STEAM-JET HEAT RECOVERY IN A LUMBER DRY KILN

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Introduction

Between October 1, 1973, and April 1, 1979, the price of crude oil increased from $2.80 per barrel to $14.54 per barrel (3). The economic incentive to develop energy-reducing or energy-recovery systems is becoming more important as the cost of energy increases. Because drying accounts for approximately 70 percent of the energy consumed in a sawmill operation, savings in the drying arena could result in significant cost savings in mill operation. Comstock (1) reports that a significant amount of the energy used in lumber drying is the heat required to evaporate water from the lumber, which is lost as the vapor is exhausted through the kiln vent to the atmosphere.

Objective

The objective of this study was to recover vapor heat by compressing the kiln exhaust and condensing it in kiln heating coils. Because exhaust air from a conventional lumber kiln will not condense in the steam coils, it was necessary to purge the kiln of air and to dry the lumber in a superheated steam environment. For this study, a test system was constructed to determine operational performance and the technical and economic feasibility of a steam-jet heat recovery system.

The Recovery System

Two-by-six-inch nominal Douglas-fir was dried with a superheated steam schedule in a 1,000 fbm experimental dry kiln at the Oregon State University Forest Research Laboratory. The schedule was set at 225°-230° F dry bulb temperature with a 212° F wet-bulb temperature for 42 hours. The kiln exhaust was compressed in a steam-jet thermocompressor (Fig. 1) that mixes high-pressure boiler steam at 60 psig with low-pressure kiln exhaust at 0 psig by venturi action and discharges steam at intermediate pressure. The discharge from the steam-jet thermocompressor was piped to the kiln-heating coils and condensed, and the vapor heat in the kiln exhaust recovered (Fig. 2). Approximately 20 percent of the steam required to dry lumber was in recovered exhaust.

Economic Analysis

Several methods are generally used for economic comparison. Payback, net present value (NPV), internal rate of return, and equivalent uniform annual worth are some of the more common ones (2). Each has advantages and disadvantages. Decision makers typically choose one that best suits the analysis and best communicates the results (2). I have chosen to use payback and NPV methods because they are commonly used by the forest products industry.

The payback method determines the years required to recover the initial investment if the investment is evaluated at zero interest rate. Payback is equal to the initial outlay divided by the net annual savings (after tax).

The NPV method finds the net of cash inflow minus outflow. All cash flow is discounted to a present value at an appropriate interest rate for the economic life of the project. NPV equals the present value of the discounted cash flow minus the initial outlay.

Because economic data must be projected, uncertainty with respect to future cash flow must be a consideration. Sensitivity analysis, commonly used to discover the effect on NPV of variability in economic factors, was used for this study (2).

I evaluated a hypothetical investment in a 104-foot double-track kiln, commonly used in the forest products industry, by estimating initial costs, annual expenses, annual savings, and salvage value of the recovery system. A 10-year economic life and 20-percent interest rate, also common to the forest products industry, was used for the analysis.

The initial cost of the recovery system would be: 1) the cost to build a kiln capable of holding 212°F wet-bulb temperature, steam environment; 2) the cost of duct work to recover steam for the steam-jet thermocompressor; 3) the cost of the steam-jet thermocompressor itself. Annual expenses would be for maintaining the recovery system and kiln seals. Kiln manufacturers were solicited for both initial and annual costs.

Annual savings depend on the cost of the system, which for this analysis I assumed to be the cost of fuel to produce it. Because I was looking for reduction in the steam requirement of a dry kiln and because a detailed economic analysis of power plant operation costs was beyond the scope of the study, I did not consider amortization of the boiler, labor costs, and maintenance costs. I obtained price information from local suppliers for three fuels: wood residue, Bunker C oil, and natural gas.

Riggs (2) reports that sensitivity analysis should include the effect on NPV of ± 50 percent change in each cost factor. This was included for all factors except the prices of Bunker C oil and natural gas, which were known with greater certainty. I evaluated the effect of annual growth in maintenance costs and fuel prices. The sensitivity analysis also includes the effect on NPV of changes in interest rate, economic life, initial cost, maintenance cost, fuel price, steam flow, and recovery; and the effect on NPV of growth in maintenance or fuel prices.

