UNIVERSITY OF MAURITIUS RESEARCH JOURNAL – Volume 20 – 2014
University of Mauritius, Réduit, Mauritius

Energy Optimization in Dyehouse

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Paper accepted on 04 December 2014

Abstract

Energy crisis has compelled dyehouse to review its energy usage as well as the production process. The aim of this study was to assess energy optimization in dyehouse. A dyehouse was studied where it was required to assess the effectiveness of applying one coating of an insulating paint on a dyeing machine to reduce energy losses. An energy balance based on data compiled was derived where the theoretical steam consumption was found for unpainted and painted dyeing machine. The consequent reduction in total energy and steam usage were then analysed. An economical analysis was then undertaken to assess the feasibility of the project.

The usage of the paint decreased losses by at least 15% and total energy by 6.9%. The average consumption of steam dropped from 1.06 to 0.98 Kg/Kg fabric with a coating of thickness 200 µm. Both the simple and discounted payback periods indicated that the initial investment on the paint, whose shell life is 2 years, would be recuperated by the 11th month. The positive net present value (2411 MUR) and high internal rate of return (80%) obtained suggested that the project should go ahead.

Keywords: *Insulation paint, steam consumption, energy optimization, dyehouse*

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1. INTRODUCTION

"A nation that can't control its energy sources can't control its future," Barack Obama. This era has witnessed a progressive decrease in the fossil fuel reserve and rocketing price of energy. Energy crisis has been sensed across the globe. It is without doubt that the world's hunger for energy is insatiable but yet the production of this very energy from fossil fuels is causing climate change due to emissions of green house gases (GHG). Switching to renewable sources of energy (solar, wind) can mitigate the problem to certain extent but it usually involves a high capital investment and the technology is not well developed. The best option is to use energy efficiently where for the same amount of production the energy consumption is reduced. This can also be termed as energy optimization (EO). UNIDO[1] (2011) believes that EO is a critical way out for a sustainable industry. It is estimated that if countries focused on heightening energy efficiency, they could not only afford a 10% reduction in global demand by 2030 but also have saved US$ 60 billion.

For the dyehouse as well, energy optimization is more than just a buzzword. The dyehouse is depicted as a high energy consumption section of the textile industry (Bhurtun et al., 2006). High energy consumption can also be rhymed with high emission of green house gases. Moreover, this business is vulnerable to the escalating cost of energy (electricity and fuel); hence conserving energy is more of a need than a luxury. Furthermore a fiercer competition is likely to settle in the industry given that the latter is expected to produce twice the amount of fabrics presently being produced, to cater for the rise in population by 2050 (Hasanbeigi, 2010). All these issues call for the industry to use energy efficiently to sustain the market competition.

Actual energy consumption in the textile sector or dyehouse in Mauritius is not known. However this sector is a huge consumer of energy, as claimed by many (Bhurtun et al., n.d.; Hasanbeigi, 2010; Sultan 2012). Also, Hasanbeigi (2010) reports that wet processing preparation and finishing consume the greatest share of thermal energy (35%) in composite textile plants.

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[1] UNIDO: United Nations Industrial Development Organization

Energy is principally used in electrical and thermal form in a dyehouse. Electricity can be used to run machines or provide lighting while steam may be used to heat water or air during the process. Steam is produced by burning fuel (usually fossil fuel) in boilers and is distributed to machines through pipelines. Table I depicts how energy is consumed in a Japanese dyehouse.

Table 1: Share of energy usage in Japanese dyehouse

Item	Share of total energy use
Product heating	16.6%
Product drying	17.2%
Losses through waste liquor	24.9%
Heat released from equipment	12.3%
Exhaust losses	9.3%
Equipment idling losses	3.7%
Evaporation from liquid surface	4.7%
Un-recovered condensate	4.1%
Loss during condensate recovery	0.6%
Others	6.6%

Source: Adapted from US Department of Environment
(2004 cited in Hasanbeigi 2010, p.30)

As can be seen around 66% of total energy is lost during the manufacturing process. This implies more energy must be supplied which therefore increases the production costs. Even though these statistics are not for the Mauritian context, these types of losses are inevitable in the local industries. Dyers are fully conscious of the implications of these additional costs that are incurred to obtain the end-product. However out the 66% energy lost, part can still be recuperated (e.g. wastewater recovery).

