Heat recovery in the textile dyeing and finishing industry: lessons from developing economies

Khalil Elahee
Faculty of Engineering, University of Mauritius

Abstract

Many developing countries, including African ones, look forward to developing strong integrated textile industries to add value to already-available raw materials. Dyeing and finishing activities are, however, energy-intensive. In many cases, these depend on imported fossil fuels. By turning to heat recovery, significant cost savings can be achieved improving profitability and competitiveness. The techniques and technologies of heat recovery from waste water and exhaust air are analysed. Experiences prove that in most cases heat recovery requires low investment and has a low payback of normally less than 2 years. The case of the Mauritian dyeing and finishing industry is highlighted, including the possible use of a low-cost heat recovery unit made from indigenous resources.

Keywords: heat recovery, textile energy management, mauritius, dyeing, finishing

1. Introduction

Many African countries produce textile raw materials of high quality, for example, cotton. The emergence of a textile industry can have a multiplier effect on their economy. The textile industry is capable of serving as a poverty reduction establishment, employing people on the farm, factory and garment production units. Additional people will be employed as distributors and merchants in textile materials and clothes (Adhama, 2009).

The advent of the Africa Growth Opportunity Act (AGOA) in the US and the end of the Multifibre Agreement in the EU have opened up new markets for Africa. At the same time, textile industries have moved from countries like Japan, South Korea, Hong Kong and Taiwan to other places, including African countries, where labour costs are lower and raw materials are readily available.

However, a major problem faced by textile industries in developing countries has been rising production costs, particularly energy (Kasita, 2009). In many cases strict environmental standards are called for, along with a reduction of reliance on imported fossil fuels. Whilst dyeing and finishing activities add value to the production chain, the fact is that they are highly energy-intensive. This paper focuses on lessons where heat recovery has brought significant cost reduction in textile dyeing and finishing. The focus is on steam utilization in textile mills.

2. Heat recovery from water

Re-use

The first heat recovery option to consider is the re-use of the hot wastewater. In this way, water, residual chemicals as well as energy are recovered. In textile dyeing and finishing, operations involving acrylic fibres or wool where colourants are exhausted, wastewater re-use is possible. Similarly, wastewater from rinsing operations can make up new baths, for instance, for scouring (Phipps, 1974). Dyeing and finishing specialists claim that wastewater from light shade operations can be re-utilised up to 20 times.

Cooling water recovery

Cooling of baths is a common operation. The utilisation of cooling water, that is, of a stream of cold water to absorb heat from the hot bath, can also be considered as a heat recovery process. Subsequently, cooling water is collected and re-utilised, thus, recovering heat and water. Under the most favourable conditions, cooling water recovery has been reported to have a payback period of 12 months (ITF, 1981).

Localised heat recovery (energy recycling)

Equipment such as washing-, mercerizing- and bleaching-machines often operate continuously for long hours, requiring a large volume of hot water and produce an equal volume of hot waste water simultaneously. A characteristic feature of some

technology is the incorporation of heat exchangers on such textile machines with the purpose of heating up the incoming cold-water stream with hot wastewater leaving the machine.

Centralised waste water heat recovery

Batch or non-continuous processing is common in many plants. Thus, a large volume of wastewater is available intermittently from several machines at different locations in the plant. If wastewater can neither be re-used nor can its heat be recovered locally, the feasibility of installing a centralised heat recovery system should be investigated.

