THERMAL SYSTEMS SIMULATION AS A TOOL FOR ECONOMIC DECISIONS IN THE PLYWOOD INDUSTRY IN MEXICO

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SUMMARY

This work presents results of a series of simulations performed with the purpose of analyzing the expected performance of the steam supply system of a plywood manufacturing press. A very simple model was devised and used for the simulations, with the purpose of preserving simplicity and ease of comprehension by plant engineers and to be able to evaluate many possible system designs with a minimum of computational effort. However, it was found that, by accounting for all important variables, model results were of very good quality, as judged by a comparison with manufacturers designs which are believed to be of a high accuracy.

INTRODUCTION

The use of fossil fuels as an energy source for thermal processes in the plywood industry has become very expensive in México. Aging steam generators, with poor thermal efficiency and bad maintenance, are one of the main reasons. Wood refuse from the plywood manufacturing process and saw mills is not only available, but a waste that has to be disposed off. One of the best possible means of disposition is to burn it and use released heat as an energy source.

Some plywood industries in México have been substituting steam in favor of thermal oils to be used as a working fluid in their thermal processes. They burn refuse to heat the oil and justify changes on the basis of safety, economy and the fact that equipment is available locally and has not the drawback of working at relatively high pressures for the range of temperatures commonly used in this industry. However, the use of oil implies the use of sensible heat, with its consequent temperature drop as the oil energy is used up. This fact is undesirable in some instances such as plywood forming, where wood sheets are glued and pressed together at prescribed pressure temperature and time. In this case, the temperature drop causes glue curing to be non-uniform and may require pressing times to be higher, with resulting production losses.

This problem may be avoided since hot oil is available at temperatures above those needed in the pressing process and, therefore, the use of a kettle type reboiler to produce steam from the oil's energy seems as a natural solution to the problem. However, since they were not familiar with this type of equipment, the substitution of an oil fossil fired steam generator with a reboiler was not trusted by the plywood industry personnel. In order to convince them of the applicability of such a solution, a computer program was devised and used to perform a series of steady state simulations of various possible reboiler designs.

To permit the model to be evaluated by plant personnel, not familiar with heat transfer, the model was to be as simple as possible.

This work presents results of steady state simulations of the kettle type reboiler expected performance. The main operation variables were varied within their normal operating ranges and the obtained results were an important aid for the evaluation of manufacturer's bids.

SYSTEM DESCRIPTION

Old system. Figure 1 is an schematic diagram of the plywood press and its steam supply system. As seen there, the steam boiler (an old Clayton boiler model WO-50 with a nominal capacity of 1880 lbm/h of steam at 120°C) produces a mixture of steam and water which is separated in a steam dome. Saturated steam is then directed towards the plywood press, while the water is recirculated. After giving up its latent heat, condensed water leaves the press, passes through a steam trap, and goes into the water make-up tank to be suctioned by the recirculating pump into the boiler.

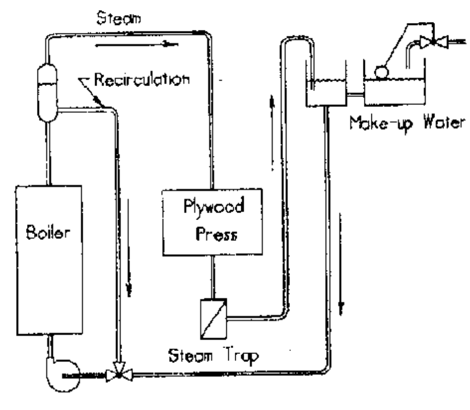

Figure 1 - Schematic diagram of the old system

In order to establish the system's required capacity, and due to the lack of data, steam demand measurements were made under various operating conditions (i.e. with the press producing plywood of different thickness). These resulted on a maximum system demand of 1550 lbm/hr of steam when 5/8" plywood was manufactured, which yields a security factor of around 21% with respect to the boiler nominal capacity. The quality of available instruments did only allow to establish that the steam pressure was between 20 and 60 psig.

Proposed system. As mentioned before, the plywood manufacturers were about to substitute the working fluid of their press and use hot oil, with its consequent drawbacks. The proposal was to circulate the available hot oil in the tubes of a kettle type reboiler, producing steam in the shell-side and substituting the boiler and steam dome of the old system with this new equipment. To absorb steam demand variations, a steam pressure controlled valve was installed to regulate oil flow and a reboiler level control was used to recirculate water from the make-up tank as shown in Figure 2.

