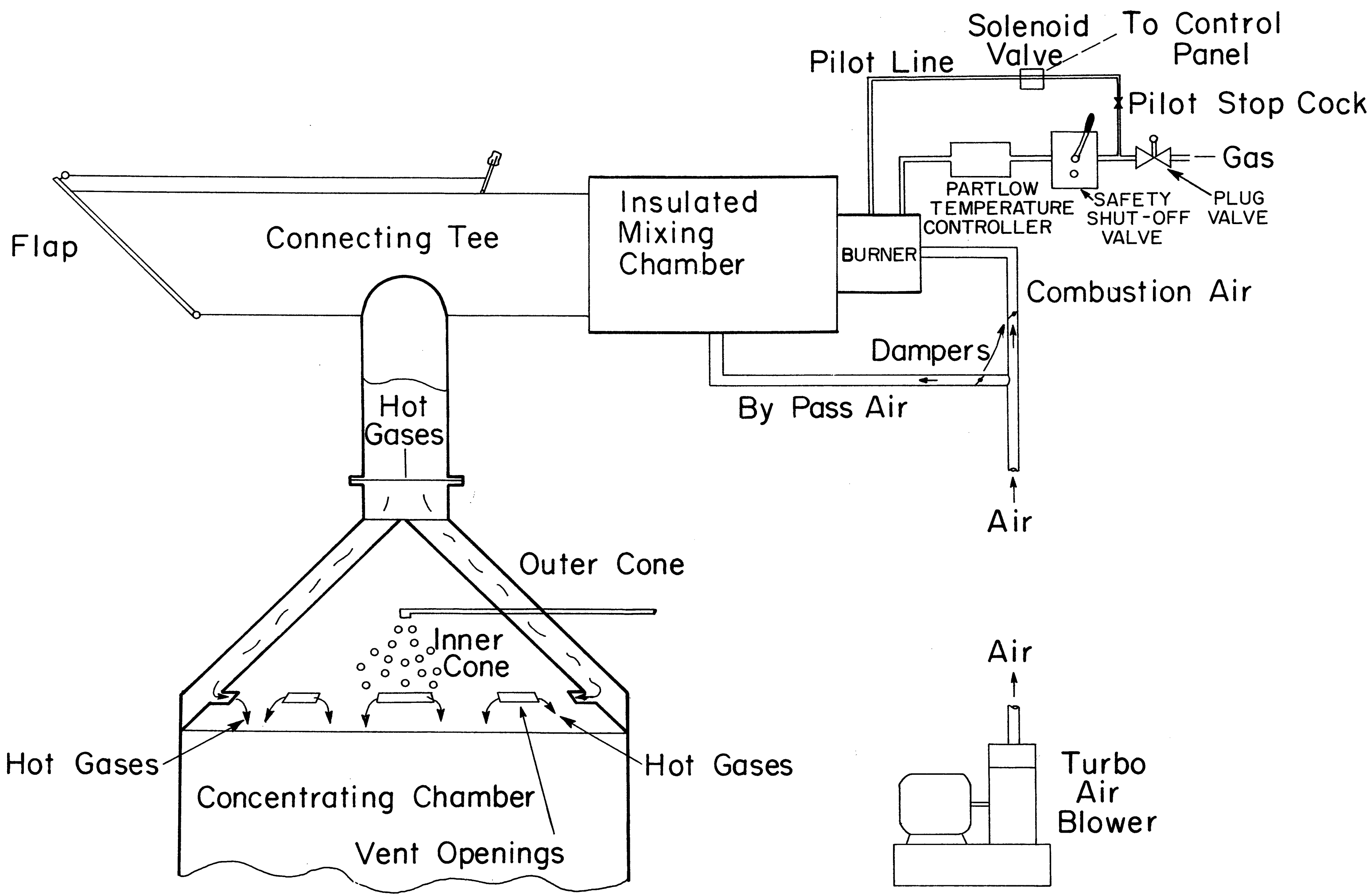



Figure 4. Diagram of air heating equipment in spray concentrator for fish stickwater.