1.1 Energy optimization

The quest for profitability has lead dyehouse to seriously consider EO techniques. EO in dyehouse has been a subject of investigation by many researchers. Reducing energy consumption can range from simple plans to complex and high capital investment projects. Apart from technical changes, EO also effects from appropriate business management, individual actions and rationale of energy consumers (Bhurtun et al., no date). Some of the energy savings schemes with particular emphasis on steam consumption in the dyeing section consist basically of wastewater recovery, condensate recovery, cooling water re-use, steam traps and dyeing machine insulation.

Most of the energy optimization techniques are already implemented in the dyehouse showing strong commitment to sustainable development of the company. For the purpose of this research work, the dyeing machine insulation energy saving scheme was studied. Insulation of DM reduces losses of thermal energy by conduction, convection and radiation. An insulating material should have a low thermal conductivity and be compatible with the machine to avoid its degradation. Asbestos, mineral and glass wool are common insulators used or the DM may also be coated with paint which inhibits heat loss. Such a coating, nansulate coating, can be found on the market. It utilizes a hydrophobic nanocomposite with an extremely low thermal conductivity. This material allows the coatings to effectively restrain heat transfer in a thin layer as well as provide corrosion and moisture resistance. Thermal insulation eventually degenerates and hence it is very important to regularly verify the equipment or even go for additional insulation.

When equipment is insulated, it is estimated that savings on fuel can range from 1.4% to 3.2% with a payback period 6-10 months at an investment of \$15000-\$47000 (NRDC[2], 2013). Saad El-Din (2004, cited in Hasanbeigi, 2010) also states that when insulation of machines and steam systems is strengthened in fabric wet-processing plants, a fuel and electricity economy of about 4 GJ/tonne fabric and 6.3 kWh/tonne fabric processed can be expected.

2. METHODOLOGY

2.1 The dyeing process

Taking about 7-8 hours to be completed, dyeing process is divided into 3 parts; bleaching followed by 2 series of washing, dyeing followed by at least 3 washings and the after-treatment. The number of washings certainly varies

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[2] NRDC: National Research and Development Centre

depending on shade of process and type of fabric. The bleaching profile of jersey cotton is given below.

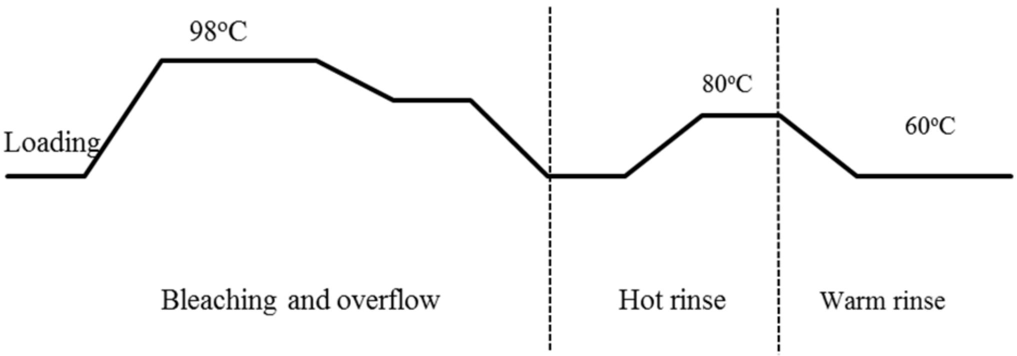

Figure 1: Bleaching profile diagram

2.2 Adopted energy optimization technique

The insulation technique employed consisted of applying a very thin layer of a special paint which is believed to decrease energy losses mainly by conduction. Decreasing losses result in reducing the amount of steam that will be used for the dyeing process. The paint was applied on only one DM and a steam meter was connected to the machine. In this perspective, the extent of reduction in steam consumption by applying the paint was investigated. A model was developed to calculate the theoretical steam consumption by the DM and the latter was compared to the actual consumption. The accuracy of the calculation was used to predict how far the model can be used to evaluate the savings. Both the energy and economical aspect of the savings were then determined.

2.3 Investigation of chosen Energy Optimization technique

Steam is used to increase the bath temperature and to maintain the desired temperature by compensating for energy losses. Heat is lost from the process through conduction, convection and radiation.