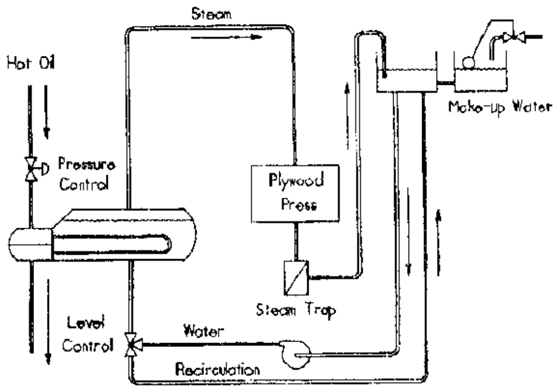

Figure 2 - Schematic diagram of the proposed system

To preserve the aforementioned security factor, the reboiler steam production capacity was set equal to the nominal capacity of the old boiler, while to fulfill this duty there was a maximum available oil flow of 60,000 lb_m/hr at 392°F. These values were obtained from measurements of the oil demand in other parts of the plant, mainly the wood sheets dryer, and from the oil heater manufacturer's stated capacity. One further restriction was set by the oil pump differential working pressure, which together with the well known rule of thumb of allotting 60% of total pressure drop to the control valve, left about 12 psi available as pressure drop through the reboiler.

REBOILER MODEL

In order to be able to convince plant personnel that the kettle type reboiler was a viable alternative a computer model was designed and implemented. As will be shown, the simulation results were also of great importance to evaluate bids for the equipment from several manufacturers. A decision was also made to develop a model as simple as possible, to allow its comprehension by engineers unfamiliar with thermal design which were to be its final users.

Heat transfer. The basic equation is the heat balance:

$$Q = M_v C_{pl}(T_v - T_a) + M_v h_{fg} = M_o(T_{oe} - T_{os}) \qquad (1)$$

and any design must also satisfy the heat transfer equation:

$$Q = UA\Theta_m \qquad (2)$$

where the logarithmic mean temperature difference, the heat transfer surface area and the overall heat transfer coefficient are given by the following equations

$$\Theta_m = \frac{(T_{oe} - T_v) - (T_{os} - T_v)}{\ln\frac{(T_{oe} - T_v)}{(T_{os} - T_v)}} \qquad (3)$$

$$A = N_p \pi D_e N_t L \qquad (4)$$

$$U = (R_i + \frac{t}{k_t} + R_o + F_s)^{-1} \qquad (5)$$

It should be noted that to devise a simple model, and based on the relatively high thermal conductivity of the tube wall, the tube resistance is simply calculated by t/k_t. It should also be mentioned that following Kern (1950), and in view of the relatively high values of the shell side boiling heat transfer coefficient as compared to the tube side oil convection heat transfer coefficient, the shell side heat transfer resistance was taken as constant and equal to 0.001 h-ft^2-°F /BTU.

The tubeside heat transfer resistance was also calculated with simple equations, the Dittus-Boelter equation for turbulent flow and the Sieder and Tate equation for laminar flow (Mac Adams, 1954)

$$\frac{1}{R_i} = h_i = 0.023\frac{k}{D}(Re)^{0.8}(Pr)^{0.4} \qquad (6)$$

$$\frac{1}{R_i} = h_i = 1.86\frac{k}{D}(Re)^{0.33}(Pr)^{0.33}(\frac{D}{L})^{0.33} \qquad (7)$$

Oil properties were obtained from manufacturers data for the oil in use in the system and the fouling factor, Fs = 0.002 h-ft^2-°F /BTU, was obtained from TEMA (1978), for the range of working temperatures and fluids in use.

Pressure drop. Again, the simplest possible pressure drop correlation found in technical literature was that of Kern (1950), where the total tubeside pressure drop is given by the addition of the straight tube pressure drop, ΔP, and the "U" tube returns, ΔP_r, to be calculated with

$$\Delta P = n(f\frac{\rho V^2}{2g}\frac{L}{D}) \qquad (8)$$

$$\Delta P_r = 4n(\frac{\rho V^2}{2g}) \qquad (9)$$

to avoid the use of Kern's friction factor graphic presentation a mean value, f = 0.003, was selected and used as a constant on the basis of the expected range of Reynolds numbers variation.