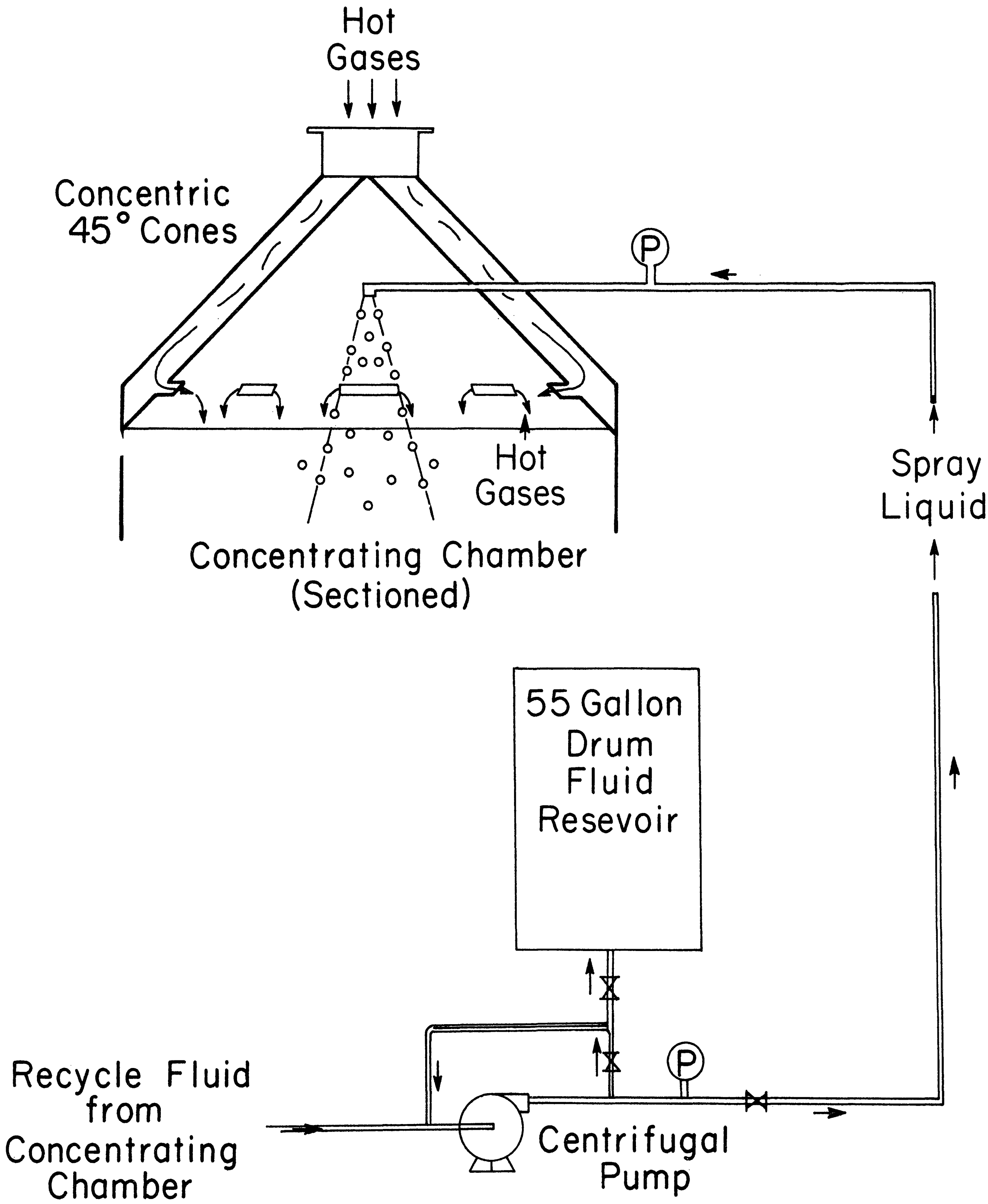



Figure 5. Diagram of fluid pumping system in spray concentrator for fish stickwater.