2.3.1 Energy Losses

Incropera *et al.* (2006) associated heat transfer with thermal resistance where it is possible to find the overall heat transferred from. Heat distribution will be computed by using the resistance of each medium and mode of heat transferred involved in the process. If the temperature in the machine is T_m and surrounding is T_{sur}, heat losses (q_l) will be

$$q_l=\frac{T_m-T_{sur}}{R_{tot}}$$

R_{tot}=total thermal resistances from the hot fluid to the surroundings(K/W)

T_m=Average temperature of water in DM (K)

2.3.2 Thermal resistances

2.3.2.1 Conduction

$$R_{t,cond}\equiv\frac{T_{s,1}-T_{s,2}}{q}=\frac{L}{kA}$$

$R_{t,cond}$= Thermal resistance for conduction (K/W)

$T_{s,1}$=Temperature at surface 1 (K)

$T_{s,2}$=Temperature at surface 2 (K)

k=thermal conductivity (W/mK)

A=Area of heat transfer

q=heat rate (W)

2.3.2.2 Convection

$$R_{t,conv}\equiv\frac{T_s-T_\infty}{q}=\frac{1}{hA}$$

T_s=temperature of surface (K)

T_∞=fluid temperature (K)

h=heat convection coefficient (W/mK)

2.3.2.3 Radiation

$$R_{t,conv}\equiv\frac{T_s-T_{sur}}{q}=\frac{1}{h_rA}$$

h_r = radiation heat transfer coefficient (W/mK)

$$h_r=\varepsilon\sigma(T_s+T_{sur})(T_s^2+T_{sur}^2)$$

T_{sur}=Temperature of surrounding (K)
ε=emissivity
σ=Stephan Boltzmann constant=5.67×10^{-8} W/m^2K^4

2.4 Data Collection on resources used

Six batches of dyeing process were considered during the survey. The batches chosen consist of relatively easy dyeing profiles where the temperature of process could be easily found. The amount of water used and the time of process were also obtained. The profiles where temperature changes were often, were disregarded since it was very problematical to find the resources used and it was time-consuming. Also it should be noted that the liquor ratio was not employed to find the amount of water used for each process. This is so because not all the water used during the process is heated. For example, from figure II, part of the required amount water of was heated until 98^{o}C and the remaining volume was added after the hold-up time. It contributed mainly in decreasing the temperature. Moreover the liquor ratio is not constant for all processes.

2.5 Developing the model for the painted DM

Assumptions

1. Steady state operation is assumed throughout the process.
2. Quality of steam is given as 0.97.
3. Information on the chemicals/dyes added was not available. Consequently the heat absorbed by chemicals (dyes, softening reagents, etc) shall not be taken into consideration but it should be noted that the amount of chemicals/dyes added is negligible as compared to that of fabric and water.
4. The DM is a horizontal tank with elliptical heads. It was very complicated to find the surface area/volume. Hence the DM is assumed to have a cylindrical shape throughout its length
5. The maximum length is taken for the calculation and a constant circular cross sectional area has been considered throughout the machine.

6. The DM is partially filled with water, air and fabric. However for ease of calculation of the surface area of air in the machine, it shall be supposed that only water and air are present in the machine. Furthermore it is difficult to predict the behaviour of the fabric inside the DM, for instance the amount of fabric in contact with the surface of DM or that present in the water.
7. The energy profile of stages involved during whole process (bleaching, dyeing, rinsing and after-treatment) consists of either increasing the temperature of the bath or maintaining or decreasing it. However the energy balance if calculated for each change in temperature becomes a very complicated task. Only where thermal energy will be required will be of interest for this project. Hence any process occurring with a negative temperature gradient shall not be considered.

