INCREASING THE EFFICIENCY OF MAPLE SAP EVAPORATORS WITH HEAT EXCHANGERS

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ABSTRACT

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A study of the engineering and economic effects of heat exchangers in conventional maple syrup evaporators indicated that: (1) Efficiency was increased by 15 to 17 percent with heat exchangers; (2) Syrup produced in evaporators with heat exchangers was similar to syrup produced in conventional systems in flavor and in chemical and physical composition; and (3) Heat exchangers reduce per unit production costs, and can yield greater production and higher profits.

INTRODUCTION

TRADITIONALLY, thermal evaporation techniques have been used in producing maple syrup. In fact, the basic principle has changed little in 200 years. Indians made incisions along the trunks of maple trees, and caught sap in bark or clay receptacles. They put the sap in a hollow tree trunk, and boiled it by dropping heated stones into the sap. The early colonists substituted a wooden spout for the reed or bark spout, and iron or copper kettles for tree trunks. Boiling the sap outdoors gave way to boiling indoors, usually in the woodshed. Kettles were later placed on arches, and iron pans were substituted for the kettles (Nearing and Nearing 1950); eventually the iron pan gave way to today's evaporator.

Modern evaporators are heated by fuel oil, solid round or split wood, or natural or propane gas; these systems differ only in the design of the firebox and the pan (Willits 1965).

The choice of fuel depends on the availability, price, and effect of the fuel on the efficiency of an evaporator. Oil has been used by most of the larger operators, but the current energy crisis has severely affected its availability and price.

Solid wood has been used by small operators because of its availability at a lower cost on the farm. However more labor is required for firing, and the moisture content of wood varies; so wood is not always as efficient as oil or gas.

The least used fuel, gas offers the greatest efficiency in pounds of steam produced per unit of heat. Gas is used mostly for firing syrup finishing pans, but its high price and limited availability in maple producing regions have minimized its use.

There have been other attempts to increase the efficiency of the evaporator system. The most accepted modification is the evaporator hood. The hood prevents steam from building up in the sugarhouse, and foreign material from entering sap and syrup pans. The use of oil fuel guns, gas pressure nozzles, and improved insulating materials has also helped increase efficiency.

An innovation that increases the efficiency of conventional evaporators significantly is the heat exchanger. The exchanger uses steam that would have been lost in the evaporation process to preheat incoming sap. This energy can raise the temperature of cold sap (40°F) in the tube bundle to about 190°F. Previous attempts to preheat sap with heat exchangers have been ineffective because these exchangers were poorly designed.

Raithby (1974) developed a well-designed heat exchanger that incorporated the tube bundle into a hood. A drip pan was added so that water that condensed on the tubes would not drip back into the sap pan. In Raithby's tests with an oil-fired evaporator, efficiency was increased by 15 percent.

The purpose of this study was to:

- Analyze the energy loss in a conventional open-pan evaporator heated by fuel oil.
- Demonstrate how a preheater affects this energy loss in increasing operating efficiency.
- Evaluate the effect of a heat exchanger on the quality of the product.
- Develop and test a prototype exchanger that can be readily built by a manufacturer or producer.
- Analyze the heat exchanger as a capital investment.

METHODS

Test Evaporators

Two identical Grimm[1] evaporators systems were compared in a laboratory to determine the increase in efficiency after a heat exchanger

