P

Plenary session

Analysis of Rendering and Hot Water Heat Energy Use in Meat Plants

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Abstract

Rendering and hot water generation are the predominant heat energy users of meat plants. Rendering plants typically consume large amounts of steam and/or hot air during their rendering and drying operations, whilst slaughter floors and boning rooms require large volumes of hot and warm water, for sterilising tools and hand wash, generated from steam or electric coils and/or heat recovery systems. Overall plant heat energy usage can be reduced substantially by reducing point-of-use consumption and maximising heat recovery.

Mathematical models describing the operation of rendering plant cookers, dryers, blood coagulators and rendering vessels; and slaughter floor and boning room water usage have been developed, tested against data measured at Australian and New Zealand meat processing plants and implemented in computer software. For existing plants, the software can be used as a management tool to assist in optimisation of the system. For new plants or extensions to existing plants the software can be used as a design tool enabling selection and matching of appropriate sized equipment as well as to predict the effect of new equipment on existing services.

This paper describes the various component models and presents a case study.

1. Introduction

Meat plants use large quantities of heat energy, predominantly in the form of steam or hot air, for cooking and drying byproducts within rendering systems, and for hot and warm water production. Reducing energy use leads to substantial cost savings and hence increased profits for the industry as well as assisting the meat and byproducts industries to reduce net CO_2 emissions in line with government policy. Furthermore, more efficient energy utilisation is likely to lead to the use of smaller heat generation equipment with concomitant savings in capital cost.

Optimisation of heat energy use requires selection and matching of appropriate sized equipment by the design engineer and correct operation and maintenance of the equipment by plant staff. Knowledge of the time-variable nature of component equipment (steam use, drying rate, product temperature, hot water consumption etc.) is vital for optimum equipment sizing and operation. Current methods are at best based on trial and error and experience so typically do not result in optimal solutions.

Studies of individual system components are important for improving equipment efficiencies but optimisation of plant-wide heat energy use requires analysis of the whole system including interactions between components. Traditionally, major energy-consuming operations such as refrigeration, rendering and steam/hot water systems have been designed separately by specialists in each area. Hence many opportunities for heat exchange between these operations have been overlooked, and those that have been implemented may not be optimal (Chadderton,1995).

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Process integration techniques such as pinch analysis can be used for plant-wide analysis of energy use and optimisation of heat recovery opportunities. Pinch analysis was developed in the late 1970s as a technique for designing heat exchange networks in the chemical processing industries, but has now spread to many other industries including food processing. Pinch analysis matches plant process heating and cooling loads and determines the optimum heat exchange between each. Chadderton (1995) assessed heat recovery opportunities for case study beef and sheep plants using pinch analysis while Drew (1993) reported on 20 pinch analysis studies undertaken in New Zealand of which about half were at meat plants. Process integration using techniques such as pinch analysis is easiest to implement when plant heating and cooling demands are relatively constant with time, as is generally the case with chemical processing industries and continuous food processing plants (such as dairy plants). Meat plants however, generally have more batch processes and hence time variable heating and cooling demands making pinch studies more difficult. Chadderton (1995) suggested the need for improved software tools, which could be linked into an integrated meat plant utilities modelling package (Figure 1). Such software would allow engineers to size equipment, perform sensitivity analysis on plant operating procedures, and assess overall plant efficiency. Of the component packages shown in Figure 1, refrigeration loads and cycle software such as the RADS package (Cleland, 1985) and the MIRINZ package ***Refrigeration Loads Analyser*** (MIRINZ, 1995) have been commercially available for some time, and each can provide refrigeration heat loads versus time. Models of rendering plant energy consumption and plant wide hot and warm consumption have recently been developed and these will form the main focus of this paper. Development of process analysis and integration and site energy cost optimisation packages has not begun, but now that the underlying packages are all available it would be possible to commence work in this area.

2. Rendering System and Hot Water Analyser

Kallu (1993) developed dynamic mathematical models of meat plant rendering systems and hot water usage and tested some of the models against measured data. He developed rendering models for continuous dry rendering, batch dry rendering, and low temperature rendering (LTR) using gas-fired rotary dryers, batch heating and continuous conduction heating. Hot water modelling focused on water use in relation to production, heat recovery and hot water storage and generation.

In follow-up work MIRINZ has further tested and enhanced a number of Kallu's component models, developed new component models, validated the models against a wider range of measured data and placed the models in user-friendly software.

