A COMPARISON OF ENERGY CONSUMPTION IN DIFFERENT KILN DRYING PROCESSES WITH EMPHASIS ON VAPOR RECOMPRESSION

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Introduction

In these times of diminishing energy resources, increasing demand for energy and consequent price rises for energy and fuels, industries using energy intensive processes are being forced to investigate their energy consumption and seek ways of reducing it.

The drying of wood is the largest single user of energy in the production of dry dimension lumber. Up to 70% of the energy used in processing from the log to the final dried product is accounted for by the drying process.

Numerous studies have focused attention on the energy savings which can be made by adherence to proper kiln drying practices. Although significant savings can be made by these means, they are only a small fraction of the total amount of energy consumed by a kiln. Attention must be focused on the drying process as a whole in order to achieve major reductions in energy consumption.

The purpose of this paper is to demonstrate the savings which potentially can be made by changing the drying process.

Energy Consumption for Drying

Heat energy is used in conventional kiln drying in the following ways:

1. Heat is required to evaporate moisture from the lumber, i.e., the latent heat of vaporization plus the energy needed to remove bound water from the wood substance.
2. Heat is lost from the kiln because of venting or exhausting moist air at the kiln operating temperature and the inlet cold air requires heating to the operating temperature. Heat is also required to raise the evaporated moisture from the wet-bulb temperature to the dry-bulb temperature.
3. Heat is required to raise the dry lumber to the final dry-bulb temperature and to raise the moisture which is evaporated to the wet-bulb temperature.
4. Heat is required to raise the temperature of the kiln to the final dry-bulb temperature.
5. There are heat losses by conduction, convection and radiation from the kiln structure.
6. Miscellaneous heat losses caused by leakage, over venting and other minor effects.

To compare the efficiency of different kiln drying processes, it is useful to use heat efficiencies (η) defined as:

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$$\eta = \frac{\text{heat required to evaporate moisture}}{\text{total heat supplied to dryer}}$$

It is possible to calculate the various amounts of heat as categorized above, by using a similar method to that devised by Shottafer and Shuber (1974).

The results of these calculations are given in Table 1 for the case of drying 25.4 Mfbm of 2-inch southern yellow pine using schedule AS11-AK6 of Rasmussen (1961). The moisture content data for this calculation was taken from Hopkins, Choong and Fogg (1969).

It is obvious that for conventional kiln drying most of the heat is used to provide latent heat for vaporization of water from the wood (61.9 x 10^6 Btu). Large amounts of heat are also lost by conduction through the kiln structure.

High temperature drying has been claimed to reduce the energy consumption of kilns by reducing the drying time. Results of similar calculations of energy consumption for drying with a high temperature schedule of 240°F dry-bulb temperature and 160°F wet-bulb temperature, are also given in Table 1. For these calculations it is assumed that 2-inch southern yellow pine takes 24 hours to dry using this schedule. Any change in drying time would only affect the heat loss through the walls. The heat losses through the kiln structure are greatly reduced due to the much reduced drying time, even though the temperature difference between the kiln and the outside ambient air is almost double that of the conventional schedule. The heat used to raise the temperature of the kiln and lumber is increased as a result of the higher dry-bulb temperature. Also, for high temperature drying the venting losses are much greater, causing the overall heat energy consumption of a high temperature kiln to be greater than a conventional kiln, drying the same material. The increased venting losses need some explanation as several authors have maintained that high temperature drying reduces energy consumption.

As water is evaporated from the wood it becomes vapor in the air circulating in the kiln. This causes the wet-bulb temperature to rise above the set point and the kiln controller opens the vents. The excess moisture in the air is exhausted at the humidity of the kiln (i.e., as calculated from the schedule wet-bulb temperature and dry-bulb temperature). The absolute humidity of the kiln air is primarily dependent on the wet-bulb temperature. At high wet-bulb temperatures the humidity is high, while low wet-bulb temperatures cause low humidities. High temperature drying with a wet-bulb temperature of 160°F, therefore, results in the excess moisture being exhausted at low humidity. Consequently, large amounts of hot air at the dry-bulb temperature are exhausted with the excess moisture. The cold, inlet ambient air needs to be heated to the dry-bulb temperature. An equal amount of air needs to be inlet to the kiln, as is exhausted from the kiln, otherwise pressures inside the kiln will change.