The reader is again reminded that the set of equations (1) to (9) and the associated described simplifications were selected *purposefully* with the objective of developing the simplest possible model, however it should also be noted that all important variables are included in the model. The application of the present model provided results which equal those of much more involved calculation procedures (i.e. manufacturer's computer programs) showing that, in some instances and with the present state of knowledge, the use of the most complicated calculations may not be the best alternative. The selection of this simple model permitted the evaluation of over 250 different designs, which would have had a prohibitively high cost with a more complicated model.

MODEL IMPLEMENTATION

The described model equations were programmed in a spreadsheet with the main objective of obtaining a set of computer graphics which represented the expected equipment performance under different design and operating conditions. Results were also deemed to be useful for evaluation of the different manufacturer's bids for the reboiler. The set of equations is so simple that a description of equation implementation would be trivial.

Variables kept constant and restrictions are shown in Table 1. Steam consumption was dictated by process requirements, as well as oil inlet temperature which was fixed by the dryer operating conditions. The tube diameter was set on the basis of heat exchanger tubing commonly available in México, either 3/4" or 1" nominal size and 18 BWG, from which the former was selected for the analysis. The feedwater temperature is relatively unimportant and was maintained at a constant value. Since the make-up water tank is atmospheric, and the plywood press works at a higher pressure, the recirculation water attains saturation temperature.

Table 1.- Constants and Restrictions

Constants	Restrictions
Steam Consumption, M_V	Oil mass flowrate, $M_o \leq 60{,}000 lb_m / h$
Oil inlet temperature , T_{Oe}	Oil pressure drop, $\Delta P \leq 12 psi$
Tube diameter and BWG	Oil velocity, $3 \leq V \leq 7 ft / s$
Feedwater temperature, T_a	Steam Pressure, $20 \leq P \leq 60 psig$

As mentioned before, restrictions on the oil flow were set by existing process conditions, except for oil velocity which was restricted within the range of flow velocities commonly used in heat exchangers. The steam pressure was varied within the range shown in Table 1 because, as mentioned before, it was not possible to define it clearly with the old equipment layout and instrumentation available.

The steady state simulator's structure was designed by defining the set of dependent and independent variables shown in Table 2.

Table 2.- Dependent and independent Variables

Independent Variables	Dependent Variables
Oil exit temperature, T_{Os}	Oil mass flowrate, M_O
Oil velocity, V	Oil pressure drop, ΔP
Tubeside passes, n	Tube length, L
Steam pressure, P_V	Heat transfer surface area, A_t

Therefore, given a set of independent variables, the simulator calculations produced a kettle design consisting of a required oil mass flowrate, the corresponding pressure drop and the geometric characteristics: heat transfer surface area and number and length of the exchanger tubes. The number of tubeside passes, n, was obtained by fixing a maximum equipment length of about 3 m, dictated by space availability. Thereafter, an approximate shell diameter was obtained by an estimation of the bundle diameter and a steam disengagement required area. This last quantity is not shown in the remaining of the analysis as it is not a major component of the exchanger costs, comprised mainly by the tube bundle costs.

SIMULATION RESULTS

Figures 3 and 4 were prepared to show the equipment expected performance as affected by prescribed oil flow velocity and exit temperature. Figure 3 corresponds to the minimum selected oil flow velocity, 3 ft/s, while Figure 4 shows predictions for the maximum oil velocity of 7 ft/s. In both figures the oil exit temperature is varied from 320°F to 370°F, which are set by the lowest and highest possible oil temperatures according to process conditions. Given these two variables, the heat balance dictates the oil mass flowrate, which is shown on the right Y axis, while the heat transfer surface area, shown on the left side Y axis, is obtained by the heat transfer and related equations. The highlighted vertical line shown in both figures separates possible designs (leftward region of the graph) from designs which do not fulfill the 60,000 lbm/h mass flowrate restriction.