A rotary pump and its accompanying 3/4 hp electric motor are positioned directly below the drum. Fluid is drawn from the drum to the pump through the by-pass line. The pumped fluid flows through a flexible hose to a 2-ft section of 3/8 in. stainless steel pipe. This pipe is inserted through the exterior cone of the spray chamber so as to locate the stainless steel nozzle in the center of the cone, directly above the spray chamber. The spray nozzle is located 1-ft above the point of attachment of the cones to the top of the chamber. The pipe to which the nozzle is attached is screwed into a coupling welded to the exterior cone.

Evaporation occurs as the sprayed drops fall through the length of the chamber. Concentrated fluid is removed from the bottom of the tank and returns to the by-pass line of the pump (Figure 2).

Pressure gages are present at the exit of the pump and at the entrance to the spray nozzle. Valves are located at various places in order to allow the operator to regulate the liquid pressure in the recycle line as well as the pressure at the nozzle. The latter is particularly necessary because the nozzle is designed to produce drops with a mean diameter of 800 $\mu$ at flow rates varying between 1-3 gal/min. with a line pressure of 20 psig.

Concentrating Chamber

The detailed drawing shown in Figure 6 was used for fabricating the spray concentrator. The chamber was fashioned from 3/16-in. steel. It stands 18 ft tall, has a diameter of 5 ft. 4 in., and weighs approximately 3000 lb. Basically, it consists of a concentrating cylinder covered with two 45° cones. The cylinder itself is 12 ft high. Two, 8-in. exhaust ports are located near the bottom of the cylinder. They are positioned opposite each other with centers 2 ft above the level at which the conical floor of the chamber joins the cylinder. A 20-in. covered manhole is located 4 ft above the base of the cylinder and directly above one of the exhaust ports. The chamber stands on four 1-ft legs, each equipped with 8-in. square pads; its conical bottom drops 4 in. from edge to center to facilitate drainage.

Atop the cylinder are the two concentric, 45° cones (Figure 4). Hot combustion gases are forced into the 2.8-in. annulus between the two cones. Six inches above the base of the interior cone are eight symmetrically spaced slots each of which are 2 in. high and 8 in. wide. These slots direct hot combustion gases out of the annulus perpendicularly into the rain of descending water drops from the nozzle.

This concentrating chamber was fabricated by the Plymouth Tank Co. of Plymouth, Michigan. Since the chamber weighs about 3000 lb, a large crane was needed to lift it to the roof of the G. G. Brown Laboratory where it is now located. All of the auxilary services are located inside the building