The wet-bulb temperature of the conventional schedule is similar to that used for the high temperature schedule, hence the kiln absolute humidites are approximately equal. This results in similar quantities of total inlet air being required for each type of drying. Since with conventional drying the inlet air is required to be heated to a much lower temperature than for high temperature drying, the energy loss by venting is much less for the conventional schedule than for the high temperature schedule. This is shown in Table 1.

Overall, the total heat energy used by high temperature drying is slightly higher than for drying by a conventional schedule.

It has been shown above that the venting losses are dependent on the wet-bulb temperature. If the wet-bulb temperature were high, then the kiln humidity would be high and less inlet air would be required when the excess moisture was vented from the kiln. Therefore, to reduce venting losses as much as possible we should use the highest wet-bulb temperature. For atmospheric pressure, the highest wet-bulb temperature obtainable is 212°F, at which temperature the kiln atmosphere is pure steam. When venting occurs, only steam is exhausted and no inlet vents are required. To obtain drying conditions, the dry-bulb temperature needs to be higher than the wet-bulb temperature, i.e., the kiln operates with an atmosphere of superheated steam.

Similar calculations to those for conventional and high temperature schedules were performed for drying by superheated steam using a dry-bulb temperature of 257°F and a wet-bulb temperature of 212°F. An earlier, unpublished study has shown that overall drying times for drying by high temperature with a dry-bulb temperature of 240°F and wet-bulb temperature of 160°F, and by superheated steam with a dry-bulb temperature of 257°F, are similar (Miller 1976). The results of the heat energy consumption calculations for superheated steam drying are also shown in Table 1. As expected the venting losses are greatly reduced, the residual venting loss is due to heating the evaporated moisture from the wet-bulb temperature to the dry-bulb temperature. The total heat energy consumption is much reduced from that used by conventional and high temperature drying. To conserve energy in kiln drying it is, therefore, apparent that one must dry at as high a wet-bulb temperature as possible.

In the above analysis it is apparent that the largest amount of energy is used to evaporate the moisture from the lumber. Apart from small gains by operating at high wet-bulb temperatures (with lower latent heat of vaporization), schedule changes can have no effect on reducing this energy category. Only changes in the drying process can affect this reduction.

One method of changing the drying process is considered in the next section.

Application of Vapor Recompression to Reducing Energy Consumption

One of the properties of steam is that it has a characteristic condensing temperature which depends on the pressure (e.g., steam condenses at 212°F at a pressure of 16.7 psia). Steam used in the heating coils of the kiln, is supplied at sufficient pressure that it condenses at such a temperature that a temperature difference for heat transfer to the kiln atmosphere is established. If the kiln is operating at 257°F then steam must be supplied at a pressure greater than 33.7 psia for use in the heating coils. Usually, the steam is supplied at much higher condensing temperature (hence higher pressures) so the amount of heating surface inside the kiln is reduced.

If we consider a kiln, drying lumber by superheated steam, the steam inside the kiln has a condensing pressure of 14.7 psia (atmospheric pressure) and a corresponding condensing temperature of 212°F. During operation of the kiln, moisture is continually being evaporated from the lumber and adding to the steam inside the kiln. This causes a build-up of pressure and this is relieved by venting the excess steam to the atmosphere. It would be advantageous for energy saving, to convert this excess steam, which is exhausted from a kiln operating with a superheated steam schedule, into a form suitable for use in the heating coils of the same kiln. This is the basis of the vapor recompression system, which is described below.

In the vapor recompression process (see Miller 1977), compression of the exhaust steam transforms it into a state suitable for use in the heating coils of the kiln.