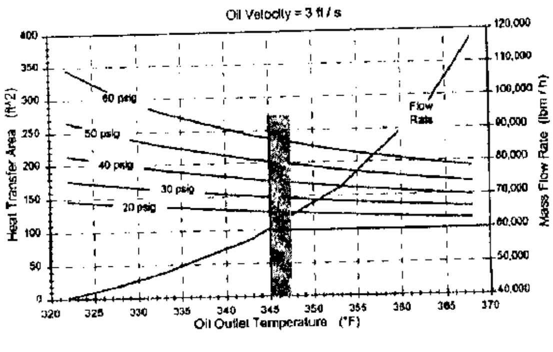

Figure 3 - Simulation results for 3 ft/s velocity

The heat duty is set by the steam mass flowrate and pressure and, due to the negligible effect of steam properties, the resulting oil mass flowrate is practically constant and changes can not be appreciated with the scale of Figures 3 and 4.

As expected from physical considerations, the minimum heat transfer areas are obtained, for any steam pressure, when the maximum oil mass flowrate is used. At this value there is obtained the minimum oil temperature drop and, therefore, the maximum oil exit temperature of 345°F and the maximum LMTD.

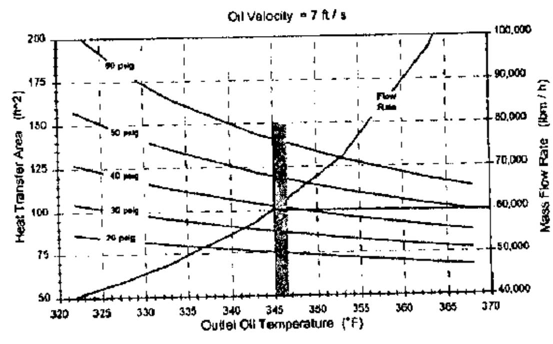

Figure 4 - Simulation results for 7 ft/s

Finally, a comparison of the required heat transfer surface areas of both figures, shows that the use of high oil velocities results in lower surface requirements. This is due to the effect of oil velocity on the overall heat transfer coefficient values, which given the low values of other resistances are dominated by the oil side heat transfer coefficient.

In order to select the best designs from the set of available alternatives the pressure drop restriction must be considered. Since the feedwater temperature is a constant, the highest heat duty is obtained at the highest steam pressure. This also causes the largest heat transfer surface area requirements and simulation results are shown in Fig. 5 for this case.

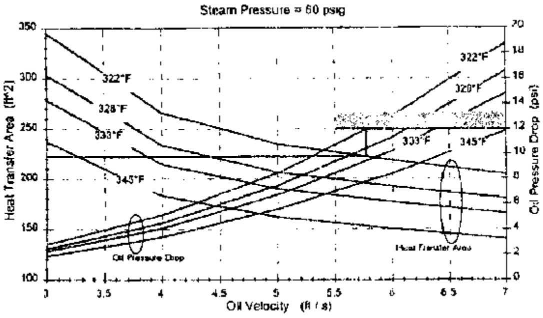

Figure 5 - Simulation results at 60 psig

In Fig. 5 the calculated pressure drop is shown on the right hand Y axis as a function of the oil flow velocity for various values of the oil exit temperature by the curves which start at the leftmost part of the figure and show increasing pressure drops as the oil velocity increases according to equations 8 and 9. The maximum allowable pressure drop, 12 psi, is shown by the highlighted horizontal line. As mentioned before, the oil mass flowrate restriction is equivalent to a maximum oil exit temperature of 345°F and, therefore, the figure only shows lower temperatures for this analysis.

The left hand side Y axis of Fig. 5 shows the heat transfer surface area as a function of the oil flow velocity and parameterized by oil temperature curves which start at the left side of the figure and go down as oil velocity is increased. These set of predictions are auxiliary to define designs as will now be described.

The best possible designs are those using the maximum available pressure drop, since they are obtained by using maximum oil velocities and, therefore, result in the highest possible heat transfer coefficients. On these basis, each point where an oil exit temperature curve crosses the maximum allowable pressure drop defines an optimum design under the set of restrictions. The heat transfer surface areas are then found by going down from these points to intersect the temperature-area corresponding lines and reading areas on the left axis.

The use of the aforementioned procedure yields a minimum heat transfer surface area of around 140 ft^2 which is calculated at the maximum investigated velocity and the maximum allowable oil mass flowrate (set by the temperature curve of 345°F) and pressure drop. On the other hand, a value for the heat transfer surface area of around 220 ft^2 is obtained at the minimum possible oil exit temperature of 322°F (i.e. when all available energy is used up), and the maximum allowable pressure drop, which corresponds to an oil velocity of around 5.7 ft/s.