The system involves storing hot wastewater in a large tank from where a hot stream is pumped to a heat exchanger in order to warm up process water. Experience has shown that the payback period is invariably more than 12 months and a payback of 18 to 36 months is common (EEO, 1992a; Pozzi, 1982; ITF, 1981). The importance of an in-depth feasibility study should not be underestimated – examples in the literature have shown that in some cases, the payback period can extend over more than 10 years in spite of the availability of a large volume of waste water at high temperature (Woodall *et al.*, 1976). Figure 1 shows a typical set-up for centralized waste water recovery.
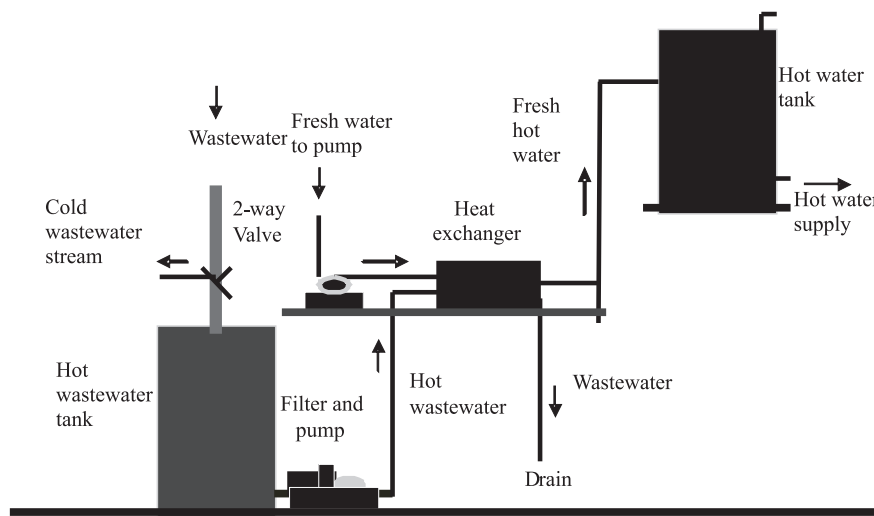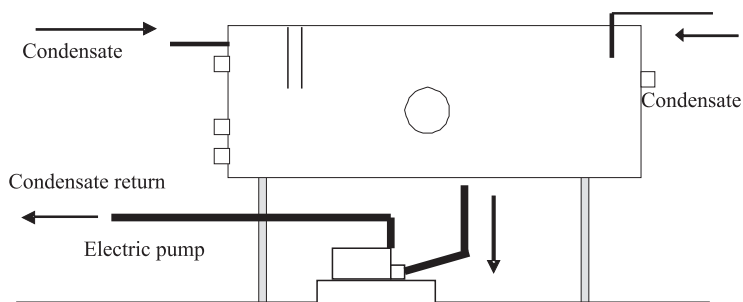
Condensate recovery

The fuel consumption in a dyeing and finishing plant should decrease by about 1% for every 6°C rise in the boiler feed-water temperature (EEO, 1984a). As it is pure and it has a high temperature, condensate should be returned to the boiler unless the user site is far from the boiler-house or contamination is a risk. However, a low efficiency in condensate recovery is common due to problems with the condensate network and with flash steam recovery. Figure 2 illustrates a typical condensate recovery system.

Waste-water heat exchangers

Shell-and-tube and plate heat exchangers have been used with mixed results in heat recovery in industry (Finbeiner, 1987; Raymand 1984; APV, 1996). The latter is generally preferred to the former because its heat transfer efficiency is higher by 3 to 5 times. Plate heat exchangers require less capital investment than shell-and-tube heat exchangers made of materials like high-grade stainless steel, essential to resist corrosion due to textile wastewater. However, both are affected by fouling (Finbeiner, 1987).

Thus, designers in the 1980's introduced a new concept aimed at attaining high heat recovery effi-

Figure 1: Centralised waste water heat recovery

Figure 2: Pump and condensate receiver

ciency and at preventing the problem of fouling, for example, due to textile wastewater. The design has been marketed as the spiral flow or the rotary heat exchanger.

The above heat exchanger has the following characteristics:

- It can work without filters and is self-cleaning as a result of the rotation of the scroll preventing the accumulation of fibres, particulates and other foulants.
- Heat exchanger efficiency is enhanced as a result of agitation caused both inside the scroll for the fresh water stream and outside the scroll for the wastewater stream.
- The pressure drop due to wastewater flow is lower than in the case of other heat exchangers and negligible power is needed to rotate the scroll at low speed.
- Less space is required for the heat exchanger than for a shell-and-tube heat exchanger for the same heat recovery duty. Unless the heat exchanger is used on continuously operating machines, storage tanks will also be required.