2.5.1 The model

According to the principle of conservation of energy,

Total energy provided by steam= energy transferred to the fabric + energy transferred to water bath + energy losses

Energy losses=energy lost by conduction + convection + radiation

2.5.2 Energy transferred to fabric/water

This can be found by applying the following formula:

$$q=mc_p(t_f-t_i)$$

q=energy transferred to water/fabric (KJ)

m=mass of water/fabric (Kg)

C_p=specific heat capacity of water/fabric (KJ/Kg .K)

t_i=temperature of water/fabric when loading machine (K)

t_f=temperature of water/fabric when unloading machine (K)

2.5.3 Energy losses in DM

Losses from hot fluid inside the machine to the surrounding are as follows:

1. From hot fluid and air in DM to inner surface of machine by convection in parallel (DM is partially filled with water).
2. From inner surface to outer surface of DM (thickness of machine) by conduction.
3. From outer surface of wall to the painted surface by conduction.
4. From painted surface by convection to surrounding air (i.e. $T_\infty = T_{air}$) by convection and from DM surface by radiation in parallel.

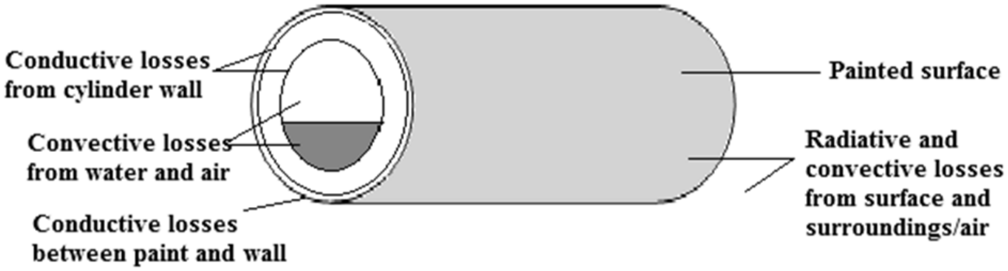

Figure 2: Losses from dyeing machine

Hence the total resistance becomes:

$$R_{tot} \text{ per unit length} = \left(\frac{h_w A_1 \times h_{ai} A_2}{h_w A_1 + h_{ai} A_2}\right) + \frac{1}{k_A A_3} + \frac{1}{k_B A_4} + \left(\frac{h_{ao} A \times h_r A}{h_{ao} A + h_r A}\right)$$

A_1:Area of heat distribution between hot fluid and inner wall of DM (m^2)

A_2:Area of heat distribution between air in machine and inner wall of DM (m^2)

A_3:Area of heat distribution within walls of DM (m^2)

A_4:Area of heat distribution between wall and painted surface of DM (m^2)

A= surface area of DM (m^2)

h_w=heat convection of hot water in DM (W/mK)

h_{ai}=convection coefficient of air in DM (W/mK)

h_{ao}=convection coefficient of air in surroundings (W/mK)

h_r=radiation coefficient (W/mK)

Note: Since heat loss from air and water in DM act in parallel, the thermal resistance becomes $\left[\frac{1}{(1/h_wA_1)}+\frac{1}{(1/h_{ai}A_2)}\right]^{-1}$. This also applies to heat loss from convection and radiation to the surroundings. The expression has been simplified and plugged in equation below.

The thermal resistance across a cylinder wall is given as (Incropera *et al.* 2006):

$$R=\frac{\ln(r_2/r_1)}{2\pi k}$$

Hence the equation becomes:

$$R_{tot}=[\frac{h_wA_1\times h_{ai}A_2}{h_wA_1+h_{ai}A_2}]+\frac{\ln(r_2/r_1)}{2\pi k_A l}+\frac{\ln(r_3/r_1)}{2\pi k_B l}+[\frac{(h_{ao}2\pi r_3 l)\times(\varepsilon_p\sigma 2\pi r_3 l(T_s+T_{sur})(T_s^2+T_{sur}^2))}{(h_{ao}2\pi r_3 l)+(\varepsilon_p\sigma 2\pi r_3 l(T_s+T_{sur})(T_s^2+T_{sur}^2))}]$$

r_1=inner radius of DM (m)

r_2=inner radius of DM + thickness of DM (m)

r_3=inner radius of DM + thickness of DM + thickness of paint (m)

ε_p:paint emissivity

$$\boxed{\textbf{Total Energy Used}=m_fC_f(t_f-t_i)+m_wC_w(t_f-t_i)+\frac{(T_{hot\ fluid}-T_{air})\times t}{[\frac{h_wA_1\times h_{ai}A_2}{h_wA_1+h_{ai}A_2}]+\frac{\ln(r_2/r_1)}{2\pi k_A l}+[\frac{(h_{ao}2\pi r_3 l)\times(\varepsilon\sigma 2\pi r_3 l(T_s+T_{sur})(T_s^2+T_{sur}^2))}{(h_{ao}2\pi r_3 l)+(\varepsilon\sigma 2\pi r_3 l(T_s+T_{sur})(T_s^2+T_{sur}^2))}]}}$$

l=length of DM (m)