Economic Results

The cost, savings, payback time, and NPV associated with one energy-recovery system are shown in Table 1. The 104-foot, double-track kiln is economically sensitive to the fuel (Table 2). It is economically feasible if Bunker C oil or natural gas is used to generate steam, but not economically feasible if wood residue is used to generate steam.

If the cost of steam was high, as with Bunker C oil or natural gas, the NPV was sensitive to steam-value factors: fuel price, steam flow, and recovery. If the cost of steam was low, the NPV was sensitive to initial cost and growth in maintenance cost. The sensitivity of the recovery system using Bunker C oil is made graphic in Figure 3 by the method outlined by Riggs (2). A full economic analysis would of course be done according to company policy and would include additional factors.

Conclusions

Steam-jet heat recovery yielded 20 percent of the energy requirement, reducing the steam required from the boiler.

Such a system would be economically feasible when Bunker C oil or natural gas is used to generate steam but not feasible when wood residue is used.

In a hypothetical investment in a 104-foot, double-track kiln, the NPV was sensitive to steam cost factors.

Literature Cited

1. Comstock, G. L. 1975. Energy requirements for drying of wood products. In Proc. P-75-13, Wood Residues as an Energy Source. For. Prod. Res. Society, Madison, Wis.

2. Riggs, J. 1974. Engineering Economics. McGraw-Hill. New York, N. Y. 617 p.

3. Energy Impact on Your Pocketbook. 1979. U.S. News and World Report 86(14):19-21.

TABLE 1. Cost data for use of three fuels in a 104-foot double-track kiln.

Factor	Wood residue	Bunker C oil	Natural gas
Fuel			
Initial cost ($)			
Kiln modifications	55,000	$55,000	$55,000
Duct work	2,000	2,000	2,000
Steam-jet	700	700	700
Total	57,700	57,700	57,700
Annual maintenance ($)	4,000	4,000	4,000
Annual savings ($)	4,636	37,181	54,092
Salvage value ($)	0	0	0
NPV ($)	−44,272	23,951	59,397
Payback (years)	18.0	2.96	2.07

TABLE 2. Economic effects of fuel used to generate steam in a 104-foot double-track kiln.

BUNKER C OIL

Interest Rate deviation		Economic Life deviation		Costs						Savings							
				Initial deviation		Maintenance deviation		growth		Fuel Price deviation		growth		Steam Flow deviation		Recovery deviation	
%Δ	NPV	%Δ	NPV	%Δ	NPV	%Δ	NPV	%	NPV	%Δ	NPV	%	NPV	%Δ	NPV	%Δ	NPV
+50	2,666	+50	31,958	+50	1,149	+50	19,759			+25	43,436			+50	62,921	+50	62,921
+25	13,308	+20	28,042	+25	12,550	+25	21,855	5	22,662	+12.5	33,693	5	35,930	+25	43,436	+25	43,436
0	23,951	0	23,951	0	23,951	0	23,951	10	21,374	0	23,951	10	47,908	0	23,951	0	23,951
-25	40,644	-30	15,989	-25	35,352	-25	26,047	15	20,085	-12.5	14,208	15	59,887	-25	4,466	-25	4,466
-50	61,980	-50	6,350	-50	46,754	-50	28,144	20	18,796	-25	4,466	20	71,866	-50	-15,019	-50	-15,019

NATURAL GAS

%Δ	NPV	%Δ	NPV	%Δ	NPV	%Δ	NPV	%	NPV	%Δ	NPV	%	NPV	%Δ	NPV	%Δ	NPV
+50	28,872	+50	71,485	+50	36,595	+50	55,205			+25	87,744			+50	116,091	+50	116,091
+25	44,135	+20	65,574	+25	47,996	+25	57,301	5	58,109	+12.5	73,571	5	76,824	+25	87,744	+25	87,744
0	59,397	0	59,397	0	59,397	0	59,397	10	56,820	0	59,397	10	94,250	0	59,397	0	59,397
-25	83,337	-30	44,686	-25	70,799	-25	61,494	15	55,532	-12.5	45,224	15	111,677	-25	31,051	-25	31,051
-50	113,935	-50	29,307	-50	82,200	-50	63,590	20	54,243	-25	31,051	20	129,103	-50	2,704	-50	2,704