The spiral flow or rotary heat exchanger had a payback of less than 12 months if applied on continuously operating machines with high wastewater flow. A survey in 1987 in the UK showed that 26 % of textile dyeing and finishing plants proposed to adopt the latter heat exchanger (DoE, 1987). Such units have been used for decades to date in different plants. (Crawshaw, 1995; Wright, 1995). Figure 3 shows the layout of such a heat-exchanger.

3. Heat recovery from air

The evaporation of water is an energy intensive process – at least half of the energy consumption in dyeing and finishing is usually due to drying in several cases (Brookstein, 1979; Ratna *et al.,* 1981). There is also potential to reduce the latter figure by as much as 50% (EEO, 1985). Most of the saving is due to simple low-cost measures such as mechanical de-watering and good housekeeping. After the application of the latter, heat recovery from hot air exhaust is the next stage of Energy Management. As

reported by Reay (1979), the potential of hot air exhaust heat recovery is significant, second only to the potential of heat recovery from wastewater.

Characteristics of hot air exhaust heat recovery
a) Hot air exhaust in industry is from two sources:

- Thermofixation and similar finishing processes produce dry air exhaust at about 180°C. Organic chemicals, dyestuffs, oil droplets, particulates, fibres and mist are normally present in the exhaust (Lavoignet, 1985).
- Drying is the predominant source of hot humid air exhaust. Typically, its latent enthalpy is more than 50% of its total enthalpy and its dry bulb temperature is about 150°C. Fibres and fluffs are often present in the exhaust. Heat recovery involves recuperating the latent enthalpy of moisture in the exhaust (Prabhu *et al.,* 1981).

b) It is not uncommon in industrialised countries to have scrubbers, electrostatic precipitators or filter bags installed to remove particulates or trace gases from the hot air exhaust – the particulate level often exceeding 1 kg per hour (KOENIG AC, 1995; Hindman, 1977). Coupling of heat recovery and environmental control has also been reported in the literature, for example, a heat exchanger and an electrostatic precipitator can be implemented (see Figure 4).

c) The installed cost should not be underestimated – it can be between 1.5 and 4 times the cost of the heat exchanger (Reay, 1979). Maintenance costs also are significant if fouling of the heat exchanger is to be prevented.

Hindman (1977) briefly reviewed the characteristics of air-to-air and air-to-water heat exchanger systems. In general, matching the high temperature stream with the low temperature stream in the heat exchanger is easily achieved if hot air exhaust can be used to warm up the inflow of fresh air. Such systems are highly practical for use in the dyeing and finishing industry. Several types of heat exchangers have been commercialised and details are provided
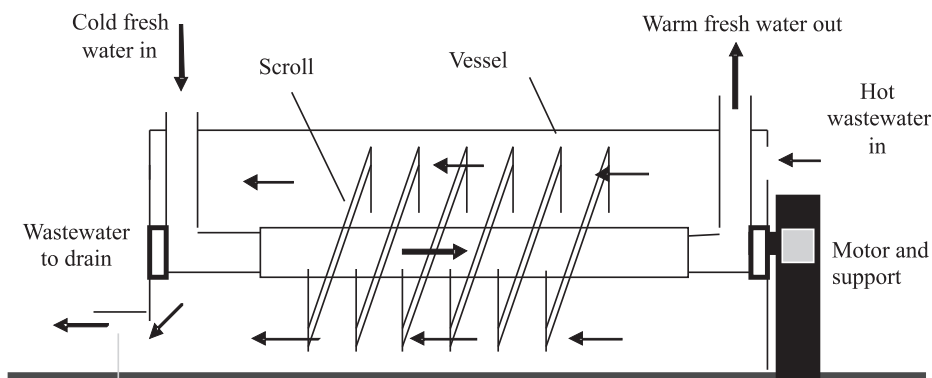
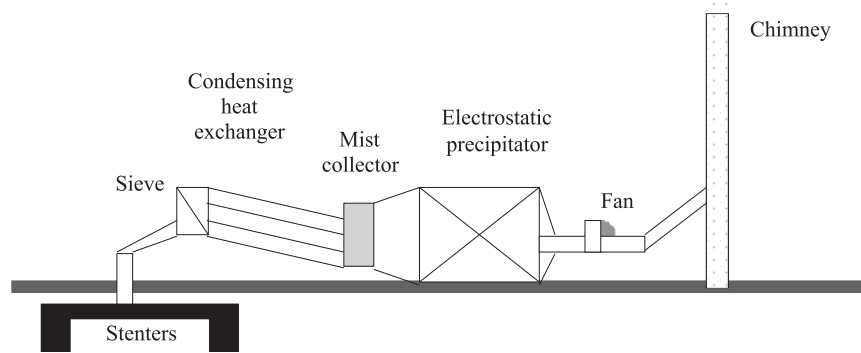**Figure 3: Spiral or rotary heat exchanger**

