Recommendation

Install a heat exchanger to recover heat on the discharge streams from the juice resin columns. This recovered energy can be used to preheat the incoming water used to clean the same columns, which will save 5.4% of boiler fuel usage.

Annual Savings Summary

Source	*Quantity*	*Units*	*Cost Savings*
Natural Gas	5,382	MMBtu	$53,820

Implementation Cost Summary

Description	*Cost*	*Payback*
Implementation Cost	$22,612	0.4

Facility Background

The facility currently has six resin exchange columns. These are primarily used to remove unwanted compounds from the juice being produced, especially those associated with color. At any given time, two of these columns are being used, two are being cleaned/regenerated, and two are on standby. The flow rates through these columns is variable (30 - 150 gallons per minute). However, we were informed that the flow rate averages around 70 GPM and is always flowing during light juice processing: four to five months a year during operating hours. The water used for cleaning can be pure, slightly acidic, or slightly caustic depending on the cleaning required. Prior to cleaning, the water is heated either directly or indirectly by the boiler. The temperature of the water being discharged from the columns after cleaning was measured at 153 °F while inlet water temperature from the city was right around 50 °F.

Technology Background

A heat exchanger installed on site would allow for the heat contained in the discharged cleaning water to be recovered. The hot fluid in the heat exchanger delivers heat to the cold fluid, flowing the opposite direction. The counter-current configuration allows for maximum heat transfer and simultaneously cools the hot fluid and heats the cold fluid. The heat could be used for any desired purpose at the facility. This would reduce the steam demand on the natural gas fired boiler and would also avoid any inefficiencies associated with the combustion process, effectively reducing natural gas costs.

Some of the most common heat exchange equipment is briefly discussed below.

Double-Pipe and Multiple Double-Pipe
In its simplest form, the double-pipe heat exchanger is simply a "tube inside of a tube". Modern industrial designs incorporate U-turns or hairpin turns inside the exchanger, where the flow in each section is essentially countercurrent. Double-pipe exchangers using traditional piping have limited applications but are useful where heat transfer magnitudes are small or where high pressures exist for both fluid streams.

Shell-and-Tube
There are many different possible design configurations for shell-and-tube heat exchangers. There is even a dedicated nomenclature that describes the specifics of the design, which has been put forth by TEMA (Tubular Exchanger Manufacturer's Association). Consult their documentation for more details regarding specific naming standards. The fixed-tube type is the most commonly used, with a simple and economic construction. The U-tube type exchanger is able to handle stresses due to thermal expansion, but the U shaped design makes cleaning more difficult. The U-tube design is similar in cost and performance to the fixed-tube type when operating at low pressures, but has significant performance increases when operating at high pressures. The only other major disadvantage with the U-tube design is that complete counterflow across the tubes is not achieved except with certain designs. The floating-head type of exchanger, where one end of the tube bundle is not attached to the shell and is free-floating, is a more robust design that is capable of handling the stresses associated with high temperatures and high pressures. Fabrication is more complex and takes longer than the simpler designs, and as a result the floating-head type exchangers are typically 25% more expensive for an equivalent heat transfer surface area.

Plate-and-Frame
A gasketed plate or plate-and-frame exchanger consists of a stack or a series of corrugated metal plates that are pressed together and held together by a frame and sealed. This forms an arrangement of narrow, interconnected passages that the fluids flow through. The hot and cold fluids pass through these channels in an alternating fashion and heat transfer occurs through the thin metal plate separating the two fluids. Overall surface area can be increased simply by adding more plates. The plates can be sealed with a rubber or other compressible material through simple compression, but this design fundamentally limits operational temperature and pressure limits. To circumvent this, the plates can be welded together but at the cost of creating a permanent exchanger that is much more difficult to clean, maintain, and adjust.

Other Designs
There are many other type of heat exchange equipment, which will be briefly summarized here. Scraped-Surface exchangers are used with highly-viscous, crystallizing, or heavily fouling materials, where a rotating blade periodically removes buildup from heat exchange surfaces. Spiral plate and tube heat exchangers are comprised of spiraled plates that form countercurrent flow passages, and are good for small scale, compact heat exchange requirements. Gas-to-gas exchangers are typically nothing more than arrangements of tubes or surfaces that maximize surface area to facilitate heat transfer for low density, low heat capacity fluids such as air and stack exhaust. Air-cooled exchangers are similar to the heat sinks found in computers and electronic devices, and consist of a finned surface with a fan forcing air flow across the fins. There are many heat exchanger types that are designed specifically for condensation and evaporation that are not discussed in detail here as the design of these processes is often more complicated than simple heat exchange without phase change.

