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Importance of Understanding Variable and Transient Energy Demand in Large Multi-product Industrial Plants for Process Integration

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Two case studies are presented to highlight the value of understanding variable and transient energy demand of a plant as a precursor to developing Process Integration (PI) and energy cost reduction solutions. A dairy factory example illustrates how heat recovery combined with thermal storage is vital for smoothing out variable energy demand of dissimilar processes coming offline for regular cleaning. A batch pulp mill example illustrates how large steam swings occur even with evenly scheduled batch cycles and that process modifications through dynamic analysis and modelling can lead to reduced peak steam swings and reduced supplementary gas boiler costs.

1. Introduction

Many industrial plants experience variable energy demands due to a multiplicity of factors. Short term variations may occur due to natural fluctuations in stream temperatures and/or flow rates. Longer term variations may occur due to scheduled production interruptions for cleaning or washing, changes in production rates and product grades, plus seasonal and feedstock changes. Understanding both the short and long term variability of plant energy demand is therefore important when seeking enhanced PI and energy saving opportunities.

In low temperature pinch applications, such as dairy, integration using heat recovery loops can be designed better when the variable nature of the demand is understood. The heat storage and the control requirements of the heat recovery loop can be matched better to the system and more heat recovery is possible (Atkins et al., 2009). Likewise a key element in the integration of renewable energy is the need to understand the variation in both supply and demand (Atkins et al., 2010). In batch scheduling the effect of predetermined demand changes on the utility load is also worth understanding to identify credible PI solutions that minimise energy costs. Previous researchers have considered the challenge of integrating semi and non-continuous processes (Klemeš and Varbanov 2010). The Time Slice Model developed by Kemp and MacDonald (1988) has typically been employed on batch processes. Mixed Integer Linear Programming has been applied to batch scheduling and HEN design problems (Foo et al., 2008). Constraint Logic Propagation methods have also been applied for energy targeting of process plants under fuzzy process conditions, i.e. the stream variables vary about the

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average (Noureldin et al., 2009). However, accounting for large and random variations in stream flows in PI solutions is very process sensitive and therefore analysing case studies to look for common PI themes has merit.

2. Dairy factory case study and CIP cleaning

Dairy factories maintain clean hygienic equipment to ensure the production of safe to eat dairy products. Process units and ancillary equipment such as heat exchangers, pipes, valves, pumps, ducts, fans and filters must be regularly cleaned to avoid microorganism buildup in the process. Hot 50° C water in combination with hot caustic and hot acid rinses is typically used in cleaning. A lot of hot water (HW) is required and Cleaning-In-Place (CIP) related energy can account for up to 25 % of total factory energy demand. Plant cleaning by nature is intermittent and extremely variable. In large dairy factories, involving many plants, the variable cleaning schedules combine to produce an overall HW use profile that is less variable than a single plant yet still highly variable compared to the average demand. In Figure 1 the CIP HW storage system for a large dairy factory involving four plants (A, B, C and D) with different CIP requirements is presented. CIP HW is produced through heat integration of fresh water with evaporator waste heat via the COW water stream. The 50 °C HW produced is then stored in a large insulated tank or tanks ready for use by the various plants. In the system the HW storage capacity is a critical parameter. If HW demand exceeds the level of HW generated using recovered heat, costly hot utility (steam) must be used to supply the deficit and the amount of required utility can be decreased and more waste heat recovered through optimising storage capacity and the cleaning schedules.

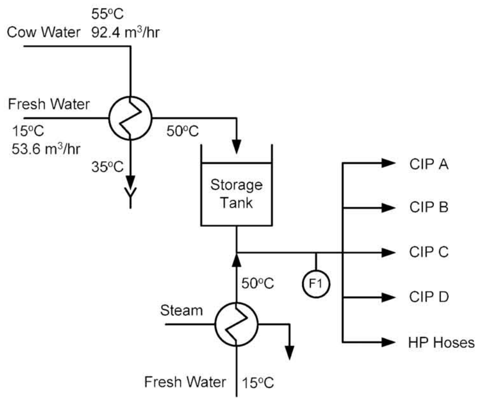

Figure 1: Schematic of dairy factory CIP hot water storage system.

