Sap Preheaters:
Efficient Maple Syrup Processing

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INTRODUCTION

The use of sap preheaters to transfer heat energy from stack gasses or steam above the evaporator pan to incoming sap is not new to maple producers. They have experimented with these techniques in the past. In general placing coils or tubes in the stack usually leads to either scorched sap or extreme surging, air locks, or even entrapped steam in the tube bundles. Tubes placed above the evaporator pans have been tried, also, but syrup producers either failed to enclose the tubes in a hood or permitted condensate from the tube bundle to fall back into the evaporating pan. As a result, the maple industry has not adopted heat exchangers or sap preheater technology to any great degree.

George Raithby, University of Waterloo, Ontario, developed a sap preheater encased in a specially designed hood that yielded a 15 - 17 percent increase in evaporator production (1). During that same year, research by Neil K. Huyler, Northeastern Forest Experiment Station, Burlington, VT, revealed that general field evaporator efficiencies using wood, oil, and gas energy were averaging only 45, 55, and 65 percent respectively (2). This coincides with the fact that in 1973, the world became acutely aware of the declining supply of fossil fuels. Since then the price of energy has become a critical aspect of the economics of processing all food products.

In 1974 the Vermont Experiment Station, Proctor Maple research team, and the Northeastern Forest Experiment Economics Research Unit at Burlington, VT, launched an intensive 4-year processing research program. This program was designed to accomplish two major goals: (1) increase the efficiency of the conventional open-pan evaporator system from approximately 65 percent to approximately 80 percent; and (2) evaluate new evaporator systems for processing maple syrup products. As an initial

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part of the first research objective, the energy balance of the conventional open-pan evaporator has been completed. Also, design and laboratory and field testing of a sap preheater system has been completed.

TEST PROCEDURES

Two identical 4' x 10' Grimm-Lightning evaporators were installed, one as a control unit, the other for experimental tests. Sap from the storage tank was divided and fed to each evaporator through parallel lines. Each sap line was connected to a water meter and a flowmeter before entering the evaporator.

Each evaporator was equipped with an oil burner with a firing rate of 10 or 12 gal/hr. Oil flow was measured by using a 32-gallon drum as an oil reservoir; each drum was placed on a platform scale. The oil return line from each burner was connected back to the drum so that the weight differences obtained indicated the exact amount of oil consumed as fuel. A manometer and hygrometer were used with each burner to measure firebox draft and relative humidity of air supply respectively.

We monitored temperatures of the boiling medium at 10 points within each evaporator by using copper-constantan thermocouples and a recording potentiometer. We placed a thermometer in the smokestack for stack temperatures and withdrew gas samples from the stacks at intervals. We analyzed the samples, using a Fisher-Hamilton gas partitioner Model 29 with a strip chart recorder.

The syrup or concentrated sap was generally drawn from the evaporators at about 50° Brix, weighed, and brought to standard syrup in a gas-fired finishing pan.

We made the first preheater tests by using a series flow preheater after the design of Raithby. In 1975 and stir sequent years, we used parallel flow preheaters (Fig. 1). The data presented refer to the results obtained with the parallel flow preheaters.

RESULTS

Table 1 shows the direct effect on evaporator efficiency with an installed preheater as compared to an evaporator without a preheater. The test evaporator with the preheater produced an average of 38.4 lb of syrup/10 gal of oil, whereas the evaporator without a preheater produced only 33.0 lb of syrup /10 gal of oil (Table 1). The amounts for 12 gal of oil/hr is 34.6 and 39.6 lb of syrup, respectively. The computed average efficiency over the six tests for the evaporator with the pre-heater was 84.3 percent as opposed to 72.8 percent for the evaporator without the preheater. The average efficiency increase was 15.8 percent (range 11.1 - 20.5).