Proposal

AR No. # - AR Name

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Install a counter-current heat exchanger on the discharge streams from the resin columns on the juice lines. This would allow for a significant portion of currently wasted heat energy to be recovered and used. We suggest using the recovered energy to preheat the water used to clean the resin columns. This set up would allow the resin columns to be partially self-sustaining, with the hot discharge water warming the incoming cleaning water. This recovered heat will reduce the energy consumption on the natural gas fired boilers by 5%, or 5,382 MMBtu per year. This results in an annual cost savings of $53,820 with an implementation cost of $22,612 for a payback of 0.4 years.

Based on	Data Collection	Author	Orange Team Review	Black Team Review
Original Template	*Insert Name* *Insert Name*	*Insert Name*	*Insert Name*	*Insert Name*

AR No. # - Data Preparation

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Heading 2

Heading 3

Heading 4	Variables	***Input***	Units	**(Rf. 1)**
Heading 4	Variables	***Input***	Units	**(Rf. 1)**
Heading 4	Variables	***Input***	Units	**(Rf. 1)**

Heading 2

Heading 3

Heading 4	Variables	***Calc***	Units	**(N. 1)**
Heading 4	Variables	***Calc***	Units	**(Eq. 1)**
Heading 4	Variables	***Calc***	Units	**(Eq. 2)**

Heading 3

Heading 4	Variables	***Calc***	Units	**(N. 2)**
Heading 4	Variables	***Calc***	Units	**(N. 3)**

Equations

Eq. 1) Equation 1 (V)

AR No. # - Analysis

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Data Collected

Flow Configuration

Counter-current

Flows

Condensate (Hot) Flow	($\dot{m}_H$)	*30,000*	lb/hr	**(N. 1)**
Auxillary Water (Cold) Flow	($\dot{m}_C$)	*30,000*	lb/hr	**(N. 1)**

Temperatures

Hot Fluid Inlet Temperature	($T_{H,i}$)	*168*	°F	**(N. 1)**
Cold Fluid Inlet Temperature	($T_{C,i}$)	*64*	°F	**(N. 1)**

Operating Conditions

Annual Operating Hours	(t_{OH})	*3,120*	hrs/yr	**(N. 1)**

Boiler Data

Annual Boiler Fuel Use		*100,000*	MMBtu	**(Rf. 1)**
Boiler Efficiency	(η_B)	*80%*		**(N. 1)**

Incremental Energy Data

Incremental Natural Gas Cost	(IC_N)	*$10.00*	/MMBtu	**(Rf. 1)**

Assumptions

Constants

Specific Heat (Hot Fluid)	(CP_H)	*1.00*	Btu/lb·°F	**(Rf. 2)**
Specific Heat (Cold Fluid)	(CP_C)	*1.00*	Btu/lb·°F	**(Rf. 2)**

Heat Transfer

Overall Heat Transfer Coefficient	(U)	*150*	Btu/hr·°F·ft^2	**(Rf. 3)**

Energy Savings Summary

Temperatures

Cold Exit Temp	($T_{C,o}$)	*110*	°F	**(N. 2)**
Hot Exit Temp	($T_{H,o}$)	*122*	°F	**(Eq. 1)**
Log Mean Temp Difference	(ΔT_{LM})	*58*	°F	**(Eq. 2)(N. 3)**

Energy Savings

Heat Exchange Rate	(Q)	*1,380,000*	Btu/hr	**(Eq. 3)**
Energy Savings	(E_S)	*5,382*	MMBtu	**(Eq. 4)**

Equations

Eq. 1) Hot Exit Temp ($T_{H,o}$)

$$T_{H,i} - \left[\frac{\dot{m}_C}{\dot{m}_H} \times \frac{CP_C}{CP_H} \times \left(T_{C,o} - T_{C,i} \right) \right]$$

Eq. 2) Log Mean Temp Difference (ΔT_{LM})

If Counter-current flow

$$\frac{\left(T_{H,i} - T_{C,o} \right) - \left(T_{H,o} - T_{C,i} \right)}{\ln \left(\frac{T_{H,i} - T_{C,o}}{T_{H,o} - T_{C,i}} \right)}$$