The total heat loss can be found by using:

$$q_l=\frac{\Delta T}{R_{tot}}$$

where $\Delta T=T_{hot\ fluid}-T_{air}$ (K)

Hence total energy required becomes

ε=stainless steel surface emissivity

2.6 Determination of surface area of air and water in DM

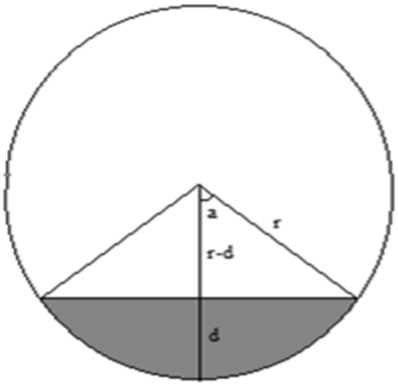

Figure 3: Cross-sectional area of cylinder

It was assumed that the DM consists of water and air only. However the fabric has a certain volume which will reduce the volume of air present. Hence when taking the volume of water, that of the fabric is added to it.

volume of water considered= volume of fabric + volume of water used
d=depth of water and fabric in DM
r= inner radius of DM
Cross sectional area of water and fabric= area of sector- area of triangle

$$\text{Area of sector}=\frac{1}{2}r^2(2a)$$

$$\cos a=\frac{r-d}{r}$$

$$\text{Area of sector}= r^2\cos^{-1}(\frac{r-d}{r})$$

$$\text{Area of triangle} = \frac{1}{2}\times \text{height} \times \text{base}$$

height=r
Using Pythagoras theorem on one part of triangle;

$$\text{base}=\sqrt{(r^2-(r-d)^2)}$$

$$\text{Area of whole triangle}=\frac{1}{2}\times 2\times r\times\sqrt{(r^2-(r-d)^2)}$$

Hence, cross sectional area of water = $[r^2\cos^{-1}(\frac{r-d}{r})]-[r\times\sqrt{(r^2-(r-d)^2)}]$

% cross sectional area of DM in which water is filled, F%, is given by:
F% =Area of water/Total cross sectional area

$$F\% = \frac{[r^2 \cos^{-1}(\frac{r-d}{r})] - [r \times \sqrt{(r^2-(r-d)^2)}]}{\pi r^2}$$

$$F\% \text{ is also} = \frac{\text{volume of water}}{\text{volume of cylinder}} \times 100\%$$

Knowing the volume of water used and calculating that of the cylinder ($\pi r^2 h$), F% can be found. The depth of water is then calculated by trial and error until F% is obtained. This is the depth of water in the DM and can be plugged in the following equation (Ankur, 2009) to find the surface area of water.

$$A = 2lr \cos^{-1}(\frac{r-d}{r})$$

2.6.1 Energy savings

The energy savings may be calculated using:

$$\% \text{ saving} = \frac{\text{steam consumed wihtout paint-steam consumed with paint}}{\text{steam consumed wihtout paint}} \times 100\%$$

2.7 Economics

The time to recuperate the investment will be calculated by payback period. The efficiency of project shall be evaluated by using the internal rate of return (IRR) and net present value (NPV) method.

2.7.1 Payback period

a) Simple payback period

$$\text{Payback period} = \frac{\text{Total investment}}{\text{Annual savings}}$$

b) Discounted payback period

The discounted payback, unlike the simple one, takes into account that the value of money changes. Hence future cash flows are considered are discounted to present time.

$$\text{Discounted cash inflow} = \frac{\text{Actual cash inflow}}{(1+i)^n}$$

i = discount rate (6% per year)

n = service life

This discounted cash flow is added to the initial investment (which is negative because it is represents an outflow of money) until a positive cash flow is obtained. This means at the corresponding period, the company will start making profits.

Payback period only measures the period after which profits will be made not the profitability of the investment. Hence Net Present Value (NPV) and Internal Rate of Return (IRR) shall be used.