Models have been developed for:

- rendering system cookers and dryers;
- hot water generation (including heat recovery), storage and usage;
- steam boilers;
- blood coagulators;
- slaughter and boning room rendering chain operations; and
- raw material production.

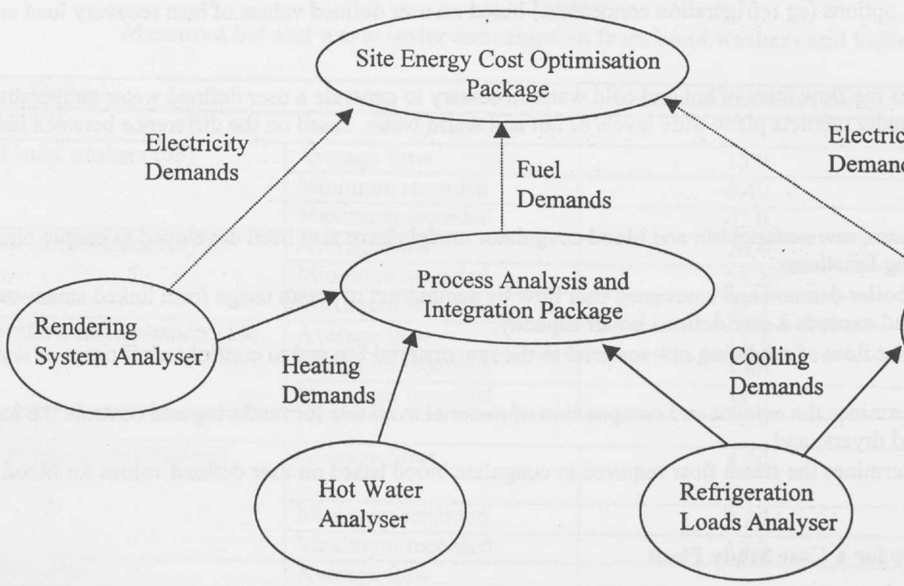

Figure 1: Proposed design of an integrated meat plant utilities modelling package (Chadderton, 1995)

The models have been implemented in user-friendly MS-Windows based software using icon representation for component models (Figure 2). The models are based on energy and mass balances and most contain ordinary differential equations, which are solved numerically. Full mathematical descriptions of the developed models are not given here, but are to be published.

2.1 Rendering Models

Models have been developed for batch and continuous dry rendering cookers, LTR vessels and LTR batch and continuous dryers (both conduction and gas-fired rotary). The models predict steam demand, flash steam flow rate and material temperatures, moisture content, mass and vaporisation rates.

The batch cooker model is derived from the model developed by Kallu (1993) and is based on energy balances on each of the cooker heating surfaces and the material within and a mass balance on the material in the cooker. Our model takes into account changes in heat transfer coefficients from heat exchange surfaces as functions of material composition during drying and the cookers shaft speed using empirical correlations developed using data measured by Mamers (1971) and Haughey (1973). Our model also calculates drying as a vaporisation process (with the vaporising rate taken as the rate which provided balance between the latent heat of the vaporising water and the net heat supplied to the material), rather than the evaporation approach used by Kallu.

Continuous cookers are modelled as a number of perfectly mixed zones linked together down the length of the cooker. Flow of material through the cooker is modelled using a combination of forced flow and mixing. Mixing between zones is based on a combination of zone mass differences, zone end-area differences or a user-defined mixing ratio. The model used for each zone of the continuous cooker is the same as that used for batch cookers.

LTR batch and continuous conduction dryers are modelled the same way as batch and continuous cookers, but using modified heat transfer coefficient calculations.

2.2 Hot Water Streams

Models have been developed for:
- water usage on slaughter floors or in boning rooms;
- hot water generation using steam heat exchangers;
- heat recovery from rendering system vapours and flash steam;
- heat recovery from other heat sources such as refrigeration condensers;
- mixing valves for generating warm water from hot and cold streams; and
- water storage tanks.

Kallu's models used what was described as "good practice" water consumption for water using devices. Our model requires the user to specify water using devices for each application (ie all devices used on a particular chain or boning room) and to specify the consumption for each. This allows the user to measure their actual plant water usage rates to assess current practice and thereby identify major areas for savings, or to input best practice values to obtain the optimum usage for their plant. MIRINZ has surveyed hot and warm water usage in several meat plants in Australia and New Zealand. Walford et al. (1994) provides tables of values measured in the New Zealand industry. These values along with those measured and reported by Kallu (1993) can be used as industry good practice values until a more comprehensive set of data becomes available.