If Co-current flow

$$\frac{\left(T_{H,i} - T_{C,i} \right) - \left(T_{H,o} - T_{C,o} \right)}{\ln \left(\frac{T_{H,i} - T_{C,i}}{T_{H,o} - T_{C,o}} \right)}$$

Eq. 3) Heat Exchange (Q)

$$\dot{m}_C \times CP_C \times \left(T_{C,o} - T_{C,i} \right)$$

Eq. 4) Energy Savings (E_S)

$$\frac{Q \times t_{OH}}{\eta_B} \times \frac{1 MMBtu}{10^6 \, Btu}$$

References

Rf. 1) Developed in the Site Data section

Rf. 2) www.engineeringtoolbox.com/specific-heat-fluids-d_151.html

Rf. 3) Peters, Timmerhaus. *Plant Design and Economics for Chemical Engineers* ., 2001

Notes

N. 1) Data collected on site during the visit.

N. 2) Chosen based on maximum acceptable incremental payback period.

N. 3) When the temperature differentials between the two fluids are equal, the arithmetic mean is used instead of the log mean temperature difference.

AR No. # - Analysis

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Implementation Costs Summary

Material Costs

Heat Exchanger Cost per Sq. Ft.	(C_E)	*$100*	/ft^2	**(N. 5)**
Heat Exchanger Surface Area	(A)	*159*	ft^2	**(Eq. 5)**
Piping Costs	(C_P)	*$5,000*		**(Rf. 4)**

Labor Costs

Labor Rate	(C_{LR})	*$35*	/hr	**(Rf. 4)**
Labor Hours	(tL)	*50*	hrs	**(Rf. 4)**

Economic Results

Cost Savings	(C_S)	*$53,820*	/yr	**(Eq. 6)**
Implementation Costs	(C_I)	*$22,612*		**(Eq. 7)**
Simple Payback	(t_{PB})	*0.4*	yrs	**(Eq. 8)**

Notes

N. 5) Heat exchanger cost based on conversations with local vendors.

Equations

Eq. 5) Surface Area (A)

$$\frac{Q}{U \times \Delta T_{LM}}$$

Eq. 6) Cost Savings (C_S)

$$E_S \times IC_N$$

Eq. 7) Implementation Costs (C_I)

$$\left(C_E \times A\right) + C_P + \left(C_{LR} \times t_L\right)$$

Eq. 8) Simple Payback (t_{PB})

$$\frac{C_I}{C_S}$$

References

Rf. 4) RSMean Building Construction Cost Data 2009

Heat Exchanger Summary

Cold Exit Temp. ($T_{C,o}$)(**N. 2**)	*Hot Exit Temp.* ($T_{H,o}$)(**Eq. 1**)	*LMTD* (ΔT_{LM})(**Eq. 2**)	*Heat Exchange* (Q)(**Eq. 3**)	*Energy Savings* (E_S)(**Eq. 4**)	*Surface Area* (A)(**Eq. 5**)	*Cost Savings* (C_S)(**Eq. 6**)	*Implementation Cost* (C_I)(**Eq. 7**)	*Simple Payback* (t_{PB})(**Eq. 8**)	*Increm. Payback*
(°F)	(°F)	(°F)	Btu/hr	MMBtu/yr	ft^2	$	$	years	years
70	162	98	180,000	702	12	$7,020	$7,974	1.1	--
75	157	93	330,000	1,287	24	$12,870	$9,116	0.7	0.2
80	152	88	480,000	1,872	36	$18,720	$10,386	0.6	0.2
85	147	83	630,000	2,457	51	$24,570	$11,810	0.5	0.2
90	142	78	780,000	3,042	67	$30,420	$13,417	0.4	0.3
95	137	73	930,000	3,627	85	$36,270	$15,243	0.4	0.3
100	132	68	1,080,000	4,212	106	$42,120	$17,338	0.4	0.4
105	127	63	1,230,000	4,797	130	$47,970	$19,766	0.4	0.4
110	122	58	1,380,000	5,382	159	$53,820	$22,612	0.4	0.5
115	117	53	1,530,000	5,967	192	$59,670	$25,995	0.4	0.6
120	112	48	1,680,000	6,552	233	$65,520	$30,083	0.5	0.7
125	107	43	1,830,000	7,137	284	$71,370	$35,122	0.5	0.9
130	102	38	1,980,000	7,722	347	$77,220	$41,487	0.5	1.1