Overall CIP HW demand for all plants (A, B, C and D) and the high pressure hoses has been measured at 'F1' using a non-intrusive ultrasonic flow meter. Results for six days of measurement are summarized in Figure 2a. Over a 24 h period, HW demand changed dramatically from 30 to 154 m^3/h (Fig 2b). Sorting the flow data from lowest to highest and plotting as a percentage of a day the dynamic characteristic of each of the six days measured are shown to be similar with an average around 53.4 m^3/h (Fig 2c). Across a single hour variability is more distinctive and in some parts regular (Fig 2d), however when all 144 h of the six days measured are plotted, using the sort method previously described, hour to hour HW demand is confirmed to be extremely variable (Fig 2e). Hourly averages vary by several 100 %. HW storage and HW inflow to the tank is therefore critical for maintaining HW supply in such a variable situation.

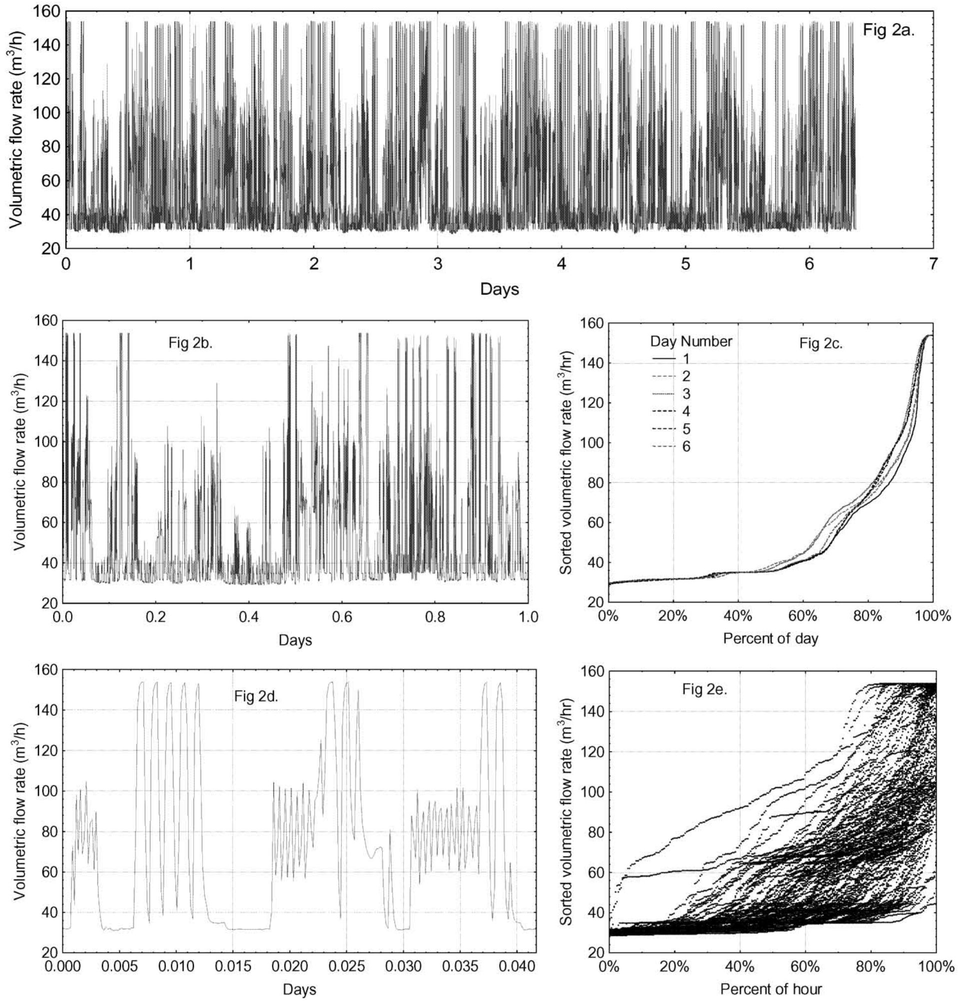

Figure 2: (a) Overall CIP hot water energy demand from a large dairy factory. (b) CIP water demand for one d, (c) Sorted one day CIP water demand repeated for 6 d, (d) CIP water demand for one hour, (e) Sorted hourly CIP water demand repeated for all 144 h.