Simple heat exchanger models were developed for generating hot water. The steam heat exchanger model determines the steam flow required to heat water based on user defined values for water flow rate through the exchanger, and input and outlet temperatures. The vapour condenser calculates the flow rate of cooling water required to condense vapour from cookers (or dryers) and/or flash steam based on user defined values for water input and output temperatures and condensate approach to the input water temperature. Water output temperature is determined for other heat recovery options (eg refrigeration condensers) based on user defined values of heat recovery load and water flow rate.

The mixing valve model determines the flow rates of hot and cold water necessary to generate a user defined water temperature and flow rate out of the valve. The water tank model predicts plant-wide levels of hot and warm water, based on the difference between linked supply and demand streams.

2.3 Other Models

Boiler, slaughter and processing chain, raw material bin and blood coagulator models have also been developed to enable plant-wide energy optimisation, and have the following functions:

- The boiler model predicts total boiler demand and associated fuel flow by summation of steam usage from linked steam-using models, and limits steam supply when demand exceeds a user defined boiler capacity;
- The chain model is used to predict flow of rendering raw material to the raw material bin and to control on/off times of water using devices;
- The raw material bin model determines the amount and composition of material available for rendering and controls the loading and starting of rendering cookers and dryers; and
- The blood coagulator model determines the steam flow required to coagulate blood based on user defined values for blood composition, flow and temperature rise.

3. Analysis of Heat Energy Flows for a Case Study Plant

3.1 Plant description and model parameters

This section will demonstrate how the software can be used to describe a meat plant, and then simulate steam and water consumption for calculation of plant-wide energy use and equipment sizing.

The plant to be studied is hypothetical, but is similar to a real plant. The plant is a beef plant, which slaughters 540 head over a 12 hour day. Energy consumption and water usage were predicted for each of three options (Figures 1 to 3):

- Option 1 uses a batch dry rendering system, has no heat recovery and generates hot and warm water with steam-heated heat exchangers;
- Option 2 uses the same batch dry rendering system as Option 1, but utilises heat recovery from rendering vapours for hot water generation and hot and cold water mixing for warm water generation; and
- Option 3 replaces the batch dry rendering system with a low temperature rendering (LTR) system utilising batch dryers and uses heat recovery from rendering vapours for hot water generation and mixing of hot and cold water for warm water production in a similar fashion to Option 2.

Options 1 and 2 both use six batch cookers for rendering. For each cook cycle the batch cookers are loaded with 3000 kg of raw material with the composition determined dynamically by the raw material bin model as a function of chain ad boning operations. During each cook a pressure cycle is used for material sterilisation. Each pressure cycle raises the internal pressure of the cooker to 3 bar (absolute) 20 minutes after the start of the cook, and then maintains this pressure for 30 minutes prior to venting. Each cook cycle lasts for a total of two hours, after which the cooker is emptied. Option 3 uses a LTR rendering vessel for cooking product and four batch dryers for drying product. The batch dryers are run in the same fashion as the batch cookers used in Options 1 and 2.

Hot- and warm-water consumption was measured at each point-of-use in a similar plant to that of the case study plant and the results are summarised in Table 1. Hot- and warm-water consumption were considered separately for the case study plant. The flow rates used for each device in the hot and warm water using streams were set equal to the measured average flow rates in the real plant. The same devices and flows were used for each of Options 1, 2 and 3.

3.2 Software predictions

The predicted boiler loading for each of the three options is given in Figure 5. In the existing plant (Option 1) the boiler supplys 265 GJ of energy in the form of steam. Option 2 substantially reduces the plant energy usage to 183 GJ, while Option 3 reduces it further to 123 GJ.

For Options 1 and 2 each batch cooker had six or seven cook cycles, while for Option 3 each batch dryer had five or six drying cycles. The predicted steam demand and material temperature for one of the batch cookers operating in Options 1 and 2 is shown in Figures 6 and 7 respectively.

The hot and warm water consumption for all three Options is given in Table 2. Option 2 had more hot water generated from rendering heat recovery than was utilised by hot and warm water using devices (Table 3).

3.3 Discussion

It is recognised that dry rendering systems consume more energy than LTR systems, and that further energy savings are possible by recovering heat from rendering vapours. However, it is often difficult to accurately determine total steam usage in such systems. The three options presented here demonstrate how the models can be used to assess energy consumption for different scenarios.

The total plant-wide steam demand can be used for sizing boilers, or conversely, the effect of boiler size on plant operations (rendering cooker performance, water temperatures etc.) can be assessed.