[1]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

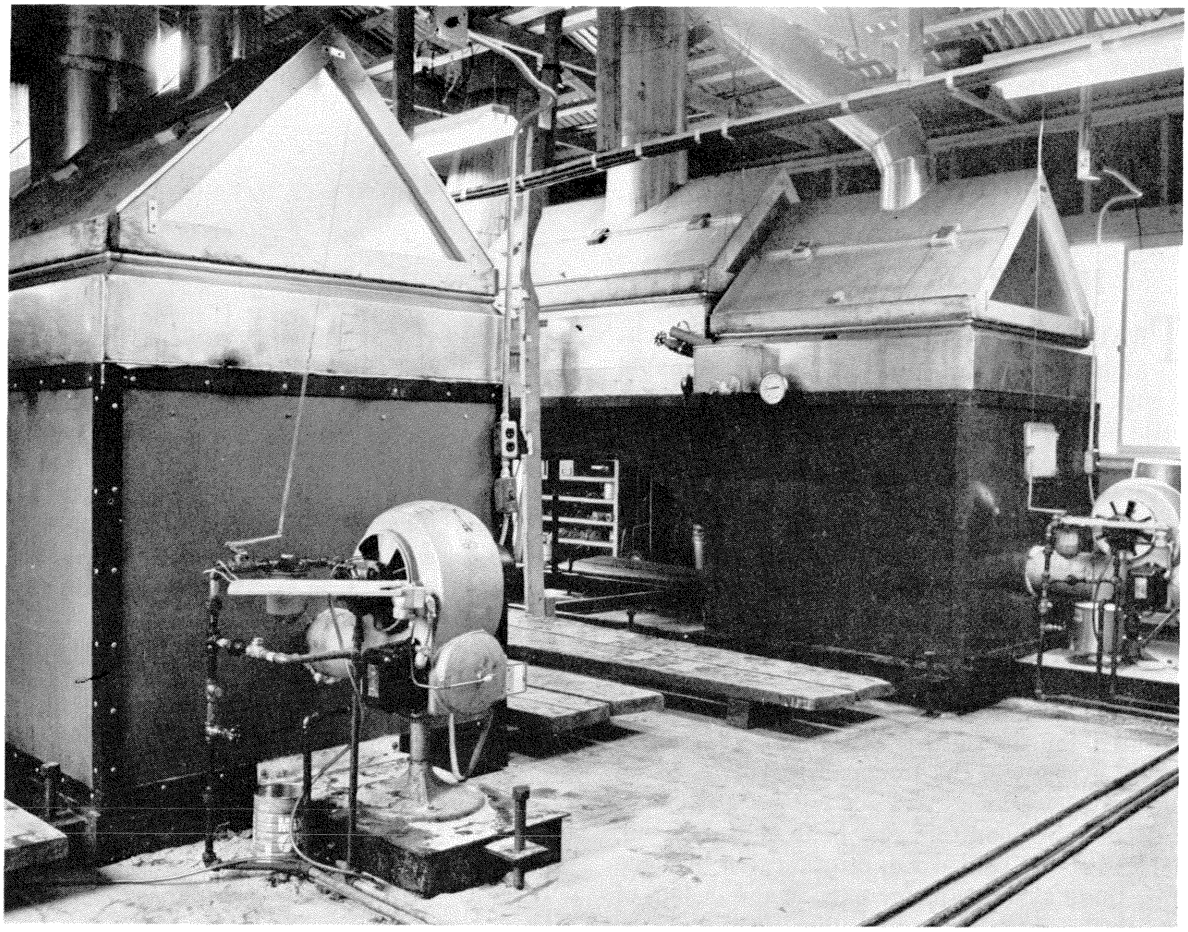


Figure 1.—Identical 4- by 10-foot Grimm evaporators used in lab tests to determine efficiency with and without a heat exchanger.

(series flow) had been installed on one of the units (Fig. 1). These results were verified by comparing the efficiency of a Lightning evaporator—with and without a heat exchanger (parallel flow prototype)—during an actual operation.

The two 4- by 10-foot oil fired, open-pan Grimm evaporators were original factory equipment, and were installed to manufacturer's specifications. These evaporators were fully insulated, and were fired by identical oil burners; each oil burner was equipped with two 5-gallon-per-hour nozzles. Each evaporator was factory rated at 175 gallons of 2.5°Brix sap per hour; the manufacturer's energy efficiency rating for each unit was 75 percent.

The 6- by 19-foot Lightning evaporator was 10 years old and was in an average state of repair; insulation was poor to average. This evaporator was fired by four oil burners, two under the front or syrup pan, and two under the back or sap pan. A total of 31 gallons of fuel was fired per hour.

Experimental Heat Exchangers

The initial series flow heat exchanger that we designed was encased in a hood, and was installed over the 4- by 6-foot sap pan on one of the Grimm evaporators (Fig. 2). A total of 36 feet of 1-inch copper tubing, connected in series, comprised the tube bundle. The hood was a 1/16-inch aluminum sheet, and was constructed so that it was as air-tight as possible. A drip pan and transfer tube were used to collect water that condensed on the tube bundle.