In using this method to reduce energy consumption in the lumber drying process, several modifications to conventional kiln drying methods become necessary. Any air present in the system seriously decreases the efficiency of the process. It is, therefore, important that the kiln atmosphere only contains steam. To maintain the kiln conditions of superheated steam at atmospheric pressure, the compressor must be controlled so as to allow only the amount of moisture which is evaporated from the lumber at that time to be compressed and supplied to the steam heating coils. No venting of excess moisture from the kiln is necessary because any evaporated moisture is removed by the compressor and condensed in the heating coils.

The general arrangement of a vapor recompression kiln is given in Figure 1. The kiln consists only of a sealed chamber with fans for circulation and heating coils. The importance of having a thoroughly sealed (pressure tight) kiln chamber cannot be overemphasized. Any loss of steam to the atmosphere reduces the amount of steam which is compressed and condensed, and, therefore, the energy recovery is reduced. Condensation forming inside the kiln should also be avoided for the same reason. Both the steam heating coils and the kiln itself must be provided with air vents sufficient to exhaust the initial air from the kiln.

Care must be taken with the selection of a compressor for the vapor recompression task. Contrary to most uses for compressors, no cooling of the compressor is required. This results in high temperatures (up to 800°F) being attained, requiring that the compressor be specially designed. It must be possible to control the compressor so that as the drying rate drops, the steam flow rate through the compressor is reduced. Nevertheless, the outlet pressure must be maintained constant. Suitable compressors are manufactured for use in vapor recompression evaporators, in the chemical process industries, which should be suitable for use on vapor recompression lumber drying kilns.

If steam is used to heat the kiln, then operation under a vapor recompression system is simpler. The steam heating coils can also be used for the steam from the compressor. In this case the compression pressure would be the same as the steam supply pressure. If other forms of heating are used (e.g., hot oil, hot water) then additional separate heating coils for the recompression system must be installed.

The heat energy consumption for a kiln operating with vapor recompression can be calculated for the situation considered previously, and compared with that for conventional, high temperature and superheated steam (Table 1). These calculations are given in a previous paper (Miller 1977) and will not be presented here.

More energy is recovered by vapor recompression (67.6×10^6 Btu) than is used to evaporate the moisture from the timber (60.2×10^6 Btu). This is due to the additional energy supplied to the steam by the compressor, being recovered when the steam is condensed. For the process considered in Table 1, the steam is compressed to 100 psig before supplying the heating coils. This results in a large amount of electrical energy being used by the compressor (18.2×10^6 Btu). This usage of electrical energy can be minimized by reducing the compression pressure. To obtain the required heat transfer at low pressures requires much increased heating surface.

As an example of the maximum energy savings possible, consider the minimum compression pressure of 19 psig. The electrical energy used by the compressor becomes 5.6×10^6 Btu, compared with an energy usage of 18.2×10^6 Btu for compression to 100 psig. The size of the compressor can be reduced accordingly, from the 614 HP required to compress to 100 psig, to 189 HP required for 19 psig. This can result in savings in capital cost. With the lower compression pressure less energy is recovered by vapor recompression (62.6×10^6 Btu). The total energy required for drying is still the same (87.0×10^6 Btu), therefore, the net energy makeup is 24.4×10^6 Btu. The total heat energy supplied to the kiln is the sum of the makeup steam energy and the electrical energy supplied to the compressor. This amounts to 30.0×10^6 Btu or an efficiency of 2.01 for operation at a compression pressure of 19 psig.

Conclusions

By calculating the heat energy consumption of a kiln it is possible to compare the effects of different schedule types. For the particular case of drying 25.4 Mbfm of 2-inch thick southern yellow pine, it was found that high temperature drying resulted in greater total energy consumption than conventional drying. It was also shown that drying at high wet-bulb temperatures reduces energy consumption. Drying by means of superheated steam was shown to reduce total heat energy consumption by 10 percent.

The use of vapor recompression to conserve energy in lumber driers can result in substantial savings. In this case a total of 58.6×10^6 Btu or 65 percent of the energy used in conventional drying is saved. If the compression pressure is reduced to the minimum, the electrical energy used for compression is minimized and the energy savings can be as high as 74 percent for this ideal case.