The predicted time-varying flow rate of rendering vapours to vapour heat exchangers can be used to size heat exchangers, and to determine total storage volumes of cold and hot water required.

Table 1
Measured hot and warm water consumption from hand washers and knife sterilisers

Device[1]		Instantaneous Flow (l/min)	Flow (l/carcass)[2]
Warm Water (43°C)			
Knee-operated hand washers (65)	Average flow	15.0	0.70
	Minimum recorded	5.40	0.03
	Maximum recorded	42.0	2.97
Sensor-operated hand washers (5)	Average flow	26.4	0.04
	Minimum recorded	25.2	0.04
	Maximum recorded	28.2	0.04
Continuous overflow hand washers (15)	Average flow	17.7	-
	Minimum recorded	4.80	-
	Maximum recorded	38.0	-
Hot Water (82°C)			
Continuous overflow knife sterilisers (73)	Average flow	4.70	-
	Minimum recorded	0.20	-
	Maximum recorded	19.2	
Gut Barrow Sterilisers	Average flow	-	16.0
Horn Saw Steriliser (1)	Average flow	5.20	-
Splitting saw sterilisers (4)	Average flow	6.00	-
Rod Sterilisers (2)	Average flow	4.20	-

[1] Figures in brackets signify the number of each device present in the measured plant.
[2] Flow not given for continuous devices

The excess water generated by rendering heat recovery (Table 3) is not uncommon in many meat plants and generally results in little effort to seek further efficiency gains. However, other uses of the recovered heat should be sought for improved energy efficiency. Possibilities might include using recovered heat for:

- preheating boiler feed water;
- running an absorption refrigeration system for corridor and boning room air conditioning; or
- heating raw material in LTR rendering vessels.

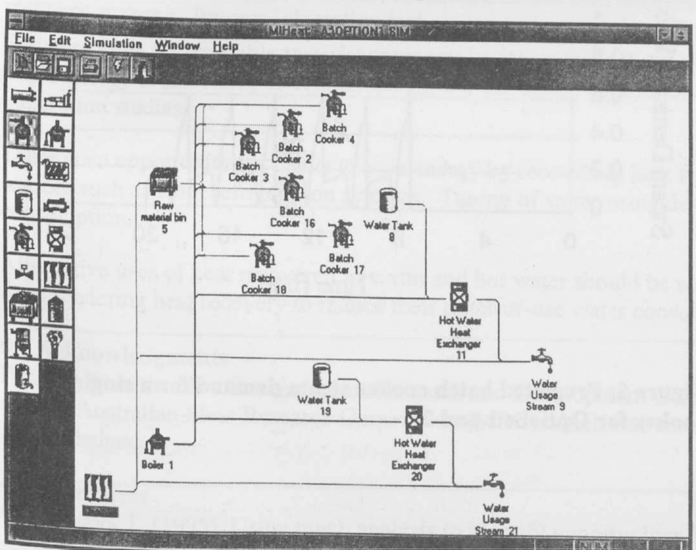

Figure 2: Plant set-up in the energy modelling software for Option 1. Water usage stream 9 represents hot water use and water usage stream 21 represents warm water use (full software screen shown).

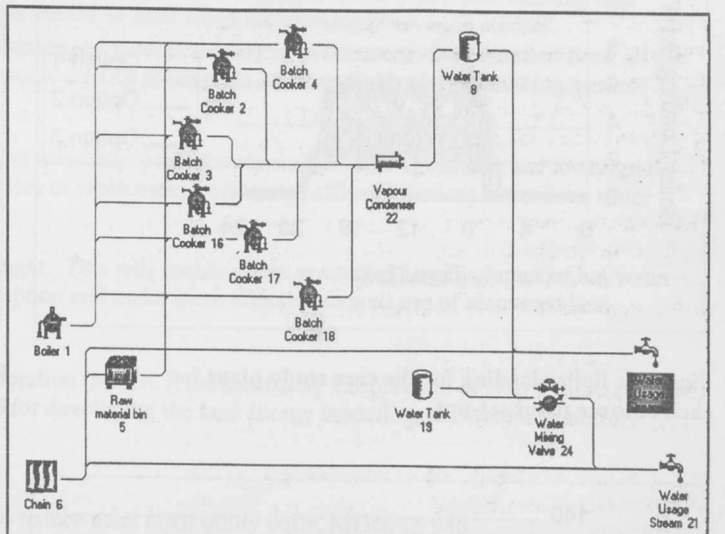

Figure 3: Plant set-up for Option 2. Water tanks 8 and 9 represents hot water storage and cold water supply respectively. Water usage streams 9 and 21 represent hot and warm water use respectively (plant window only shown).