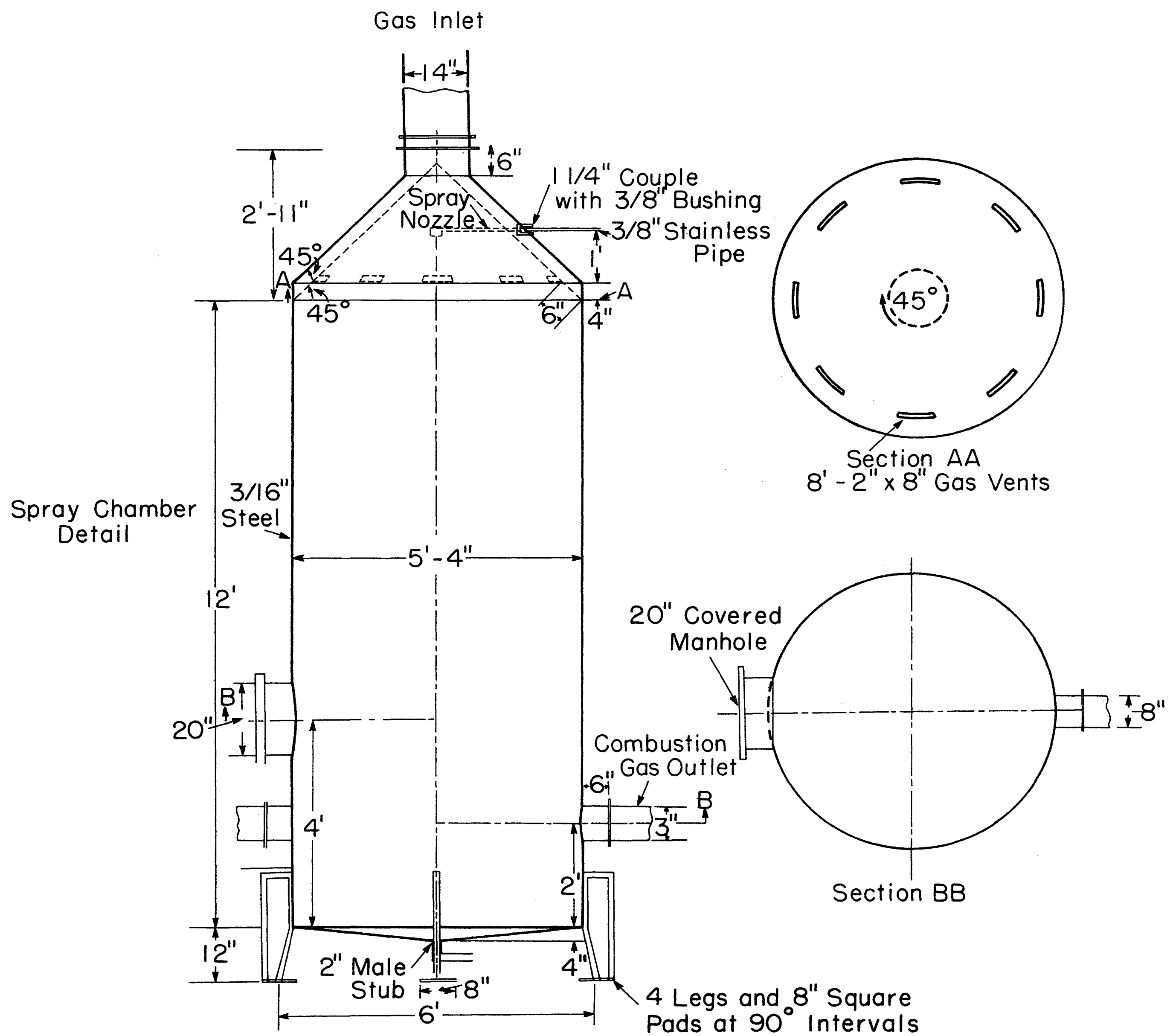



Figure 6. Detailed drawing for the chamber of the fish stickwater concentrator.

but the concentrating tank and the burner are outside, exposed to the weather. This was necessary because of the rather large amount of both heat and exhaust vapors involved. The outdoor location however does restrict testing of the equipment to about six months of the year. For other reasons as well, our tests were carried out during the summer months although the tank itself was actually installed in the middle of winter. A picture of the concentrating chamber in position on the roof of the G. G. Brown Laboratory is shown in Figure 7.

Figure 7. General view of the chamber of the fish stickwater concentrator.

## TEST EQUIPMENT AND MEASUREMENTS

Once the concentration tank was in place, test equipment was added. There are three independent variables to be controlled and measured. They are temperature of gases in the cone of the evaporator, volume of by-pass air to the mixing chamber and the rate at which water sprays from the nozzle. In addition it was necessary to measure the volume of water evaporated per hour, humidities of the inlet and outlet gases, the fluid pressure at the nozzle and the temperature of the combustion gases issuing from the burner.

Commercially manufactured thermocouples were screwed into fittings previously welded into the apparatus. These were high-temperature, chromel-alumel thermocouples. Their locations are shown in Figure 2. They were used to measure gas temperatures at any time during a run starting with the combustion products from the mixing chamber, then in the annulus, at various points in the chamber and in the exhaust. A thermocouple was also located in the pipe carrying water from the drainage port of the tank. At some locations inside the tank the thermocouples seemed to reflect wet-bulb rather than dry-bulb temperatures. This could be due to films of water on the thermocouples; it is a situation that will need further attention when other studies are carried out.