2.7.2 Net present value

NPV is given by:

$$\mathrm{NPV} = \sum \mathrm{PV}_i - \mathrm{TCI}$$

$$\mathrm{PV}_i = \frac{\text{Net income}}{(1+r)^n}$$

TCI=Total capital investment

PV= Present value

r=rate of return

When NPV>0, it means that the investment is lucrative and the project can go ahead; When NPV<0, it means that investment is unprofitable and hence the project should be dismissed.

2.7.3 Internal rate of return

The internal rate of return (IRR) is another measure of profitability. It is found by considering the NPV of an investment to be zero. Hence a trial and error method will be adopted to find that IRR which makes the NPV=0. The higher the rate, the more profitable is the investment.

3. RESULTS & DISCUSSION

The total theoretical amount of energy and steam consumed during the process was calculated for both scenarios (painted and unpainted surface of DM). The actual steam consumption was then used as a measure of evaluating the efficacy of the project. The effect of the paint on the energy losses was reviewed as well as the consequent impact on total amount of energy used. Finally an economic analysis was undertaken and the savings were considered.

The information on the six batches of fabric dyeing considered in this project has been tabulated below.

Table 2: Batch details

Batch	Shade	Fabric	Weight (Kg)	Steam Consumed (Kg)	Kg steam/Kg fabric
232300	Ruby Wine	Jersey cotton	207	379	1.83
231904	MED Pink		445	423	0.95
231783	Red		356	420	1.18
232330	Mastic		395	384	0.97
232332	Mastic		424	302	0.71
232327	Mastic		393	275	0.70

3.1 Determination of energy consumed by fabric

The mass of fabric and type of fabric (cotton blended fabric) were obtained directly from the dyehouse manager. The composition of the fabric was not available and hence when computing the energy absorbed by the fabric, the specific heat capacity of cotton only was considered. Also the temperature of fabric during the process was considered same as that of water. Standard parameter used is:

C_p of cotton=1.215 (Ashby, 2012)

3.2 Determination of energy consumed by water

The volume of water used during each stage had to be found out since the dyehouse does not record water consumption for each stage. Water usage which only required heating during a stage was obtained by reading off from the dyeing profile generated by the monitoring software of the process. Temperature changes and duration of process were also obtained from the same program. Initial temperature of water ranges from 57-59^{o}C and so an average of 58^{o}C was used for all calculations. Cp of water was assumed 4.2 KJ/KgK (Ashby, 2012).

3.3 Determination of energy losses

The surface temperature of DM could not be measured due to lack of facilities. So it was estimated using the average temperature of hot fluid in DM and air (28°C). The experts of the process observed a decrease in temperature (at least 5°C) of the surface temperature when the DM was painted. The dimensions of the DM as well as all information on the paint were obtained from the manager. Convective losses inside the DM were assumed to be mainly from water and air. Heat loss from the fabric was ignored as its behaviour (e.g. amount of fabric in water or suspended) was complex to predict. The energy and steam consumption during the 6 batches are given below.

Table 3: Energy consumption during dyeing

	Theoretical energy consumption (KJ/Kg)					
Batch	**Water**	**Fabric**	**Energy losses**		**Total energy consumption**	
			Painted surface	**Unpainted surface**	**Painted surface**	**Unpainted surface**
232300	553518	43510	247676	292804	844704	895961
231904	516264	85427	315802	374413	917492	972065
231783	518112	74829	316175	369354	909117	962296
232330	240828	57591	336854	399463	629015	691358
232332	273672	63365	343013	405168	680050	742204
232327	286608	53957	240347	284544	580912	625109

Table 4: Steam consumption during dyeing

Batch	**Total theoretical steam needed (Kg)**	**Actual amount of steam used (Kg)**	**Total theoretical steam needed (Kg)**	**Kg theoretical steam saved/Kg fabric**
	Painted	Painted	Unpainted	
232300	413	379	438	0.12
231904	449	423	475	0.06
231783	445	420	471	0.07
232330	308	384	338	0.08
232332	333	302	363	0.07
232327	268	275	279	0.05

3.4 Economics

3.4.1 Payback period

Prices and any other relevant information were obtained from the company.