We designed a research prototype preheater for one of the larger evaporators made--a 6' x 19' Lightning that consumes approximately 28 gallons of oil/hr. The preheater for this unit was designed to operate with less, as well as, more than enough tubing for heat transfer purposes. Table 2 demonstrates the performance of that evaporator under actual plant conditions. We made four tests, each running for 10 hours; test 1 was without a heat ex-changer; test 2 with an undersized heat exchanger--76.8 ft of 1" parallel tubing; test 3 with 134.4 ft; and test 4 with an oversized heat exchanger--190.0 ft. The gallons of syrup produced per hour in this unit is the effect of the combination of sap Brix and preheater surface area. It is actually higher with 134 feet of tubing than with 190 feet because of a higher sap Brix con-tent in the sap on the test using 134.4 feet of tubing. The proper size, based

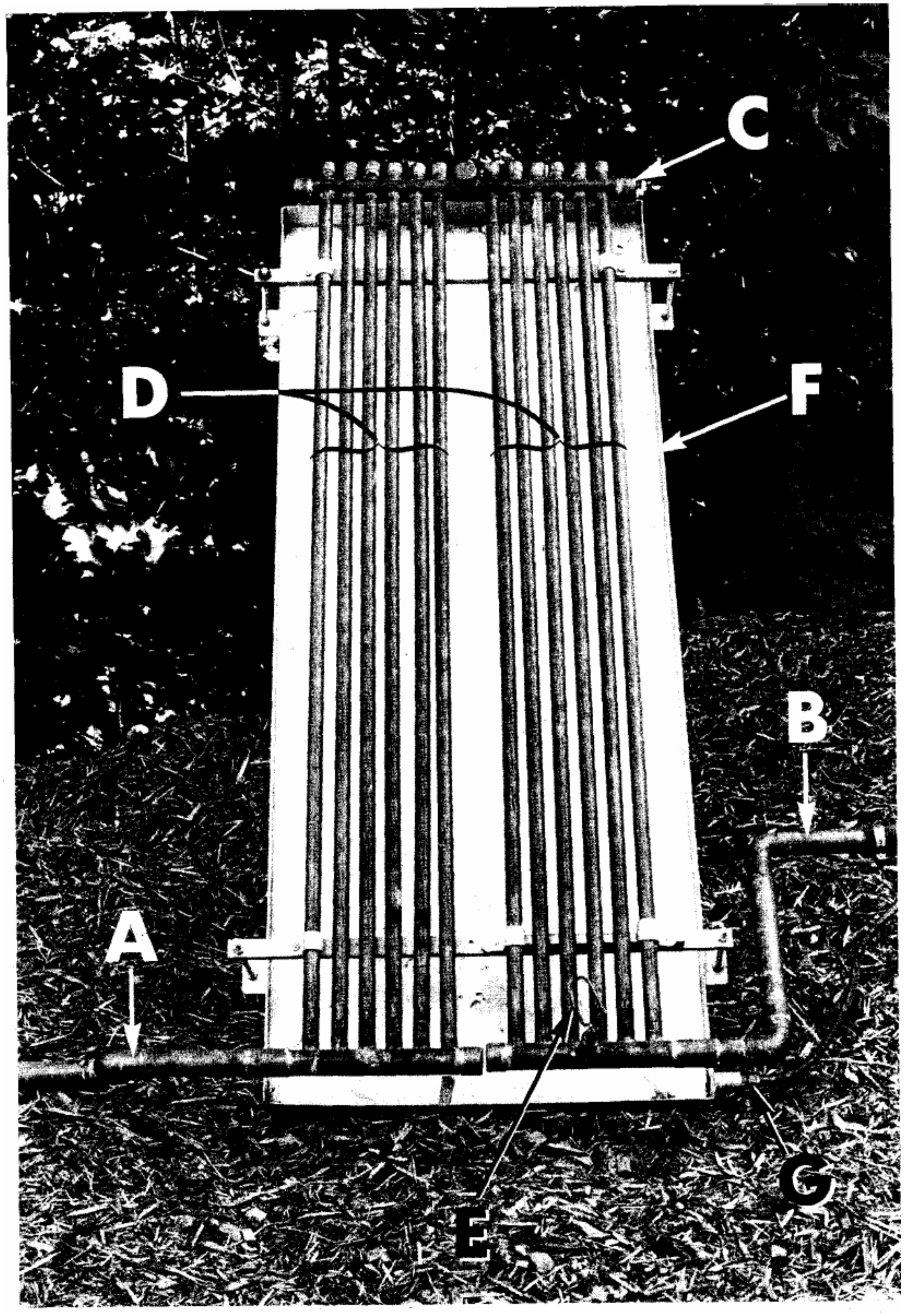


Figure 1. An experimental design of the parallel flow heat exchanger showing: A) sap inlet, B) sap outlet, C) connector manifold, D) tube bundles, E)pressure release tube, F) drip pan, and G)drip pan drain.