After the initial run, a demister was fitted to the exhaust port from the chamber; the other port was sealed. The demister consists of a 3-ft long cylinder 12 in. in diameter and closed on one end. Outlet gases enter this demister through an 8-in. pipe that protrudes about 6-in. into the chamber. This was necessary in order to exclude water that runs down the inside wall from mixing with the exit gases. Once inside the demister, the gases exit upwards through a 6-in. hole. Water that is removed by the demister drains from a 2-in. hole in the bottom of the cylinder. The amount of water thus removed was negligible compared to the amount evaporated but its volume was nevertheless included in the calculations.

Rates of gas consumption were calculated from manometer measurements of the pressure drop across the Eclipse safety valve; from this the total heat input was calculated.

Dry-bulb and wet-bulb readings for humidity determinations were made with thermometers.

Air flow rates were computed from absolute humidity measurements together with the gallons of water evaporated per hour.

The amount of heat absorbed by the fluid evaporated in order to vaporize the water was calculated knowing the amount of water evaporated per hour and the amount of heat required to vaporize a pound of water under the test conditions.

## OPERATION OF EQUIPMENT

In order to successfully fulfill requirements for a good fish-stickwater concentrator, the equipment must be easy and quick to start and stop as well as safe to use. It should be cheap to install and inexpensive to operate. With these thoughts in mind, a detailed description of the steps required to start and shut down the spray concentrator are given below.

### Start Up and Operating Procedures

1. Pour fluid to be concentrated into the 55-gal fluid reservoir (Figure 5) until it is about two-thirds full. Also pour some of the same fluid into the concentrating chamber until the fluid level gage at the bottom of the chamber shows at about the halfway mark (Figure 2). These fluid levels should be approximately maintained during a run; at the end of a run it is particularly important that both levels be exactly reestablished at their original heights in order that precise measurements of the amount of water evaporated can be made.

2. Start the air blower from the control panel.

3. Start the fluid pump and adjust the nozzle pressure using the gate valve in the by-pass line around the pump (Figure 5). Usually, only a fraction of the water sprayed evaporates. The excess water collects in the bottom of the evaporator from whence it is pumped back to the spray nozzle.

4. After the blower operates for 5 min, open the by-pass flap-valve on the "T" connection to the chamber.

5. Open the plug valve in the main gas line and also open the pilot stop cock (Figure 4).

6. Open and adjust dampers in the inlet air lines (Figure 4).

7. Set the temperature control at "minimum fire."

8. Start the pilot gas flame from the control panel. A red light indicates ignition has occurred.

9. Ignite the main gas burner by manually opening the Eclipse safety shut-off valve.

10. Adjust the temperature controller and air dampers in order to provide the desired conditions for the run (Figure 4).

11. Close the by-pass flap on the "T" connection in the pipe carrying hot combustion gases from the burner to the concentrator (Figure 4).

By following this procedure, steady state can be achieved in about 30 min. At steady state, the gas temperatures in the burner exhaust, in the cone and in the exit gases from the evaporator remain essentially constant.

## Shut Down Procedure

The spray concentrator is shut down by effecting the following steps in order.

1. Turn off the fluid pump.

2. Stop the air blower from the control panel. This automatically shuts off the gas burner.

3. Close the main gas stop cock and also the pilot stop cock.

4. Completely drain fluid from the pumping tank, the concentrating chamber and from all pipes.

## EXPERIMENTAL RESULTS

After construction of the equipment and initial checkout, several runs were made to evaluate the spray concentrator. Water was used as the working fluid.

During the first four runs considerable information was obtained concerning the operation of the evaporator and measurement of operating conditions. At first, the exit wet- and dry-bulb temperatures were measured with a sling psychrometer inserted into the exhaust port at the side and near the bottom of the evaporator through which the exit air passed. The wet- and dry-bulb temperatures were approximately equal. However when the sling psychrometer was placed in the path of the exit gases, but outside of the duct, the dry-bulb temperature was 20 to 40°F higher than the wet-bulb temperature. Inside the duct, entrained water impinging on the dry-bulb thermometer caused the dry-bulb thermometer to behave as a wet-bulb thermometer.