Investment

1 gallon of paint covers a surface area of 41.81 m^2.
Total surface area of DM =37.52 m^2
Hence at most one gallon (3.785 L) is sufficient to paint the machine.
Price of paint= Rs850/L
Total price=850×3.785= Rs 3217.25

Savings

The total energy saved by the following batches has been calculated. Batch 232330 has been ignored given its large deviation from actual value. Energy saved per Kg fabric was computed for each batch taken into consideration. An average value of 156 KJ of energy per Kg fabric was obtained.

Table 5: Energy saved per Kg fabric

Batch No	Total theoretical energy used		Total energy saved (KJ/Kg)	Mass of fabric used (Kg)	Energy saved /Kg fabric
	Unpainted	Painted			
232300	844704	895961	51256.76	207	248
231904	917492	972065	54573.11	445	123
231783	909117	962296	53178.97	356	149
232332	680050	742204	62155.13	424	147
232327	580912	625109	44196.42	393	112
Average total energy saved (KJ/Kg fabric)					156

The amount of fabric dyed in the DM under study during year 2013 was 36749 Kg.

Total amount of energy saved=156×36749=5723 MJ

Hence the total amount of energy saved has been estimated to 5723 MJ. The lower heating value of HFO is 38 MJ/L (Staffell, 2011)

LHV HFO= 38MJ/L

Assume efficiency of heating system performance= 0.85

Price of HFO=Rs 21.08/L

Litres of HFO saved yearly= $\frac{5723\text{ (MJ)}}{0.85} \div 38\text{MJ/L} = 177.19$

Total savings=177.19×21.08=Rs3735.12

a) Simple payback period

Payback period= $\frac{3217.25}{3735.12}$ =0.861 years (~11 months)

b) Discounted payback period

The discount ratio is 10% per year. Since the time period is in month, i=0.83%. The cash flow is assumed to be constant. The total saving per year Rs 3735.12 and hence on monthly basis is Rs311.26

$$PV^{3}=\frac{1}{(1+0.008)^{n}}$$

The discounted cash flow is simply found by multiplying the cash flow by PV.

Table 6: Discounted payback period

No of month	Cash flow (CF) (Rs)	Present value (PV) factor	Discounted cash flow (CF*PV) (Rs)	Cumulative discounted cash flow (Rs)
0	-3217.25	1.000	-3217.25	-3217.25
1	311.26	0.992	308.70	-2908.55
2	311.26	0.984	306.16	-2602.40
3	311.26	0.976	303.64	-2298.76
4	311.26	0.967	301.14	-1997.62
5	311.26	0.960	298.66	-1698.96
6	311.26	0.952	296.20	-1402.76
7	311.26	0.944	293.76	-1109.00
8	311.26	0.936	291.34	-817.66
9	311.26	0.928	288.95	-528.71
10	311.26	0.921	286.57	-242.15
11	**311.26**	**0.913**	**284.21**	**42.06**

On the eleventh month, the cumulative discounted cash flow is positive. Hence time to recuperate the initial investment is between 10th and 11th month with discounted payback period.

3.4.2 Net present value

Rate of return, r= 6% per annum (0.5%)

NPV=5628.32-3217.25=Rs 2411.07

Since NPV>0, the investment is profitable.

3.4.3 Internal rate of return

The IRR has been calculated on yearly basis given that the calculation is not straightforward.

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[3] PV : Present Value

Table 7: IRR calculation

No of years	Revenue (Rs)	PV (IRR= 20%)	PV (IRR= 50%)	PV (IRR=60 %)	PV (IRR=70 %)	PV (IRR=80 %)	PV (IRR=81 %)
1	3735	3735.1	2490.1	2334.5	2197.1	2075.1	2063.6
2	3735	7470.2	1660.0	1459.0	1292.4	1152.8	1140.1
NPV		2489.2	932.9	576.2	272.3	**10.6**	**-13.5**

With an IRR of 81%, the NPV is negative which means that that IRR at breakeven point is between 80 and 81%.

By interpolating,

$$\text{IRR}=\frac{(0.81\text{-}0.80)(0\text{-}10.6)}{(\text{-}13.5\text{-}10.6)}+0.80=0.8044\ (80.44\%)$$

This IRR is very high which suggests that the project is highly profitable. Even though it does not take into account external factors such as size of project, IRR gives however a good estimation of an investment.