WOOD RESIDUE

%Δ	NPV	%Δ	NPV	%Δ	NPV	%Δ	NPV	%	NPV	%Δ	NPV	%	NPV	%Δ	NPV	%Δ	NPV
+50	-47,772	+50	-44,119	+50	-67,075	+50	-48,464			+50	-39,413			+50	-39,413	+50	-39,413
+25	-46,022	+20	-44,193	+25	-55,673	+25	-46,369	5	-45,561	+25	-41,843	5	-42,779	+25	-41,843	+25	-41,843
0	-44,272	0	-44,272	0	-44,272	0	-44,272	10	-46,849	0	-44,272	10	-41,285	0	-44,272	0	-44,272
-25	-41,527	-30	-38,083	-25	-32,871	-25	-42,176	15	-48,138	-25	-46,701	15	-39,791	-25	-46,701	-25	-46,701
-50	-38,018	-50	-34,670	-50	-21,470	-50	-40,080	20	-49,426	-50	-49,131	20	-38,298	-50	-49,131	-50	-49,131

HIGH PRESSURE MOTIVE STEAM

LOW PRESSURE KILN EXHAUST
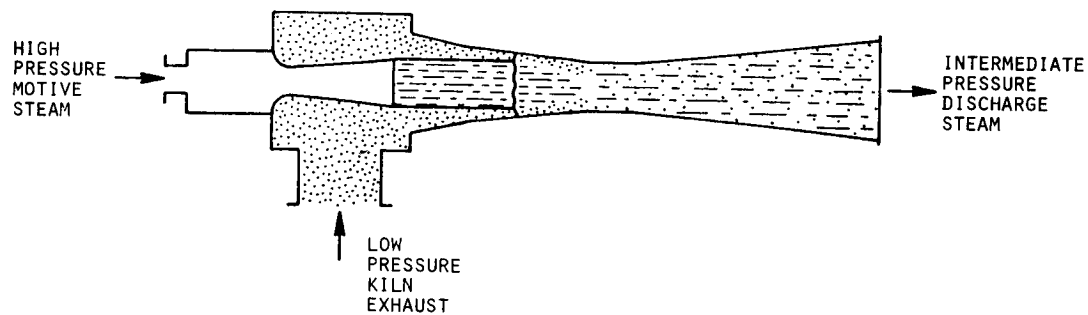
INTERMEDIATE PRESSURE DISCHARGE STEAM

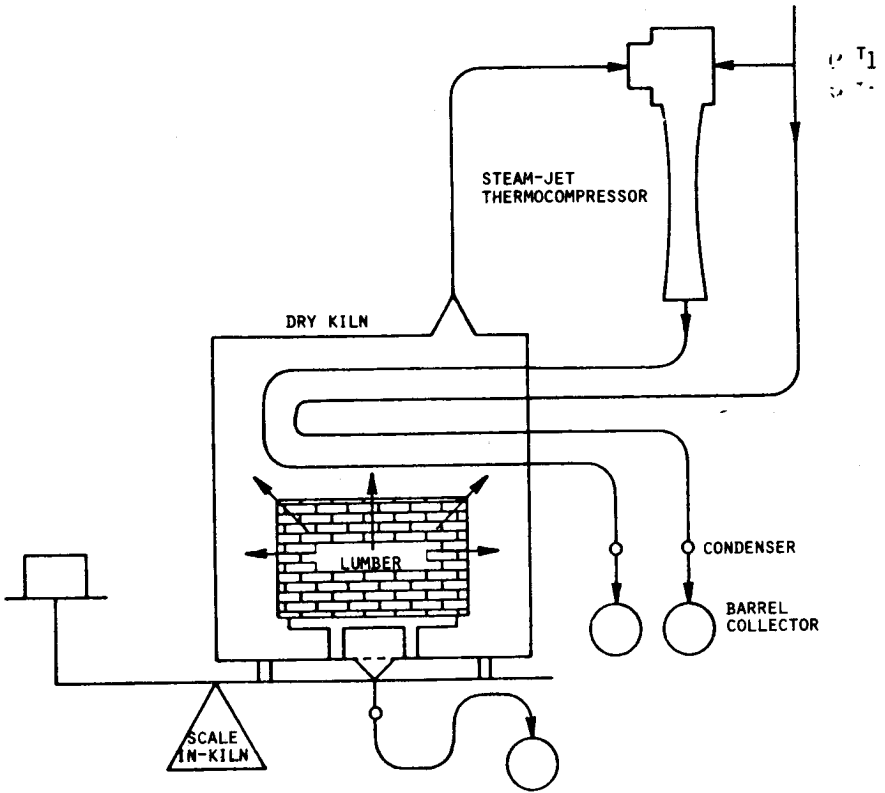Figure 1. Schematic diagram of a steam-jet thermo-compressor.