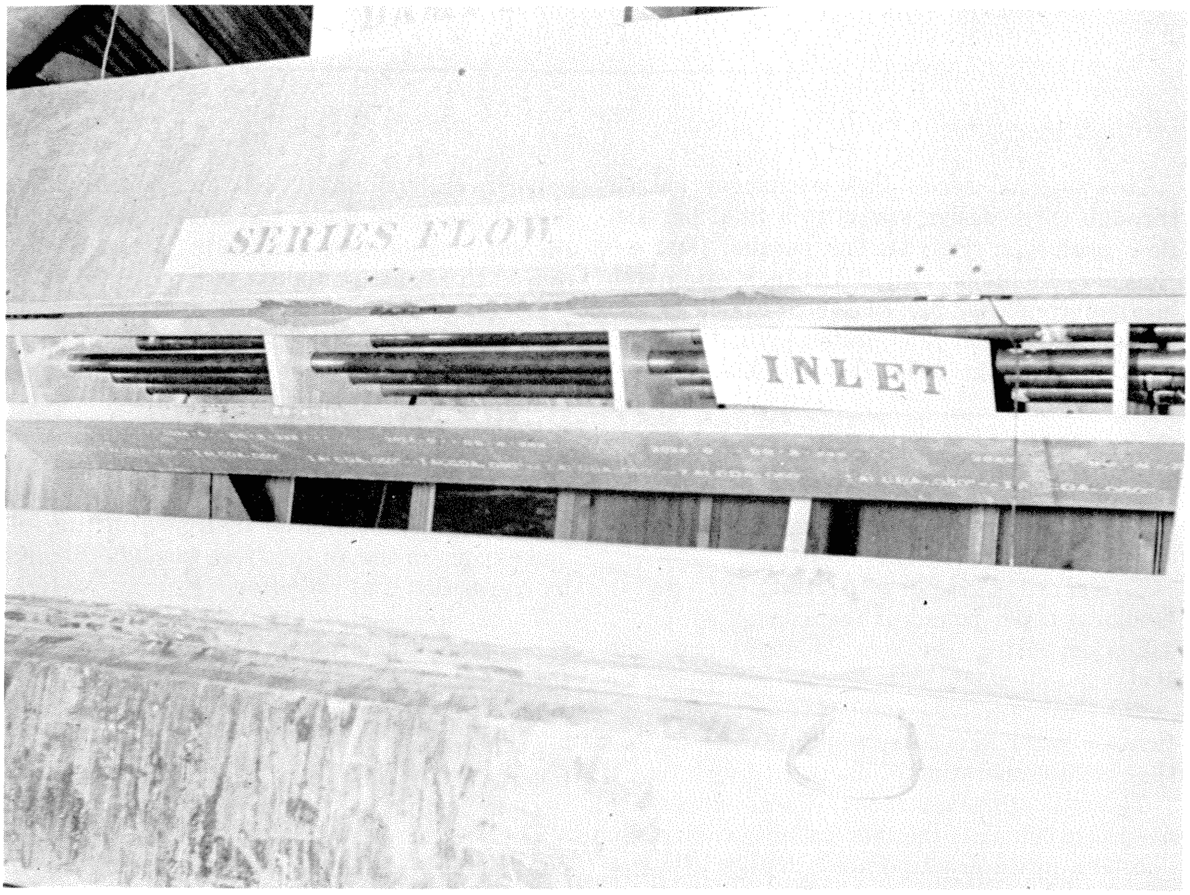
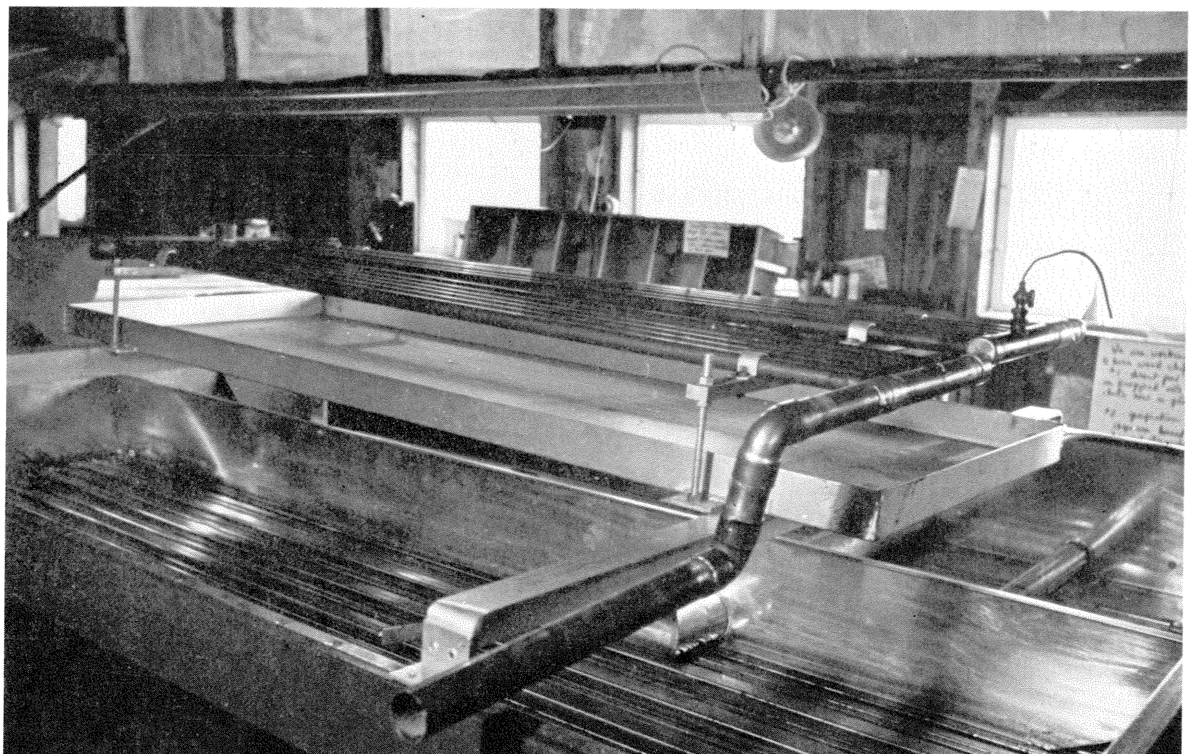


Figure 2.—Series flow heat exchanger designed for a 4- by 6-foot flue pan.

Figure 3.—Experimental parallel flow heat exchanger designed for a 4- by 6-foot flue pan.



This original series flow exchanger passed through three design stages to a final parallel flow prototype (Fig. 3). The parallel flow exchanger included two 1-1/4-inch diameter headers connected by twelve 3/4-inch copper tubes; the parallel flow prototype had a wider drip pan than the series flow exchanger.

Determining Evaporator Efficiency

The efficiency of an open-pan evaporator is determined by:

1. Calculating the pounds of water evaporated per pound of fuel consumed, or;
2. Computing the energy loss from the system.

The first procedure establishes a thermal efficiency ratio; the latter identifies the factors that reduce operating efficiency.

Thermal efficiency ratio.—Three values are needed to calculate the thermal efficiency ratio:

1. Btu in water evaporated: Pounds of water evaporated per hour times Btu required to vaporize each pound (1042.3); plus pounds of sap heated per hour times the difference between the sap temperature and 212°F; times Btu required to raise 1 pound of water 1°F (970.3).
2. Btu in syrup produced: Pounds of syrup per hour times Btu transferred to each pound.
3. Btu in fuel: Btu per pound of fuel times the number of pounds used per hour.