Before Run 5 the expansion thermometer located in the cone was withdrawn a few inches. At the new location, the cone temperature was roughly 300°F higher than at the previous location, under similar operating conditions. Water spray striking the thermometer apparently caused the lower temperature. The cone temperatures listed for Runs 1-4 are therefore low by approximately 300°F.

When the inside of the evaporator was inspected at the end of Run 7, it was found that the spray nozzle insert was missing. Since the operating conditions and results for Runs 2-7 were rather consistent, the insert apparently came out during the first run. A calibration of the nozzle without insert was made to determine water flow rate as a function of pressure. Even though the spray distribution and drop size were not ideal, the results for Runs 2-7 were the best in terms of evaporator efficiency and total evaporation rate indicating that the evaporator could be operated at higher flow rates.

As can be seen from Table I, evaporator efficiencies of over 50% can be achieved at cone temperatures of 800°F and water flow rates of 3200 lb/hr. At these conditions, approximately 17% of the water is evaporated per pass, resulting in an evaporation rate of about 560 lb/hr. The burner temperature is nearly 1400°F. At lower water flow rates the evaporator efficiency is considerably less.

A sample calculation for Run 7 is presented as Table I to aid interpretation of Table II.

TABLE I

SAMPLE CALCULATION

Run 7

Nozzle 40, Without Insert

Experimental Data:

| | |
|---|---|
| Inlet dry-bulb temperature | 85°F ± 1 |
| Inlet wet-bulb temperature | 67°F ± 1 |
| Outlet dry-bulb temperature | 200°F ± 1 |
| Outlet wet-bulb temperature | 163°F ± 1 |
| Pressure at nozzle | 20 psia |
| Pressure drop across Eclipse valve | 0.3 in. water |
| Cone temperature | 805°F ± 5 |
| Water added at 45°F | 1114 lb |
| Duration of run | 2 hr |

Calculated Results:

| | |
|---|---|
| Inlet humidity | 0.010 lb water/lb air |
| Outlet humidity* | 0.310 lb water/lb air |
| Heat required to evaporate 1 lb of 45°F feed water at 163°F, the wet-bulb temperature | 1118 Btu/lb |
| Water flow rate from calibration | 3200 lb/hr |

$$\text{Water evaporation rate} = \frac{1114\ \text{lb}}{2\ \text{hr}} = 557\ \text{lb/hr}$$

$$\text{Air flow rate} = \frac{557\ \text{lb water/hr}}{(0.310-0.010)\ \text{lb water/lb air}}$$

$$\text{Air flow rate} = 1850\ \text{lb air/hr}$$

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*Psychrometric chart for combustion products, Ref. Hatta, Chem. Met. Eng., 37, 164 (1930).

Table I (Concluded)

$$\text{Air flow rate} = \frac{(1850 \text{ lb air/hr})}{(0.076 \text{ lb air/cu ft})} = 24{,}400 \text{ cu ft/hr}$$

Gas flow rate from calibration = 1002 cu ft/hr

Heating value of gas = 1025 Btu/cu ft

Heat released = (1002 cu ft/hr)(1025 Btu/cu ft)

Heat released = 1,030,000 Btu/hr

Heat absorbed = (557 lb water/hr)(1118 Btu/lb)

Heat absorbed = 623,000 Btu/hr

$$\text{Efficiency} = \frac{(623{,}000 \text{ Btu/hr})}{(1{,}030{,}000 \text{ Btu/hr})} \times 100 = 60.4\%$$

$$\text{Fraction evaporated per pass} = \frac{557 \text{ lb/hr}}{3200 \text{ lb/hr}} = 0.174$$