Figure 2.   Schematic diagram of the experimental
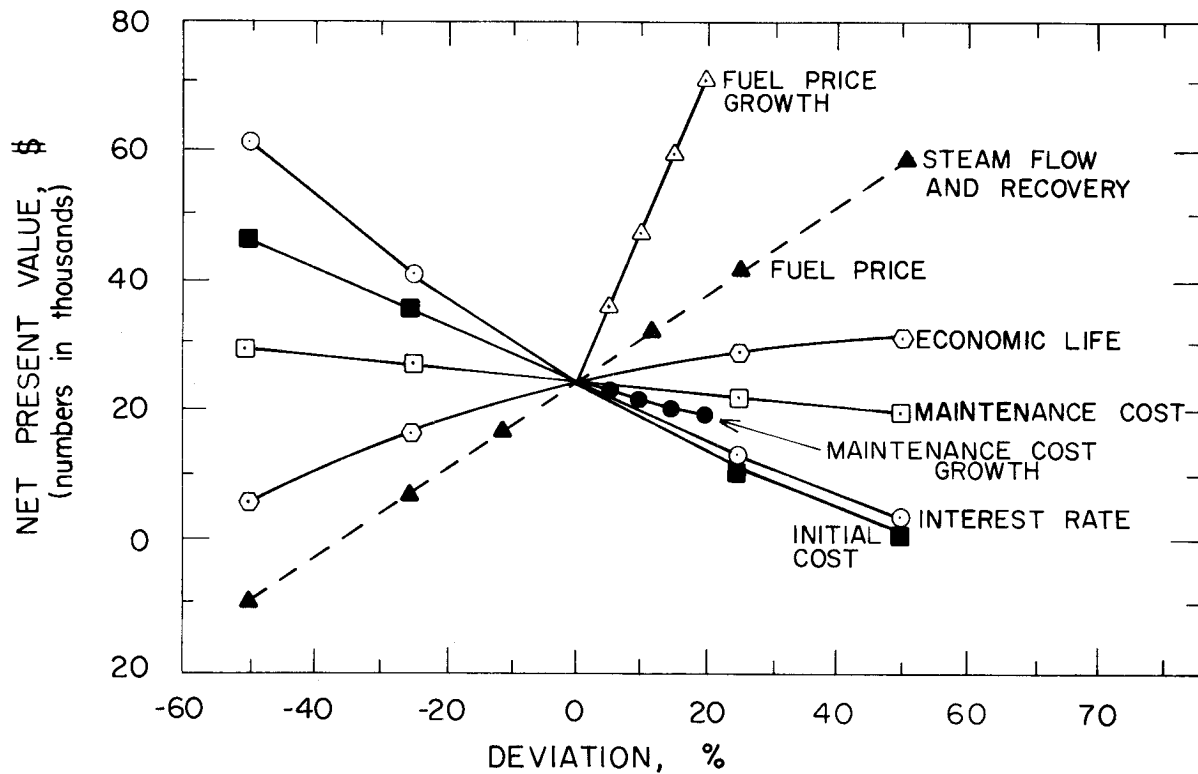
unit recovering heat from kiln exhaust.

Figure 3.   Economic sensitivity of a recovery system

using Bunker C oil to generate steam.