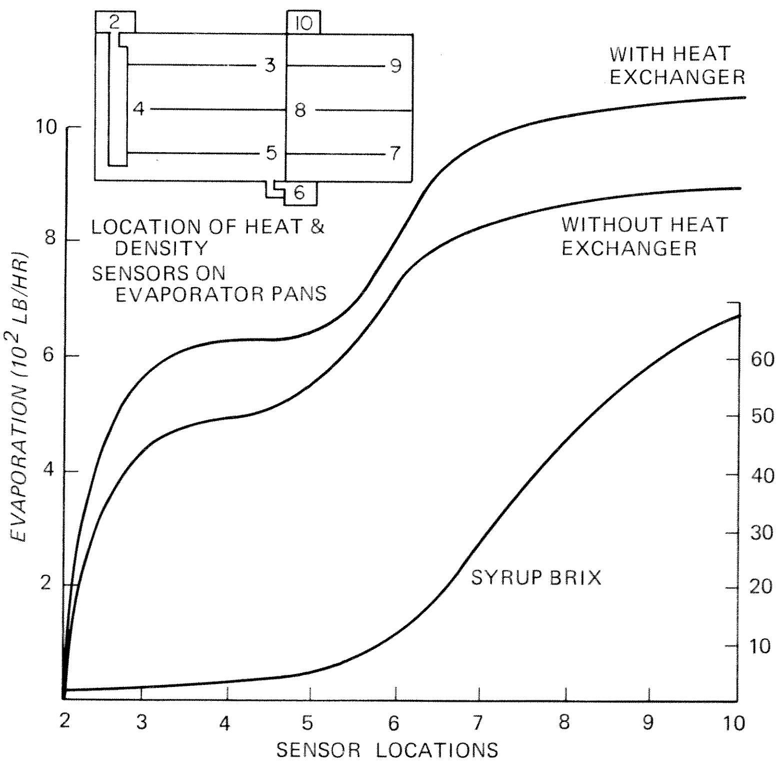
Energy loss.—The thermal energy loss from the evaporator system includes loss to stack gas; loss to incomplete combustion; loss to water formed by combustion of hydrogen in the fuel and oxygen in the air; and loss through the arch by convection and radiation.

These losses are usually expressed as a percentage of energy originating from the fuel; the efficiency of the evaporator is determined by subtracting this percentage from 100.

Location of Heat Exchanger

The steam released above the sap and syrup pans affords the greatest opportunity for increasing the efficiency of an evaporator. To

Figure 4.—Total accumulative evaporation and syrup Brix level at different locations in evaporator pan.



determine the best location for an exchanger, we measured the heat distribution (sap temperature and percentage of dissolved solids) at nine locations in the sap and syrup pans. Data indicated that the greatest amount of evaporation and heat transfer (45 to 50 percent) occur from the sap inlet to the center of the sap pan (Fig. 4); so this area above the sap pan was the best location for an exchanger.

There is relatively little heat transfer (7 to 10 percent) between the center of the sap pan and the sap pan outlet; an additional 25 to 30 percent of evaporation and heat transfer occurs between the syrup inlet and the center of the syrup pan. Seven to 10 percent occurs from the center of the syrup pan to the syrup pan outlet.

RESULTS

Evaporator Efficiency Without Heat Exchanger

Thermal efficiency ratio.—The Grimm evaporators (each without a heat exchanger) consumed an average of 71.16 pounds of fuel (8.9 gallons) per hour, and produced an average of 1029.9 pounds of evaporated water and 37.03 pounds of syrup. The Btu equivalent of the water evaporated and syrup produced was 1,-031,500, while the Btu equivalent of the fuel used was much larger, 1,394,000. The ratio $\frac{1.032}{1.394}$ equals .74; that is, 74 percent of the fuel energy was transferred directly to steam product. The efficiency ratio of the evaporator is: 1.35 pounds of steam produces 1 pound of water, $\frac{1}{.74} = 1.35$.

Energy loss.—Five 3-hour tests (Table 1) indicated that losses of energy in both evaporators (without heat exchangers) averaged about 26 percent. The major loss of energy was to stack gas, 16.6 percent. Loss of energy to formation of water in the combustion process was 7.3 percent, and loss through the arch was 2.3 percent. A small loss, 0.19 percent, was due to incomplete combustion.

Efficiency With Heat Exchanger

Series flow.—In eight 3-hour tests, the efficiency of the Grimm evaporator with a series flow heat exchanger averaged 83.5 percent (Table 2); the efficiency of the evaporator without an exchanger averaged 72.9 percent. Four tests were run on each unit; 10 gallons of No. 2 fuel oil were fired per hour, with a higher heating value of 19,585 Btu per pound. The higher heating value is the expected yield of Btu per pound of fuel for a particular type of fuel and evaporator system.

The average increase in evaporated water due to the heat exchanger was 14 to 15 percent; the average increase in syrup production was 16.7 percent. An increase in syrup production is not an accurate measure of efficiency because it varies with the sugar content of sap.

We encountered problems in testing the series flow unit; repeated surging in the tube bundle indicated that air was trapped in the bundle, causing air locks and restricing flow. So it was necessary to increase the "head", or the vertical distance between the sap tank and the regulator box.