A spreadsheet model was developed to evaluate the sensitivity of HW storage volume and HW inflow rate on steam top up requirements. Outflow data at 'F1' over a six day period was used in the model. When the tank emptied (zero level) the extra HW, over and above the inflow rate, was assumed to be supplied by fresh water through a steam heat exchanger. Results for an 80 m^3 tank and inflow rate of 2 % under the average flow are presented in Figure 3 in terms of tank level and cumulative steam load. When the tank is full, COW water heat is not able to be recovered. When the tank is empty, steam is used to supplement the demand. The trade-off between tank volume and steam load is illustrated in Figure 4. With an increasing tank volume, less steam needs to be used to meet the variable demand and more waste heat is able to be recovered from the COW water. Steam requirements are also very sensitive to the inflow rate and this is also illustrated using the model in Figure 4.

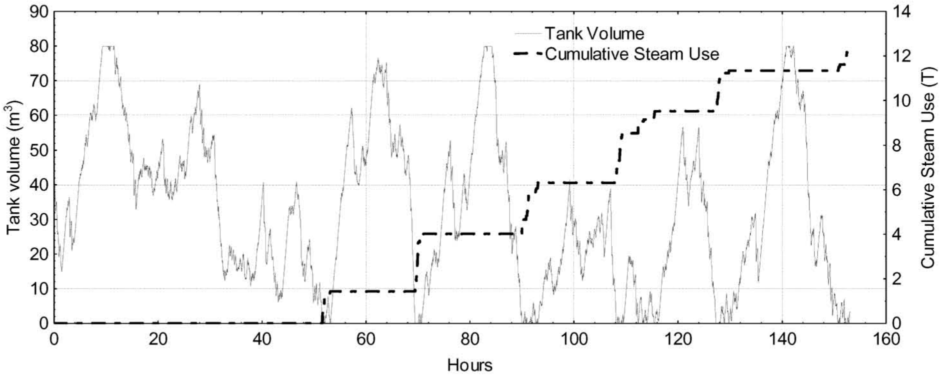

Figure 3: Tank volume fluctuations and cumulative steam top-up requirements for an 80 m^3 storage tank and 52.3 m^3/h inflow system (2% below average of 53.4 m^3/h), for an outflow profile shown in Figure 2a.

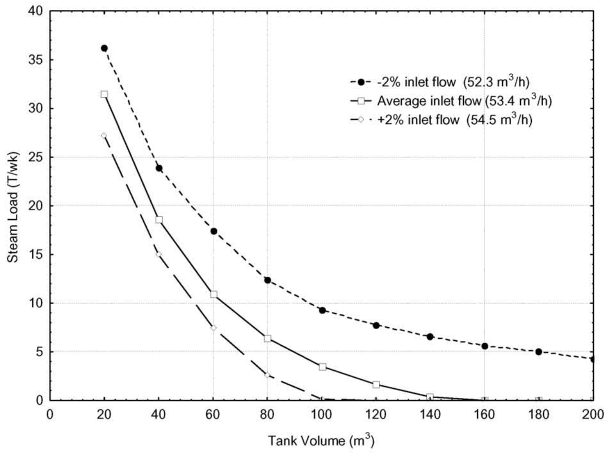

Figure 4: Effect of storage tank volume and inlet flow rate on steam load for CIP hot water heating based on measure plant demand at point F1.

With only a 2 % decrease in inlet flow rate from 53.4 to 52.3 m^3/h steam demand increases by about 6 T/h regardless of the volume of the tank. Measuring the overall HW use profile enables the cost benefit analysis of using more tank volume to be accurately assessed.

3. Batch pulp mill case study

Chemical pulp mills use large amounts of steam as part of the preheating and cooking of wood chips in the chemical pulping operation. When batch pulping is employed large variations in steam usage arise with each cycle (Figure 5). To reduce flow variability downstream and to maximize capacity, multiple batch pulpers or digesters run in regular sequence and blow into large silos. Downstream from the digesters the process runs continuously and PI opportunities in that part of the mill can be evaluated using standard pinch methodologies. Around the batch digesters dynamic analysis is required.