For the future, experimentation at a pilot plant level is necessary to clarify the following: effect of extractives and preservatives from the lumber, and method of control used for the compressor and drying process. In addition, data on energy savings likely to be achieved in commercial kilns, must be produced.

Literature Cited

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Table 1. Heat Energy Requirements in 10^6 Btu for Conventional, High-temperature, Superheated Steam and Vapor-Recompression Drying 25.4 Mfbm of 2-inch Southern Yellow Pine.

Heat energy	Conventional*	High-temperature	Vapor-recompression	Superheated steam
1. Energy to remove moisture	61.9	61.6	60.2	60.2
2. Energy loss from venting and heat needed to raise evaporated water from wet-bulb temperature to dry-bulb temperature	7.9	15.0	1.3	1.3
3. Energy to raise temperature of dry timber to final dry-bulb temperature and energy required to raise evaporated moisture to wet-bulb temperature	7.6	10.2	13.8	13.8
4. Energy to raise temperature of kiln to final dry-bulb temperature	2.6	3.4	3.8	3.8
5. Heat loss through walls, doors, roof	16.2	7.3	7.9	7.9
6. Miscellaneous	--	--	--	--
Heat energy used	96.2	97.5	87.0	87.0
Less heat recovered by vapor recompression	nil	nil	67.6	nil
Net heat energy used	96.2	97.5	19.4	87.0
Electrical energy used for compression	nil	nil	18.2	nil
Total energy consumption	96.2	97.5	37.6	87.0
Efficiency	0.64	0.63	1.60	0.69

*Schedule AS11-AK6 of Rasmussen (10)

N.B. (1) No account is taken of steam spray used for humidification.
(2) Heat energy refers to energy used in the heating sections of the kiln.

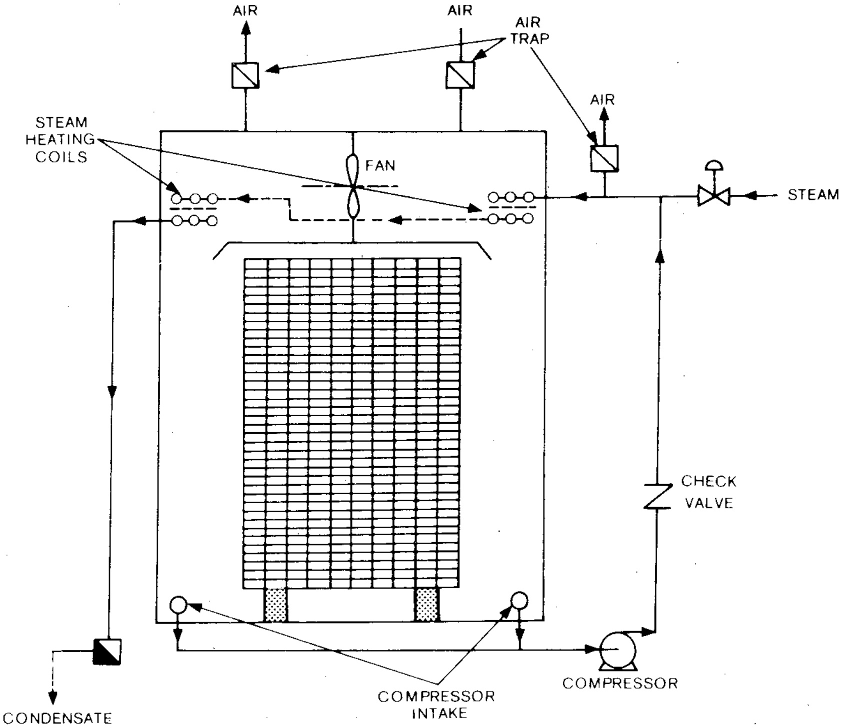

Figure 1. — General arrangement for vapor-recompression timber-drying kiln.