Figure 4: Coupling heat recovery and environmental pollution control

in the literature by Reay (1977) and Applegate (1983). The properties of heat exchangers for hot air exhaust heat recovery in the textile industry are summarized in Table 1.

4. Alternative developments

Apart from the increasing use of Information Technology, steam utilization is also characterised more and more by the use of gas as combustible and the decentralisation of steam production. However, decentralised steam supply needs high capital-intensive investment and the payback period is generally more than 2 years (ITF, 1991; EEO, 1991; EEO, 1992). The potential to lower energy consumption by more than 20%, the reduction in process time, the absence of steam starvation and the avoidance of production bottlenecks are strong reasons for shifting to decentralised generation.

Gas is practical for use in direct water heaters and directly fired dryers – it is also more environmentally friendly than coal or fuel oil. An interesting technique under research currently involves a gas-fired heater used to superheat steam generated from conventional boilers – drying and finishing of

textiles with super-heated steam is reported to yield positive results in terms of quality, productivity as well as energy efficiency, although the rate of heat transfer may have to be carefully monitored (Luiken, 1997).

Other developments have occurred in the form of process improvements and the use of recovery techniques. The former refers to new process design, often associated with the use of Information Technology, to minimise not just steam consumption but also that of water and chemicals, to reduce process time and to enhance quality (Anon., 1993). Examples include non-stop processing (Meyer, 1995), single stage preparation (Anon., 1990), solvent dyeing (ITF, 1991), use of low liquor ratio and high speed processing (Meyer, 1995). A wide variety of recovery techniques have also been experimented such as heat recovery by exhaust air incineration (KOENIG AG, 1995; Ramaszder, 1992), suction slot dewatering (EEO, 1990); and the application of heat pumps to recover energy from waste water (ITF, 1991; EEO, 1984). The investment required to implement the above is invariably high. Except in rare cases, such as in the case of suction

Table 1: Properties of heat exchanger for hot air exhaust heat recovery in the textile industry

Type of heat recovery							
	Recirculation	*Tube heat exchanger*	*Plate heat exchanger*	*Thermal wheel*	*Heat pipe*	*Run-round coils*	*Direct contact cooler*
Cost	Low	Moderate to high for alloy material and finned	Moderate	Moderate to high	Moderate to high	Moderate to high	Low
Fouling	No	Likely unless cleaning *e.g.* use a sprinkler	Likely	Likely	Not likely	Likely	No
Cross-contamination	A high risk	No	No	Low only if purges included	No	No	Yes
Efficiency of heat recovery	Up to 30%	50–70%	60–80% with moisture recovery	Up to 80 %	50–70 %	50–60%	Up to 95%
Overall payback (estimated	Few months	Normally 2–5 years	More than one year	Variable but 3 years common	More than 2 years	Variable	Few months

slot dewatering, the payback period is above two years.

Cogeneration or combined heat power (CHP) systems

A CHP plant generates electricity and the residual energy is used for heating purposes (Energy Management, 1997; IEEF, 2000). Thus, at least part of the electricity demand of the plant is met by on-site production. Apart from the reduction of the exergy loss and the effective reduction in carbon dioxide emission, the two main advantages of CHP are in terms of an extended autonomy in electricity supply and a substantial saving in energy of typically about 40% (Hughes et al., 1996). CHP units to generate compressed air and to provide hot water for processing (ITF, 1991) are attractive.