TABLE II

SUMMARY OF STICKWATER EVAPORATOR EVALUATION DATA WITH WATER AS THE TEST LIQUID

| Run Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Nozzle Number | 40[b] | 40[b] | 40[b] | 40[b] | 40[b] | 40[b] | 40[b] | 35 | 40[c] | 45 |
| Nozzle pressure, psig | 19 | 20 | 20 | 20 | 20 | 20 | 20 | 22 | 22 | 20 |
| Inlet Air | | | | | | | | | | |
| Dry-bulb temperature, °F | 66 | 82 | 91 | 82 | 84 | 84 | 85 | 83 | 84 | 90 |
| Wet-bulb temperature, °F | 62 | 76 | 78 | 75 | 67 | 65 | 67 | 67 | 67 | 69 |
| Humidity, lb water/lb air | 0.010 | 0.017 | 0.018 | 0.012 | 0.010 | 0.009 | 0.010 | 0.011 | 0.011 | 0.010 |
| Outlet Air | | | | | | | | | | |
| Dry-bulb temperature, °F | 180 | 200 | 202 | 202 | 184 | 187 | 200 | 300 | 256 | 256 |
| Wet-bulb temperature, °F | 154 | 164 | 164 | 162 | 161 | 161 | 163 | 159 | 157 | 155 |
| Humidity, lb water/lb air | 0.220 | 0.310 | 0.310 | 0.300 | 0.290 | 0.278 | 0.310 | 0.230 | 0.280 | 0.250 |
| Cone Temperature, °F | 470 | 583 | 590 | 573 | 880 | 858 | 805 | 815 | 779 | 810 |
| Burner Temperature, °F | 1286 | 1423 | 1433 | 1416 | 1486[d] | 1300 | 1390 | 1325 | 1343 | 1325 |
| Energy Input, Btu/hr | 970,000 | 1,050,000 | 1,030,000 | 1,035,000 | 1,030,000 | 1,030,000 | 1,030,000 | 1,030,000 | 1,030,000 | 1,030,000 |
| Evaporation Rate, lb/hr | 402 | 536 | 530 | 547 | 510 | 519 | 557 | 334 | 392 | 331 |
| Air Flow Rate std. cu. ft/min[a] | 25,500 | 23,500 | 24,600 | 26,900 | 23,500 | 26,100 | 24,400 | 18,000 | 21,800 | 20,500 |
| Heat Absorbed, Btu/hr | 449,000 | 600,000 | 592,000 | 611,000 | 570,000 | 579,000 | 623,000 | 373,000 | 438,000 | 372,000 |
| Efficiency, % | 46 | 60 | 57 | 59 | 55 | 56 | 60 | 36 | 42 | 36 |
| Nozzle Flow Rate, lb/hr | 1,350 | 3,200 | 3,200 | 3,200 | 3,200 | 3,200 | 3,200 | 1,300 | 3,420 | 1,580 |
| Fraction Evaporated/Pass | 0.300 | 0.162 | 0.166 | 0.170 | 0.160 | 0.161 | 0.174 | 0.256 | 0.114 | 0.209 |

[a] Based on water evaporated and humidity change.
[b] Nozzle 40 without insert.
[c] Modified with bored out insert.
[d] Thermocouple burned out during run.

## DISCUSSION

It seems reasonable to expect that the efficiency of the spray concentrator we have built could be increased by design and operational changes. For example it was noted during some of the runs that only about 18 in. of the evaporator height were hot. This suggests that the chamber height was not matched with the size of the fluid drops. It is likely that larger drops would be desirable for use with stickwater to prevent evaporation to dryness of some of the smaller drops, also nozzles that produce large drops should require less maintenance and operate on lower line pressures.

Operating variables will also affect efficiency and adaptability of the equipment. Data should be obtained concerning effects of the following on thermal efficiencies and operating characteristics:

1. Temperature of hot combustion gases entering the annulus in the cones.

2. Amount of outside air mixed with the hot combustion gases.

3. Recirculation ratio of fresh fluid to be concentrated with partially evaporated fluid collected in the bottom of the concentrator.

4. Various styles and sizes of spray nozzles.

5. Location and number of spray nozzles.

These, along with other less important variables, should be investigated and evaluated first with water as the working fluid. They could logically be studied as a continuation of our present work.