Table 1. Effect of series flow sap preheater on the efficiency of a test maple syrup evaporator.*

Test unit without sap preheater			Test unit with sap preheater			
Oil	Syrup (Gal/hr) (Lb/hr	Eff.	Oil (Gal/hr)	Syrup (Lb/hr)	Eff. (%)	Eff. (% gain)
10+		73.0	10+	36.6	82.0	12.3
10	31.2	72.9	10	37.0	84.5$	15.9
10	33.7	71.9	10	40.2	79.9	11.1
10	33.6	74.4	10	39.8	87.8	18.0
10	33.3	72.2	10	38.2	87.0	20.5
Average**	33.0	72.9		38.4	84.2	15.5
12	34.6	72.1	12	39.6	84.7	17.5
Average (All six tests)	33.3	72.8	10.33	38.6	84.3	15.8

* 4' x 10' oil-fired evaporator.

\+ Higher heating value 19,585 BTU/lb @ 7.12 lb/gal. t

\+ Thermal efficiency calculation (example):

$$= \frac{\text{BTU's transferred to water + BTU's to dissolved solids}}{\text{BTU's to burner}}$$

$$\frac{1.176 \times 10^6 + 2.00 \times 10^3}{1.394 \times 10^6} \quad \frac{1.178}{1.394} = 84.57$$

** Average efficiency difference increase owing to sap preheater:

$$\frac{84.2 - 72.9}{72.9} = 15.5$$

on economic considerations, for this evaporator at 350 gal/hr of sap flow would be 100 ft of 1" copper tubing.

Evaporator efficiency is closely related to pounds of water evaporated per pound of fuel input. This efficiency measure is given for each test. Had sap temperature and sap Brix been precisely the same for the four tests, pounds of syrup obtained would have been more closely aligned with water evaporated. The efficiency and gain is very obvious: a gain of 16-18 percent was recorded for the three sizes of preheater systems.

An important result of these tests is that increasing tubing lengths beyond a certain point does not provide substantial gains in efficiency.

DISCUSSION

Figure 2 illustrates the heat energy efficiency of a new maple syrup evaporator used for research purposes. The evaporator is fully insulated and operated at its maximum efficiency. Our research on the energy balance of the open-pan evaporator indicates that it does not transfer all of the BTU's per hour fed to the evaporator; 16 percent is lost up the stack as hot dry gas. Seven percent is lost to water