For the following reasons, large scale CHP may not be viable in the latter plants:

i.   The capital investment, estimated at more than USD 1 million, is very high.
ii. The system is thermally oversized as the heat demand is relatively low – normally no space heating is needed in many tropical countries.
iii. Institutional and structural facilities such as favourable energy pricing, including electricity tariffs, and incentives to cut down carbon dioxide emissions are currently lacking.

It is to be noted that a CHP unit has been running in a textile dyeing and finishing plant in Mauritius for a couple of years since 2001 generating as much as 1 MW of electricity. However, due to the absence of a proper Energy Management framework within the plant, the CHP unit stopped operating. There was also insufficient institutional support to help the experience continue and become sustainable in the long-term.

Process integration

The maximum utilisation of high grade energy is subject to an optimisation of the heat exchange network, that is, an optimum matching of hot and cold streams (steam, hot water, cooling water, waste water, hot air exhaust, flue gas, etc.). A technique of Process Integration to achieve such a result has been developed (Eastop et al., 1990; Jacques et al., 1988). Such a procedure has been tried in the design and operation of batch processes resulting in an energy saving of up to 40% in the chemicals industry (EEO, 1994).

Process integration is relevant provided that:

i. Processes occur as a pre-determined sequence of large batch, semi-continuous or continuous operations rather than as a random series of small batch operations.
ii. Quality and productivity are not adversely affected.
iii. Process Integration is considered right from the design stage of the plant together with the feasi-

bility of installing heat exchangers, heat pumps and CHP units. An integrated thermo-economic analysis is necessary.

Substitutes for steam

To avoid low energy efficiency in the use of steam, one solution is to avoid using steam. Several such techniques already exist, e.g. direct gas firing and thermal fluid heating (Prabhu et al., 1981 (5); EEO, 1992c). Others are appearing in response to the need of improving productivity and quality or of protecting the Environment. But steam remains by far the main energy-carrying medium employed in the textile dyeing and finishing industry, particularly in the African context.

5. Case Study: Mauritius

The case of the textile dyeing and finishing industry in Mauritius has been investigated thoroughly (Elahee, 2001). Energy Management was applied to optimise the use of steam in dyeing and finishing plants, leading directly to the achievement of two critical objectives:

• Modernisation; and
• Sustainable use of energy.

The current state of Energy Management in the dyeing and finishing industry had similarities with that of its European or North American counterparts before the oil crisis of the seventies. The dyeing and finishing industry in Mauritius consumed about 35 000 tonnes oil equivalent annually for steam generation, mostly in the form of fuel oil and coal. The potential reduction in fossil fuel consumption was about 35% in small textile dyeing and finishing plants and 25% in large ones. Out of the latter, 15% and 10% respectively of the fossil fuel consumption can be saved with heat recovery, that is, essentially with low cost, short payback energy saving measures.

Strategies were identified to facilitate the implementation techniques and technologies in terms of the Energy, Technology and Energy Management requirements. Institutional support measures were proposed introduced with a twin-fold aim:

• Promote voluntary initiatives in industry
• Fund Energy Management programmes.

The following five measures represented innovative approaches, particularly, in the context of developing countries:

a) Energy Tax
b) Energy Management Framework (EMF)
c) Energy Management Office (EMO)
d) Different incentives such as loans, grants and cost-sharing investments in Energy Management technology are proposed
e) Discrimination is made between large and small dyeing and finishing plants in terms of their needs and appropriate programmes are proposed.

Different scenarios in terms of tax regimes and different models of the textile dyeing and finishing industry were analysed. The overall results for three-year EM programmes in small and in large dyeing and finishing plants were as follows:

- The share of LPG levelling at 3% of the fossil fuel consumption in dyeing and finishing plants in 1995 should increase to more than 10%. Coal usage estimated at 38% in 1995 should gradually decrease and, in the long term, be eliminated.
- Fossil fuel consumption should decrease by 15% in the first year and by another 15% in the next two years for small plants. In large plants, the corresponding figures were 10% in the first year followed by a further 10% in the next two years.
- The above targets were possible through the application of the following listed in order of priority:
  i.   Low-cost, energy-saving measures including waste heat recovery and reduction of live steam usage;
  ii. Planned maintenance, good housekeeping as well as the education and training of personnel;
  iii. LPG-related clean production technology, low-liquor ratio processing and use of Information Technology (automation);
  iv. Recycling and recovery of energy, including waste water heat recovery;
  v.   Solar heating and small-scale CHP.