Although Option 3 has a good balance between water use and water generated from heat recovery, savings are still possible, as the point-of-use values measured in the plant and used in this analysis are higher than the good-practice values given by Walford et al. (1994). There was a large range of measured instantaneous flows for the plant studied (Table 1), thus tuning the devices with excessive flow rates could easily reduce the average value. Using best practice figures for hot water use would reduce hot water consumption from 255 m^3 to 170 m^3.

Point-of-use reduction in water consumption should be considered as the starting point for hot and warm water energy savings with consumption monitoring of all significant water using devices undertaken and adjustment of those devices using excessive water volumes. For example, Walford et al. (1994) found that hot water savings of 25% could be made by simple adjustments to water using devices in a New Zealand beef plant. Equipment modifications such as converting from continuous overflow type devices to intermittent devices can further reduce water consumption. Studies undertaken by MIRINZ suggest that viscera tables, and any continuous overflow knife sterilisers or hand washers are the most significant water using devices.

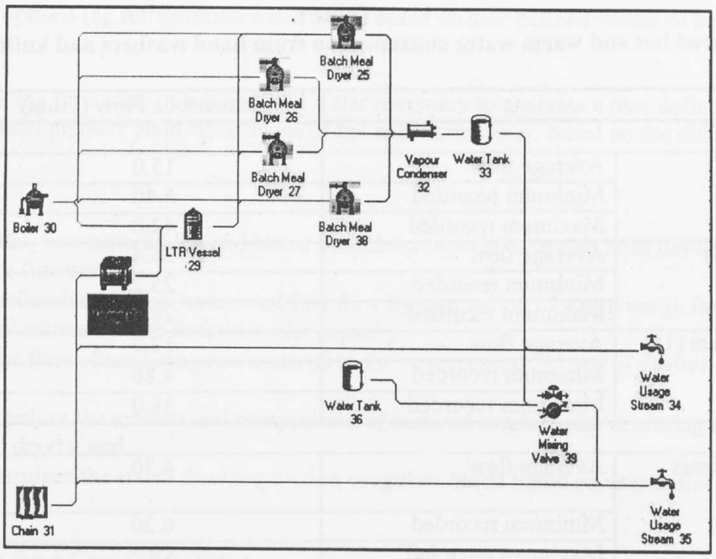

Figure 4: Plant set-up for Option 3. Water tanks 33 and 36 represent hot water storage and cold water supply respectively. Water usage streams 34 and 35 represent hot and warm water use respectively (plant window only shown).

3.4 Use of the rendering and hot water software in overall plant energy management

The software provides engineers with a new tool for evaluating time-varying energy flows in meat plant rendering systems and hot and warm water consumption. A range of plant designs and operations can be quickly assessed for overall energy use and water consumption. In addition, boiler, heat exchanger and water storage tank sizing can be better matched to the time-variable nature of heat loads and water usage in most meat plants. Selection of smaller equipment, with lower capital cost, should result.

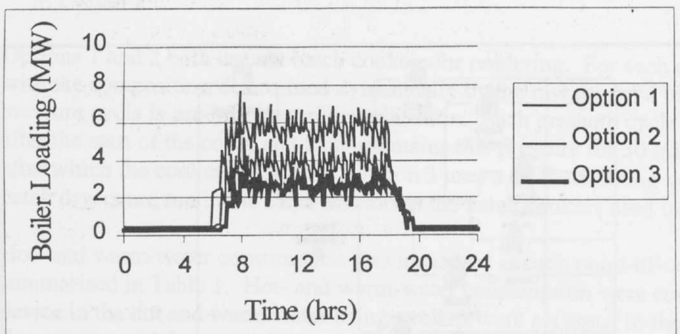

Figure 5: Boiler loading for the case study plant for each of three plant set-ups

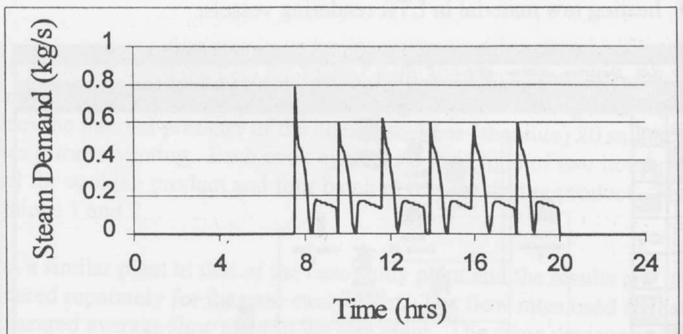

Figure 6: Predicted batch cooker steam demand for a single cooker for Options 1 and 2