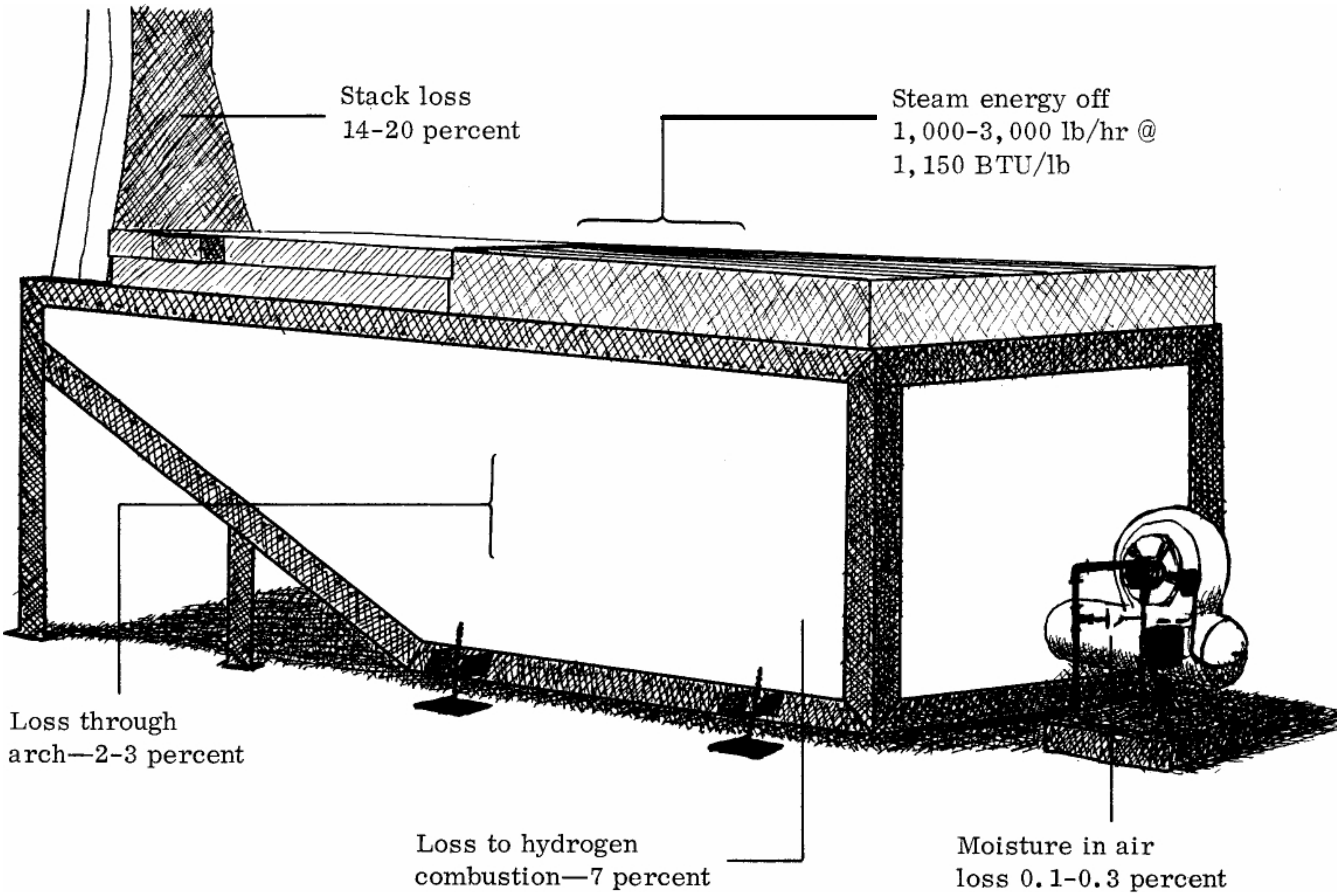
Table 2. Efficiency analysis of prototype parallel flow preheaters on a commercial maple syrup evaporator.

Preheaters	Sap (° Brix)	Sap Temp. (° F) Cold	Hot	Gallons sap/hr	Gallons syrup/hr	Lb H_2O evaporated /hr	Lb distillate /hr	Lb oil/hr	% efficiency Cold	Hot
Without heat exchanger	2.6	43.5	*	286.4	8.8	2,320.0	0	221.2	61.3	*
With heat exchanger										
76.8 ft of 1" tubing	3.3	32.7	163.5	346.3	12.8	2,686.0	375.4	222.51	71.4	16.5
134.4 ft of 1" tubing	3.4	36.2	194.4	350.5	14.5	2,713.0	439.8	222.51	71.9	17.4
190.0 ft. of 1" tubing	3.1	38.2	205.8	355.8	11.6	2,752.0	504.8	222.51	72.8	18.7

* Not applicable.

+ 19,551 BTU/lb.

t 19.519 BTU/lb.



Evaporator efficiency = 100-(16 + 2. 5 + 7. 0 + 0.2)
= 100-25.7 = 74.3

Figure 2. Schematic of conventional oil-fired maple syrup evaporator efficiency.

formed by combustion of the hydrogen in the fuel. Another 2.3 percent is lost to heat escaping through the arch and an insignificant amount, about .2 percent, is lost to moisture in the air causing additional stack lost.

Therefore, of the total heat energy available to boil sap, about 26 per-cent is not transferred to the sap. The evaporator is only about 73 per-cent efficient or it is only transfer-ring about 73 percent of heat energy directly to the sap for boiling. Tests of similar evaporators in commercial production have operating efficiencies of 45-65 percent.