A low cost and practical solution was proposed to the problem of waste heat due to textile wastewater, the most important source of heat loss in the dyeing and finishing industry. The proposed heat recovery unit was made locally and was applicable to low-volume batch processing, common in small plants. For each small dyeing and finishing plant, the reduction in fossil fuel consumption could attain up to 10% with a payback period as low as 9 months. The unit is illustrated in Figure 5.

6. Conclusion

- Techniques and technologies of implementing Energy Management, including heat recovery, in the use of steam in the textile industry vary extensively in terms of the scope of their application, their costs and their benefits. Energy Management takes the shape of a highly flexible tool with the capacity to influence the modernisation of industry in variable ways. With rising energy prices, Energy Management in industry is more urgent than ever as steam in most countries is invariably generated from imported fossil fuels.
- The introduction of low cost techniques and technologies should yield significant reduction in steam consumption in plants, where Energy Management has not been applied before. This is the case of many African countries where the dyeing and finishing industry is new, in some cases, even transposed from those in other countries.
- Although, new technology is relatively expensive, its benefits extend far beyond savings in energy. Quality, productivity and response-time gains as well as environmental benefits are significant. If properly applied, the overall payback for investment in such technology can be reduced to not more than two years. However, investing in such technology is not without risks particularly in view of the fact that these are not indigenous to developing countries in almost all cases – know-how transfer and ancillary costs should be duly considered. The progress of such technology should also not be at the expense of indigenous techniques and technologies.
- Mechanisms should be defined in order to facilitate the selective and timely introduction of Energy Management techniques and technology. The needs of modernisation and of sustainable energy use for industry justify the introduction of new institutional, regulatory and financial measures. Developing countries can tap the potential of heat recovery more easily if there are such mechanisms. Otherwise, there will be little incentive towards optimization of energy usage.
- Examples from the past show that there is significant scope to reduce production costs related
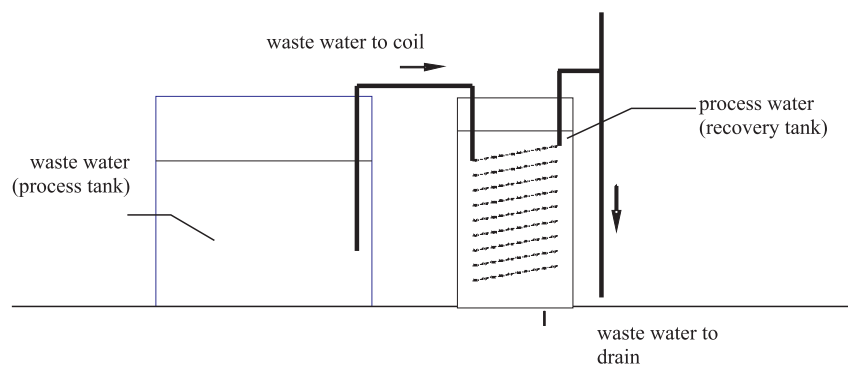

Figure 5: Coil heat exchanger for heat recovery from waste water to process water

to steam in textile dyeing and finishing plants in developing countries, including African countries. In most cases, no significant investment is needed and local indigenous technology and skills can be employed. The payback is normally less than 2 years. Heat recovery, in particular, will improve profitability and competitiveness on the international markets. Reduced reliance on imported fossil fuel will be achieved, hence, putting the industry safe from rising oil or coal prices. The reduction in global and local pollution is also an important benefit. This will help make the textile industry a pillar of sustainable development of these countries, many of whom already produce high quality raw materials. Consequently, their chances of pursuing socio-economic progress coupled with environmental protection will be much improved.

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