Parallel flow.—Four 10-hour tests of the

Table 1.—Energy loss and efficiency for two 4- by 10-foot oil-fired maple syrup evaporators (in percent)

Energy lost to:	Test 1	2	3	4	5	Average
Stack gas	15.10	14.80	17.30	16.90	19.20	16.66
Hydrogen combustion	7.60	7.20	7.10	7.50	7.30	7.34
Incomplete combustion	.14	.16	.20	.30	.18	.19
Arch	2.30	2.30	2.30	2.30	2.32	2.30
Total	25.14	24.46	26.90	27.00	29.00	26.49
Efficiency	74.86	75.54	73.10	73.00	71.00	73.51

Table 2.—*Effect of series flow heat exchanger on syrup production and efficiency of 4- by 10-foot oil-fired maple syrup evaporator* [a]

Test	Syrup production		Efficiency	
	Without exchanger	With exchanger	Without exchanger	With exchanger
	lb./h		*Percent*	
1	31.2	36.6	72.9	82.0
2	33.7	37.0	71.0	84.5
3	33.6	40.2	74.4	79.9
4	33.3	39.8	72.2	87.8
Average	32.9	38.4	72.9	83.5

[a] 10 gallons of oil fired per hour.

Table 3.—*Efficiency analysis of parallel flow heat exchanger on a commercial maple syrup evaporator*

Item	Without exchanger	With exchanger (tubing length)		
		76.8 feet	134.4 feet	190.0 feet
Sap				
Sugar content (°Brix)	2.58	3.32	3.36	3.09
Temperature				
Cold (°F)	43.50	32.70	36.20	38.20
Hot (°F)	—	163.50	194.40	205.80
Flow (gal/h)	286.41	346.32	350.46	355.83
Syrup produced (gal/h)	8.79	12.77	14.49	11.56
Water evaporated (lb/h)	2,320	2,686	2,713	2,752
Distillate (lb/h)	—	357.44	439.82	504.79
Oil (lb/h)	221.19 [a]	222.49 [b]	222.49 [b]	222.49 [b]
Average efficiency (%)	61.2i	71.39	71.93	72.75
Average increase (%)	—	16.49	17.37	18.72

[a] 19,551 Btu/lb.
[b] 19,519 Btu/lb.

Lightning evaporator, with and without a parallel flow heat exchanger, indicated that efficiency with the exchanger increased by an average of 17.52 percent (Table 3).

The parallel flow exchanger seemed to offer solutions to:

- Tubing size: The manifold design should allow manufacturers to increase the tube surface by adding more tubes of the same diameter. This can result in cost savings to the manufacturer and the producer; the problem of changing design specifications for different evaporators is minimized.
- Head requirements: Because of the manifold design, there is less flow restriction and, therefore, less head requirement. A producer who uses a series flow design may be forced to use larger tubing or elevate the sap tank, or both.
- Hoods: Alteration of the low profile steam hood is not required with a parallel flow exchanger.

Vapor locking can be prevented in both the series flow and parallel flow systems if a suitable vapor vent is used.

Testing the Parallel Flow Heat Exchanger

The prototype parallel flow heat exchanger was designed so that we could simulate an undersized unit, a properly sized unit, and an oversized unit. Only 76.8 feet of tubing was used for the undersized unit; tubing length was increased to 134.4 feet and 190.0 feet for the properly sized and oversized units, respectively. Increasing the amount of tubing by 250 percent (76.8 feet to 190.0 feet) increased efficiency only by 1.36 percent (Table 3); beyond a given point, any increase in the surface area of the tube bundle only increased its cost.

As part of the efficiency analysis, we calculated the total pounds of distillate produced per hour; this is a crude measure of pounds of steam condensed by the heat exchanger and, therefore, Btu transferred to sap. This is shown in Table 3 when pounds of water evaporated are compared with pounds of distillate produced with different exchangers. Using the undersized unit, 2,686 pounds of water were evaporated per hour. From this evaporated water, 357.44 pounds of distillate was produced, or 13.3 percent of total evaporation. Increasing the size of the heat exchanger by 250 percent increased total distillate only to 504.79 pounds, or 18.3 percent of the water in the escaping steam.

Specifications for Parallel Flow Exchanger

The surface area of tubing required for efficient preheating of sap depends on the flow rate of sap, velocity of sap through the tubes, and the required inlet and outlet temperature of the sap. The tubes should be of a highly conductive material such as copper, and they must not affect food quality.

The surface area required for a parallel flow system with a constant heat transfer coefficient is a function of sap flow (Fig. 5). On the basis of our tests, we found that a heat transfer coefficient of 200 Btu per hour, per square foot of surface area, is acceptable for raising the temperature of the sap from 40 to 190°F. The size and length of tubing required to maintain a heat transfer of 200 Btu is shown for five flow rates in Table 4.

Heat exchangers can be constructed to increase the flow rate of sap. This is done by adding more tubes, or by increasing the tube size.

Figure 5.—Length of tubing required for parallel flow heat exchangers using different tube diameters at different flow rates.