The heat being transferred to the sap in our example is also leaving the evaporator as steam. Further, this heat is normally never used. However, some of it can and should be used to preheat the sap. The preheater will work on any evaporator, because most conventional evaporators will have a BTU steam heat yield above the pans of approximately 55-65 percent of the energy being fired to the evaporator by oil or wood.

Excess heat (steam) used to power preheaters

A heat exchanger, which is precisely what the sap preheater is, operates on the principle of heat transfer (Fig. 1.) Sap coming to the evaporator is normally 35-45° F. If this sap is fed directly into the evaporator pan, it requires a certain percentage of the oil or wood being fed to the evaporator to heat this sap to a boiling temperature of 212° F. The principle of the preheater is to use lost heat energy in the form of steam from the evaporator to heat the sap to approximately 190^0 F before it enters the evaporator.

Economics: Choice of reducing costs

The preheater system can be used to increase production or reduce fuel requirements. It cannot be used to do both. That is, we can expect that with the same oil requirements approximately 14 to 16 percent more syrup can be made with the sap preheater. However, we cannot expect to make more syrup on 15 percent less oil. Table 3 relates these facts more clearly.

Maple syrup processing costs have increased radically in the 1970's, causing processing costs to rise to a present $4.29/gal ; likewise, sap production costs have risen to $3.76/gal syrup equivalent, causing current total costs to equal $8.05/gal or $.73[1]/lb (2). The greatest increase in processing costs have been caused by increased fuel prices. No. 2 fuel oil in the Northeast has risen from $.28/gal in 1974 to $.48/gal currently.

Preheater fabrication

The surface area of tubing required for efficient preheating of sap depends upon three factors: (1) sap flow rate, (2) velocity of sap through the tubes, and (3) required inlet and outlet temperature of the sap. The tubes should be of high conductivity such as copper and must be compatible with food quality requirements.

Table 4 provides recommended specifications for fabrication of parallel flow preheaters. The specifications insure a heat transfer coefficient equal to or exceeding 200 BTU/hr per °F per sq ft of tubing surface area. Also, maximum head requirement for these designs is 2 ft.

A parallel flow preheater using 1" tubes is pictured in Fig. 1. The unit has 1½" manifolds connecting ten 1" tubes. Although boxed manifolds are presented, tubular manifolds were also used. Inlet and outlet piping from manifolds is always /" smaller in diameter , or 1¼" for the unit presented. A 6" long piece of 1/8" copper tube with a small petcock is located at the top of the outlet end of the preheater to prevent air entrapment in the unit. All tubes should be installed with a 2 percent slope to insure efficient

[1] Assumes 11 lb sap/gal syrup.

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Table 3. Effects of a sap preheater investment on a maple syrup operation's* annual cost.

Item	Unit Value	Use Life (years)	Without sap preheater (per gal syrup)	With sap preheater (per gal syrup)	
			Maintain production	Maintain production	Increase production 15%[0]
Sap production costs[+]					
Capital (Equipment)	$6,113		$1.34	$1.34	$1.34
Orchard rental ($.11/tap)			.44	.44	.44
Materials			.22	.22	.22
Labor @ $2.75/hr & 9.6 min/tap			1.76	1.76	1.76
Total annual sap production cost			$3.76	$3.76	$3.76
Processing costs					
Land	1,000	25	.15	.15	.13
Building	2,387	25	.35	.35	.31
Equipment	8,278	20	1.30	1.30	1.13
Sap preheater	877	20		.20	.12
Labor			.53	.46	.46
Fuel			1.92**	1.63	1.63
Other			.04	.04	.04
Total annual processing cost			$4.29	$4.13	$3.82
Total manufacturing costs			$8.05	$7.89	$7.58

* Assumes a 3,000 tap operation producing 25,800 gals of 2.5° Brix sap and 750 gals syrup; costs are 1977 market values.

\+ Sap production and processing costs from Huyler (2).

t Assumes 34.3 gal of sap equals 1 gal syrup.

** 1977 estimated price = 480gal.

\# Assumes a 15 percent increase in sap and syrup production of (25,800 x 1.15) = 29,670 gals. sap and (750 x 1.15) = 862 gals. syrup.