Besides the thermal efficiency, other characteristics of the overall concentration process require investigation. Some of these are listed below:

1. Will chemical and physical characteristics of fish stickwater cause corrosion problems?

2. Will the organic solids result in caking of dried material on the nozzles? This caking is a condition commonly known as "burn-on" in the food industry.

3. Will sludging of pipes and pumps occur and prove troublesome?

4. How will odors from hot vapors emitted from the concentrator be eliminated or at least reduced to acceptable levels?

These and similar problems arise from the fact that the solids in fish stickwater are mostly putrescible, soluble proteins. It should be possible to evaluate some of these problems with equipment now located on the roof of the G. G. Brown Laboratory. It would be best to initially use working fluids prepared from corn steep solids or distiller's solubles, diluted with water. Such solutions have many of the physical and chemical characteristics of fish stickwater without its intense odor producing potential. Preliminary laboratory studies to devise methods for controlling odors would also be desirable before a pilot, demonstration unit is designed.

While some useful information leading to the solution of the above problems can be obtained at the G. G. Brown Laboratory, final answers concerning the actual performance of the equipment must result from using actual fish stickwater as the working fluid. This will require a demonstration unit at a suitable fish rendering plant site.

One other major factor should be investigated. City gas has been used as the fuel in the present work. Gas will not likely be available at fish rendering plants. It will therefore be necessary to evaluate the acceptability of using fuel oil for this service. Oil should be satisfactory because it is already used in the kiln driers at these plants, but the adaptability of oil as a fuel for the operation of the concentrator should nonetheless be established. Such studies could be initiated at the present location but should be one of the main objectives of a pilot demonstration unit.

LITERATURE CITED


(R-1) Kempe, Lloyd L., N. E. Lake, and R. C. Scherr. Disposal of Fish Processing Wastes, Final Report ORA Project No. 01431, The University of Michigan, July 1968.

(R-2) _____. There's Good Hard Cash in Stickwater, Food Ind., 22(2) 96-99 (1950).

(R-3) Vincent, Daniel B. (to Prentice E. Edrington), Process of Evaporating Moisture from Syrup Forming Solutions, U.S. Patent 2,818,917 (January 7, 1958).

(R-4) Personal Communication, Allen, E. D., Selas Corporation of America, 743 New Center Bldg., Detroit, Michigan 48202.

(R-5) Selas Corporation of America, Submerged Combustion Dividion Dresher, Pennsylvanis 19025. Subcomoco Transchanger Concentrator, A New System for the Concentration of Solutions, Bulletin TC-1.

(R-6) Eclipse Fuel Engineering Co., Combustion Division, Rockford, Ill., and Industrial Burner Co., 16911 Eight Mile Rd., Detroit, Michigan 48235.

(R-7) Manning, W. P., and W. H. Gauvin, Heat and Mass Transfer to Decelerating Finely Atomized Sprays. A.I.Ch.E. J. 6(2), 184-190 (1960).

(R-8) Baltas, Leon and W. H. Gauvin, Performance Predictions for a Cocurrent Spray Dryer. A.I.Ch.E. J. 15(6), 764-771 (1969).

(R-9) _____. Transport Characteristics of a Cocurrent Spray Dryer. A.I.Ch.E. J. 15(5), 772-779 (1969).

(R-10) Dickinson, D. R., and W. R. Marshall, Jr. The Rates of Evaporation of Sprays. A.I.Ch.E. J. 14(4), 541-552 (1968).

(R-11) Tate, R. W. Sprays and Spraying for Process Use. Part I. Chem. Eng. 72 (July 19), 157-162 (1965); and Part II, 72 (August 2), 111-116 (1965).

(R-12) Bete Fog Nozzles, Catalog No. 70, Bete Fog Nozzle, Inc., 332 Wells St., Greenfield, Massachusetts 01301.

(R-13) Industrial Spray Nozzles, Catalog No. 1118A-1169 (1969). Delavan Manufacturing Co., 811 Fourth St., West Des Moines, Iowa 50265.