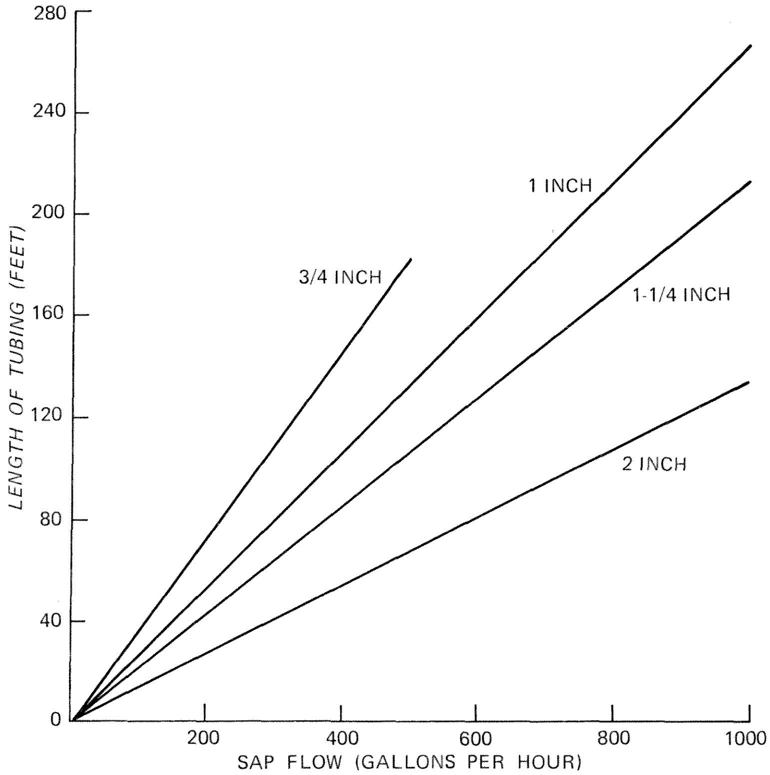


Table 4.—*Specifications for parallel flow heat exchanger on conventional evaporator* [a]

Sap flow (gal/h)	Tube size	Tube length	Manifold	Lateral spacing of tubes	Head	Number of banks	Number of tubes per bank	Diameter of hood stack [b]	Inlet and outlet tube
	Inches	*Feet*	--------- *Inches*	---------	*Feet*			---------*Inches*	-------
50	3/4	20	1 1/4	1 3/4	1.2	1	6	6	1
130	3/4	48	1 1/4	2	1.3	1	8	8	1
370	1	105	1 1/2	2 1/4	1.5	1	12	12	1 1/4
500	1 1/4	106	1 3/4	2 1/4	1.7	1	8	14	1 1/2
1,000	1 1/4	212	2	2 1/4	2.0	2	16	16	1 3/4

[a] Tube slope of 2 to 5 percent, and 1/4-inch pressure relief tube for all flow rates.
[b] With damper.

To maintain the same heat transfer, greater lengths of smaller tubing are required. For example, 48 feet of 3/4-inch tubing is required for a sap flow of 130 gallons per hour. If 1-inch tubing is used, only 35 feet are required.

A parallel flow heat exchanger using 1-inch tubes is shown in Figure 6. The unit has 1 1/2-inch manifolds connecting ten 1-inch tubes. Although boxed manifolds are shown, tubular manifolds were also used. The diameter of inlet and outlet piping from manifolds is always 1/4 inch smaller than the manifold, or 1 1/4 inches for the unit shown. A 3-inch curved copper tube (1/4-inch inside diameter) located at the top of the outlet end of the heat exchanger will prevent air from becoming trapped in the unit. All tubes should be installed with a 2- to 5-percent slope to ensure efficient operation. Head requirements for series and parallel flow exchangers using different tube diameters are shown in Figure 7.

An additional attribute of the prototype parallel exchanger is its adaptability. This heat exchanger is designed to be suspended from the inside of any hood, or to be freestanding above the sap pan.

A final modification that improves the operation of this heat exchanger is a damper. The damper assembly is installed in the stack, 18 inches above the ridge of the hood, so that a slight positive pressure is maintained in the hood. The pressure prevents cold air from leaking into the hood and around the tube bundles, which can

Figure 6.—A commercial design of the parallel flow heat exchanger design show: a) Sap inlet; b) Connector manifold; c) Tube bundle; d) Pressure release tube; e) Drip pan; f) Drip pan drain; g) elevating rods; h) Sap outlet.