On the basis of these results, obtained through simulation, the plywood personnel was convinced of the viability of the project and a call for bids was prepared and sent to various heat exchanger manufacturers. The call for proposals only included information about the exchanger heat duty and the thermal oil properties and restrictions. The former was given through specification of feedwater temperature and steam process demand (with the proviso that steam was required at either 20 or 60 psig), while the latter consisted of the maximum available oil flow and pressure drop, its inlet temperature and its minimum required exit temperature.

Proposal Evaluation and Simplified Cost Analysis. The most important data given by heat exchanger manufacturers in their proposals are shown in Table 3.

Table 3.- Comparison of Manufacturer's Proposals

	A	B	C	D	E
Shell diameter (in)	37	28	24	48	22
Bundle diam. (in)	25	18	--	18	16
Number of tubes	--	51	--	52	68
Heat transfer area (ft^2)	846	303	320	249	236
Pressure drop (psi)	8.35	--	6.2	5.5	6.16
Exchanger type	BKT	BKU	BKU	BKU	BKU
Cost (U.S.$, 1969)	12,000	8,600	11,750	7,300	5,500

The usefulness of the simulation results becomes evident by a comparison of exchanger costs which, as shown in the last row of Table 3, vary over a twofold range. Without the generated results it would not have been possible to make a clear-cut decision between the proposal of the very prestigious manufacturer A, probably the most recognized in México, and the rest of the proposals, which come from smaller plants.

All of the proposals met the set of imposed restrictions although not all of the data is shown in Table 3 because some manufacturers did not specifically mentioned it and calculations were required to verify this fact. However there are large differences in the proposed heat transfer surface areas (in general reflected in exchanger costs) which were evaluated on the basis of the results of simulations to decide that manufacturer E was to be selected to provide the exchanger. This decision was made mainly by noting that their proposal offered a heat transfer surface area well within model predictions and fulfilled all restrictions.

When visits were made to the shop, for acceptance testing, it was found that this manufacturer owns a full fledged heat exchanger design program leased from a very recognized company, which greatly supported the decision.

It should now be noted that, as judged from the manufacturers proposals, the results of the simple simulations used in the present analysis compare very favorably with results of calculations made by manufacturers. Since they not only have to make proposals, but also have to guarantee their equipment, it could be asserted that their predictions have to have a high degree of accuracy and, therefore, we may conclude that even a simple program, given that it accounts for all important variables, yields results that can be used and trusted.

The overall cost of the project, including control valves, pressure and level controllers, associated piping and installation and engineering costs amounted to U.S.$14,500. This yields savings of at least U.S.$3,500 when compared to the initial proposal of changing the press platens to work with oil, since each plate would have cost about U.S.$1,000 and the plywood press has 18 plates.

The system has been working since June of 1996 with a very small downtime and, since it replaced an oil-fired boiler with a consumption of about 300 lt/day of Diesel oil, the project costs were estimated to be paid in only eight months.

CONCLUSIONS

A simple simulation program to predict the expected behavior of a kettle type reboiler was designed and applied to generate data as an aid to select a manufacturer for the equipment.

The program was purposefully kept as simple as possible but all important variables were accounted for.

The simulation results provided information which greatly simplified the selection process and which would have been very difficult without these results.

In turn, the data in the manufacturers proposals were used as an indirect aid to test the goodness of the simulations results. These were found to compare well with the manufacturers designs, proving that even a simple model is capable of producing good results.

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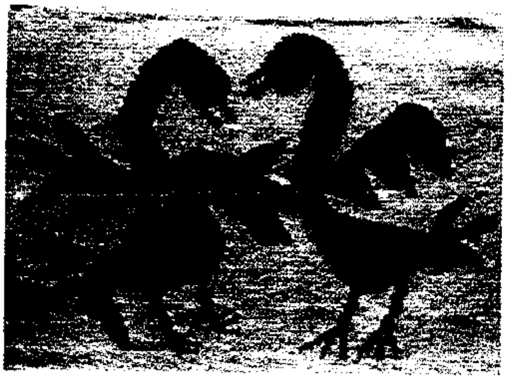

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