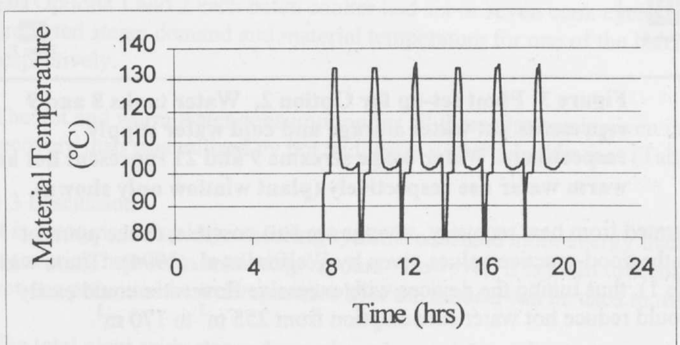

Figure 7: Predicted material temperature within a batch cooker for each of six cook cycles for Options 1 and 2

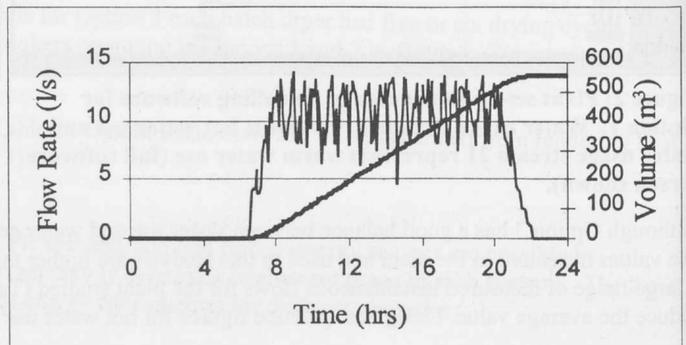

Figure 8: Predicted cooling water flow rate and cumulative volume from the rendering vapour heat exchanger for Option 2

Table 2
Water usage for Option's One, Two and Three

Water Use		Total Usage (m^3)	Water Source		
			Steam heat exchanger	Rendering vapours heat recovery	Cold water for mixing
Option 1:	Hot water using devices	255	255	0	0
	Warm water using devices	215	215	0	0
	Total Consumption	470	470	0	0
Options 2 & 3:	Hot water using devices	255	0	255	0
	Warm water using devices	215	0	80	135
	Total Consumption	470	0	335	135

Table 3
Excess Water Generation from Rendering Heat Recovery for Options Two and Three

Option	Water generation from rendering vapour heat recovery (m^3)	Hot water usage (m^3)	Excess Heat Recovery Water (m^3)
1	553	335	222
3	329	335	-6

Overall plant energy optimisation should be undertaken using some form of process integration, such as pinch analysis. The time-varying heat loads and water usage predicted by the software presented in this paper would provide valuable input data for an overall process integration package which optimised plant-wide energy use from all major energy users (refrigeration, rendering, hot and warm water). The software described in this paper is the last of the underlying models for an overall process integration package to be developed and commercialised. Work should now focus on developing process analysis and integration and site energy cost optimisation packages which use the time-variable heat loads predicted from the existing refrigeration, rendering and hot water software.

4. Summary

Plant-wide energy optimisation requires use of models that can predict the time-varying energy consumption of each component, and interactions between components. Point-of-use studies can help identify and reduce energy consumption from individual components. Without plant-wide analysis, however, reductions in one area may create difficulties in other areas, particularly in plants utilising heat recovery systems. Process 'ntegration techniques such as pinch analysis should be used when undertaking plant-wide studies. Software tools are available to assist engineers in determining the magnitude and time-variability of plant energy consumption from all the major energy users: refrigeration, rendering and hot water. Additional tools are still required to assist engineers in undertaking process integration studies.

There is an opportunity for plants to save energy by recovering heat from non-traditional sources such as drainage water, and lower grade sources such as from refrigeration systems. Tuning of water using devices or replacement with more efficient devices can reduce water consumption.

Alternative uses of heat recovered as warm and hot water should be sought. This will enable plants producing large volumes of hot water from rendering heat recovery to reduce their point-of-use water consumption and make more effective overall use of recovered heat.

5. Acknowledgments

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6. References

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