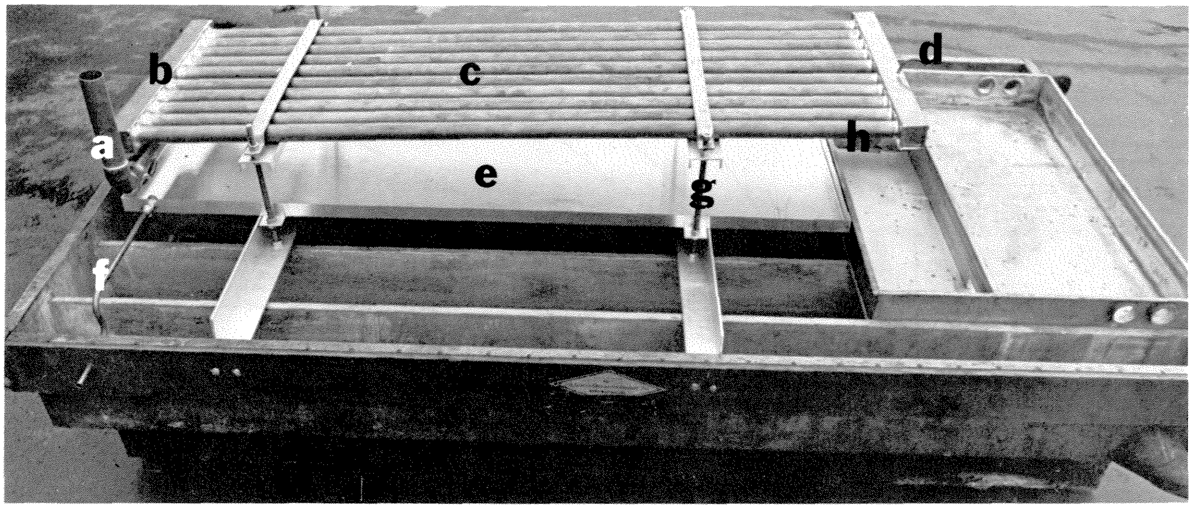
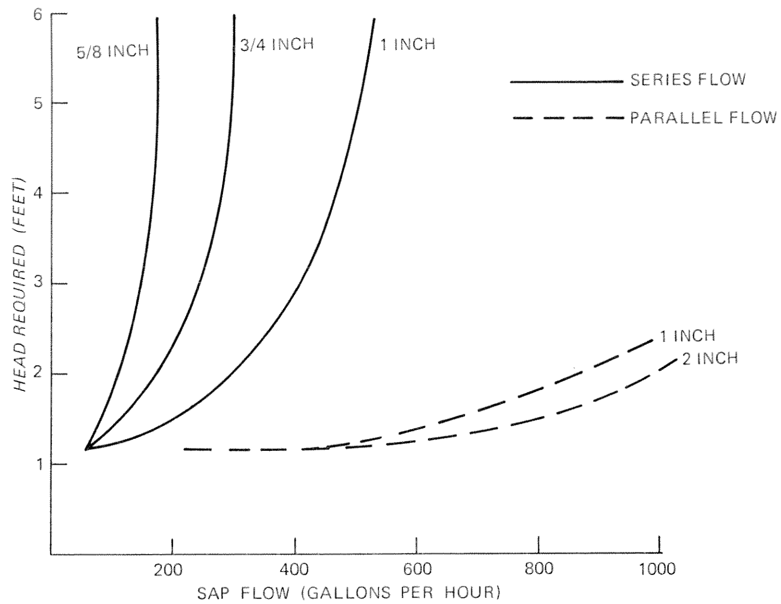


Figure 7.—Head requirements for series and parallel flow heat exchangers using different tube diameters.



reduce efficiency significantly. The damper can be adjusted properly by closing it until a whiff of steam is emitted from the hood base.

Effect of Heat Exchanger on Quality of Syrup

The preheating of sap differs only slightly from the normal treatment of sap in the evaporation process. Heat is applied through a contact vessel made of copper rather than English tin or stainless steel. Analysis of syrup produced with and without a heat exchanger indicated that preheating had no significant effect on the physical or chemical properties or the flavor of the syrup (Table 5). We expected that some copper might be leached from the surface of the tubes, but tests showed that the copper content of the syrup from evaporators with and without the exchanger was virtually identical.

A second question concerned the effect of deposits in the heat exchanger tubes on syrup quality over time; but an analysis of deposits from tubes used to preheat 15,000 gallons of sap showed that the deposits were the same as those that usually occur as scale in the evaporator pan.

ECONOMIC RETURN FROM HEAT EXCHANGER

There are many ways to analyze a capital investment such as a heat exchanger; we demonstrated the effect of the exchanger on the annual net profit of a typical maple producer. Let's first look at this typical operation and its mix of costs and revenues.

Manufacturing Costs

Huyler's 1974 economic analysis of sap collection systems showed that the average annual cost of getting 35 gallons of sap to the sugarhouse is $3.36.[2] Stated differently, the cost of producing a gallon of 2.5°Brix sap and delivering it to the sugarhouse is approximately $0.10.

Huyler's[2] analysis of processing costs showed an average annual cost of $2.96 in processing 35 gallons of 2.5°Brix sap to produce 1 gallon of 66.5°Brix syrup. These costs would be incurred by an operator producing approximately 750

[2]Huyler, Neil K. 1976. Cost and return estimates for maple syrup operations. Unpublished report. Data on file at George D. Aiken Sugar Maple Laboratory, Burlington, Vt. 05401.

Table 5.—*Analysis of pure maple syrup processed in conventional evaporator with and without a heat exchanger*

Statistic	pH	Sugar concen-tration	Invert sugars	Phenols	Amino nitrogen	Mineral salts				Light trans-mittance [f]
						Fe	Zn	Pb	Cu	
		------Percent-----				--------------ppm-------------				
				WITH HEAT EXCHANGER [a]						
Mean (x)	6.925	66.1	0.36	779.33	159.92	1.025	3.958	0.292	0.68	591.67
Standard deviation (SD)	.503	.847	.182	270.41	45.39	.615	1.13	.505	.162	281.90
Variance (s^2)	.253	.718	.033	73122.33	2060.45	.378	1.277	.255	.026	79469.70
				WITHOUT HEAT EXCHANGER [b]						
Mean (x)	7.23	65.01	.27	679.87	150.40	1.18	3.74	.380	.614	432.13
Standard deviation (SD)	.40	1.75	.204	156.57	53.98	.96	.837	.487	.174	246.12
Variance (s^2)	.16	3.08	.042	24513.27	2913.83	.93	.701	.237	.030	60573.98
Degrees of freedom [c]	25	25	25	25	25	25	25	25	25	25
t value [d]	2.060	2.060	2.060	2.060	2.060	2.060	2.060	2.060	2.060	2.060
Computed t	1.781 [e]	1.976 [e]	1.203 [e]	1.205 [e]	.488 [e]	.483 [e]	.577 [e]	.460 [e]	1.008 [e]	1.569 [e]

[a] 12 samples.
[b] 15 samples.
[c] $n_1 + n_2 - 2$; $12 + 15 - 2 = 25$.
[d] t value at 10 percent level of confidence.
[e] Not significant.
[f] 560 nanometers with 1 cm cell.

gallons of syrup per year from 25,800 gallons of sap.