Table 4. Recommended specifications for fabrication of parallel flow preheaters for conventional evaporators.*

Sap flow (gal/hr)	Tube size (in.	Total length (ft)	Manifold size (in)	Tube spacing	Head (ft)	# tubes /bank	# banks	Stack diam. (in)	Inlet/outlet tube	tube slope %	Pressure relief tube (in)
50	3/4	20	1 1/4	1 3/4	1.2	6	1	6	1	5	1/4
130	3/4	48	1 1/4	2	1.3	8	1	8	1	5	1/4
370	1	105	1 1/2	2 1/4	1.5	12	1	12	1 1/4	5	1/4
500	1 1/4	106	1 3/4	2 1/4	1.7	8	1	14	1 1/2	5	1/4
1,00	1 1/4	212	2	2 1/4	2.0	16	2	16	1 3/4	5	1/4

* The above sizes are recommended on the basis of keeping the head required (distance of bottom of the sap storage tank above the preheater) to as small a dimension as possible, of providing a surface area on the preheater sufficient to heat the sap to 190° F, and of providing a steam stack adequate to carry off the excess steam with no condensation in the stack.

operation.

Sap preheaters are designed so that cold sap enters at a low point and travels up a slight slope, where it's taken out hot. This design permits the operator to have a full liquid load in the tube bundle and vent the tube bundle at the high point where hot gases would naturally accumulate. In effect, the system works with the natural state of gases, which separate from sap when heated and expand and can cause a vapor lock.

Head requirement--or the difference in height between the preheater and the sap source-- is critical both in design and installation of the preheater (Table 3). Sap moves from the tank to the regulator box by gravity. The greater the head, the greater the pressure. The plumbing from the sap tank to the preheater should not restrict flow. This is also true of the connection from the preheater to the regulator box.

Some producers have little chance to increase head because of built-in storage. As such, it is possible that a series flow preheater with many bends and small diameter tube could produce such marginal flow as to cause inefficient production and possibly even burn the pans. The parallel flow system in Fig. 2 is specifically designed to minimize pressure reduction. It will, therefore, accomodate systems that have minimum differences in sap tank and regulator box sap surface. See Table 3.

Closefitted hood

To operate effectively, a preheater must be enclosed in a relatively closefitted hood. Steam currents within the hood are in constant motion, which will permit cold air movement into the hood if the hood is not fairly tight. Air entrapped around the tube bundle could severely decrease heat transfer and the efficiency of the heat exchanger.

The tube bundle should accomodate a sap flow equivalent to 1½ times the normal flow rate of the evaporator. This is to allow any necessary rapid increase in flow should hot spots develop in the pan or a need arise to rapidly increase sap flow.

The vent noted in Fig. 1 occurs at the outlet side or the upper end of the sloped tube bundle; the vent permits the emission of entrapped gas and, therefore, prevents vapor locking of the tube bundle system. This gas vents directly into the hood along with a very small flow of heated sap, which also passes through the vent and into the pan.

Condensate is yet another factor that affects efficient operations of the preheater. For every 980 BTU's of energy transfer from steam to sap, a pound of condensate collects on the tube bundle. If the condensate is permitted to drip back into the pans, direct heat from the oil burner must re-evaporate this water. If this occurs, the preheater's efficiency is significantly reduced. The condensate must be collected in a drip pan as shown in Fig. 2 and taken out of the hood by a tube. This condensate can be used as hot water for cleaning or other purposes.

A final factor necessary for efficient operation of a preheater system is damper control of positive pressure in the hood. This permits the operator to entrap steam around the tube bundle and maximize heat transfer. The positive pressure is maintained by a simple damper in the hood stack (Fig. 2). Regulation for proper opening is determined by closing the damper gradually during a full boil. When whiffs of steam emit from the base of the hood, the proper pressure is being maintained.

SUMMARY

The steam normally lost from the boiling of maple sap can be used to preheat the sap as it enters the evaporator. A gain in evaporator efficiency of nearly 16 percent can be expected from a properly designed preheater and steam hood.

This efficiency gain can be used to decrease costs for the amount of sap the producer currently processes. Or the producer may choose to enlarge his operation.

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