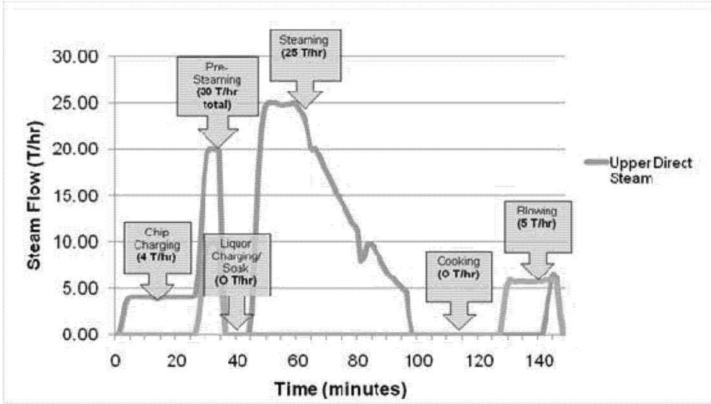

Figure 5: Typical steam use per batch digester cycle at a pulp mill.

Running multiple batch digesters in sequence creates a complex steam flow demand profile illustrated in Figure 6. Steam swings 150 % above a base load of 40 T/h occur at periodic locations in the sequence.

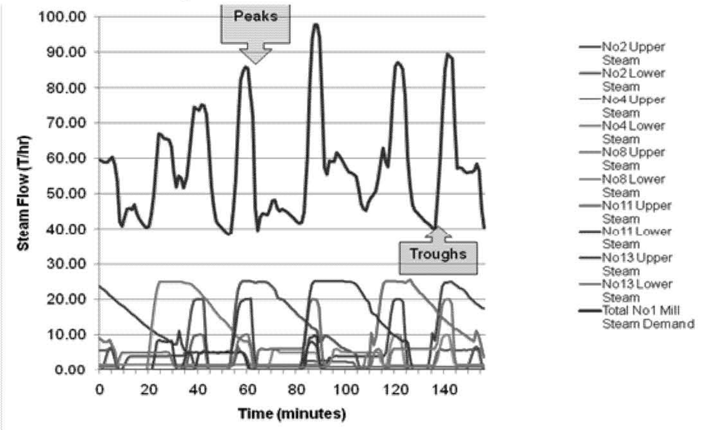

Figure 6: Illustration of steam swings arising from sequential batch pulping.

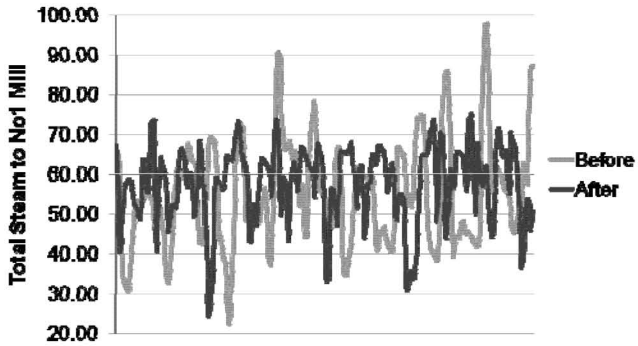

Figure 7: In plant modifications lead to significant reduction in peak steam demand.

The large steam fluctuations create a challenge for the mill to meet peak steam demand without burning imported gas in a fast responding boiler. Creating steam from wood waste and black liquor is the preferred and cheapest option, but responding to large steam swings is hard to do in these slow responding boilers. A steam swings minimization project was initiated at the mill with the aim of leveling out steam demand without affecting pulp quality. After dynamic analysis and modeling, several in plant process modifications were proposed and eventually implemented and steam use peaks reduced considerably to yield significant energy and costs savings to the mill.

4. Conclusions

Processes involving variable and transient energy demand require a dynamic analysis and modelling approach to find credible PI solutions. In plant utility profiling provides real-time dynamics that can be used for heat storage optimisation, flow rate range targeting and batch process or scheduling modifications.

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