However the above costs have increased radically since 1974; the processing cost has increased to $4.29 per gallon, and the sap production cost has increased to $3.76 (Table 6). Current total manufacturing costs are $8.05 per gallon, or $0.73 per pound. The greatest increase in processing costs is due to increased fuel prices. The price of No. 2 fuel oil in the Northeastern and North Central U.S. rose from $0.28 per gallon in 1974 to $0.48 per gallon in 1977.

Approximately 4 gallons of oil are used in processing 1 gallon of syrup; so the cost of producing a gallon of syrup has increased by $0.80 since 1974 due to fuel alone. Equipment prices have increased by 15 percent per year, and labor and material cost increases have averaged 8 percent per year, with additional increases of at least 6 percent per year expected over the next 2 years.

Most new technology offers a firm an option; it can use the technology to reduce costs or to increase production. Generally, the overall impact of new technology is greater if it is used to expand production.

Reducing Costs

A heat exchanger reduces labor and fuel requirements if used to reduce costs, and if syrup production is maintained at the same level. An analysis of a firm producing 750 gallons of syrup shows that the use of a heat exchanger increases capital costs but reduces labor, energy, and miscellaneous costs; the exchanger increases the hourly evaporation rate and syrup production by about 15 percent, thus reducing processing time.

A reduction in labor and energy requirements reduced processing costs by $0.16 for each gallon of syrup produced; there was no reduction in sap production costs. The total cost of producing 750 gallons is $7.89 per gallon versus $8.05 without a heat exchanger (Table 6).

Increasing Production

Greater savings can be realized if new technology is used to increase production. When a heat exchanger is used, production can be increased without increasing the size of the plant. When production is increased, total costs are increased, but more syrup is produced; so the cost per gallon is reduced.

Table 6.—*The effect of a heat exchanger on annual costs of maple syrup production* [a]

Item	Unit value	Useful life	Annual cost without heat exchanger (per gallon of syrup) [b]	Annual cost with heat exchanger (per gallon of syrup)	
				Maintain production	Increase production 15%
	Dollars	*Years*	*Dollars*		
Sap production costs:					
Equipment	6,113.00	—	1.34	1.34	1.34
Orchard rental ($0.11/tap)	—	—	.44	.44	.44
Materials	—	—	.22	.22	.22
Labor ($2.75/h and 9.6 min/tap)	—	—	1.76	1.76	1.76
		Total	3.76	3.76	3.76
Processing costs:					
Land	1,000.00	25	0.15	0.15	0.13
Building	2,387.00	25	.35	.35	.31
Equipment	8,278.00	20	1.30	1.30	1.13
Heat exchanger	877.00	20	—	.20	.12
Labor	—	—	.53	.46	.46
Fuel	—	—	1.92	1.63	1.63
Other	—	—	.04	.04	.04
		Total	4.29	4.13	3.82
	Total manufacturing costs		8.05	7.89	7.58

[a] Assumes a 3,000 tap operation producing 25,800 gallons of 2.5° Brix sap and 750 gallons of syrup (costs are 1977 market values).
[b] Assumes 34.3 gallons of sap equals 1 gallon of syrup.
[c] Assumes a 15 percent increase in sap and syrup production (25,800 X 1.15 = 29,670 gallons of sap; 750 X 1.15 = 862 gallons of syrup).

To increase production, more sap is needed from the woods; to match the 15 percent increase in syrup production, attainable by adding a heat exchanger, the number of taps must be increased by 15 percent. Although it is conceivable that a 25 to 50 percent increase in the number of taps would gain a significant economy of scale, and therefore, lower the sap cost, a 15 percent increase is not likely to lower the cost per tap (Huyler 1975; Gunter and Koelling 1975). So the cost per gallon on sap produced remains the same (Table 6).

Syrup processing costs will increase, but only in the amount of the amortized costs for new equipment (heat exchanger). The annual amortized cost of an exchanger for a 3,000-tap bush is $103. However, this cost is allocated to a larger production base of 862 gallons of syrup (750 X 1.15). Therefore the total annual cost per gallon of syrup is reduced to $7.58 or $0.69 per pound; unit costs are reduced by $0.39 per gallon, or by 6 percent, and total manufacturing costs are reduced by 3 percent.

CONCLUSIONS

The use of a heat exchanger improved the efficiency of the open-pan evaporator:

- In the evaporators that operated at 74 percent efficiency, 16.6 percent of the energy loss was to stack gas. Research is needed to reduce the energy loss from this source.
- When sap was preheated, the efficiency of the evaporator was increased by 15 to 17 percent.
- A parallel flow heat exchanger is more versatile than a series flow exchanger because it is easily vented, the tube surface area can be increased more easily for larger evaporators, one size of tubing can be used for units of any size, and head restrictions can be accommodated easily.
- The use of a heat exchanger does not affect the quality of syrup.
- When a heat exchanger is used, processing costs can be reduced by 6 percent, and total costs by 3 percent, without increasing the size of the plant.

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