3.5 Error analysis

The actual and theoretical steam consumption from table 8 was used to assess the error associated with the model.

Table 8: Deviation of computed steam usage from actual usage

Batch	**Deviation from actual value (%)**
232300	8.24
231904	5.71
231783	5.51
232330	-24.86
232332	9.17
232327	3.18

The % error made in the calculation ranges from -25% to 9.2%. A negative error implies that more steam was used during the process than was predicted while a positive error is the opposite. This analysis between the theoretical and actual steam consumption has been given in the graph below.

Error associated with batch 232330 is huge as compared to the other. Probable causes are:

- A standard initial temperature of water was chosen (58°C) while it varied from 57-59°C. Actually the initial temperature depends on the heat being transferred from wastewater to the soft water during preheating process. The flow of wastewater varies over time and hence the temperature of water used is not constant .The temperature was most probably lower than 58°C implying that more steam was used during the process.

- Also it is possible that there were stoppages during the dyeing process. Stoppages were not taken into consideration. If it is the case, steam must have been additionally used to compensate for the losses. As soon as the temperature sensors detect a decrease in temperature, steam is supplied automatically to restore the temperature.

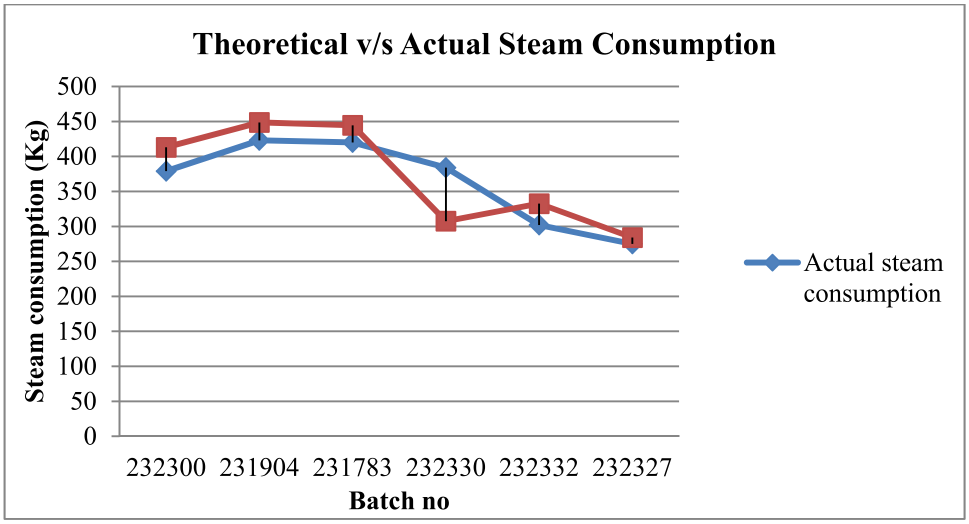

Figure 4: Comparison of theoretical and actual steam consumption

It is observed that the error % is not constant for the batches into consideration. Apart from the above reasons stated, the fluctuations may be explained by the fact that temperature in the dyeing section has been estimated to 28°C. It is only logical that temperature would surely vary, (e.g. if dyeing process is carried at night or due to climatic conditions). Changes in temperature may alter heat loss rate from DM, hence vary the steam usage. Furthermore a steady state process has been assumed while this may not be true all along the progression of dyeing. As can be seen on figure 4, actual steam consumption is slightly lower than predicted one except for batch 232330. Probable cause of the lower steam consumption for the remaining batch is due to usage of feed water at a temperature lower than 58°C (59°C). Given that apart from batch 232330, the remaining batches recorded an error less than +6.4%, the model may be judged as reasonable to proceed with the calculation.

3.6 Analysis on energy savings with painted surface

The % expected energy savings were evaluated using data from table 5. The subsequent steam economy has also been determined.

Table 9: Percentage reduction of losses recovery with paint

Batch	Energy loss (KJ)		% Reduction in energy loss
	Painted surface	Unpainted surface	
232300	247676	292804	15.4
231904	315802	374413	15.7
231783	316175	369354	14.4
232330	336854	399463	15.7
232332	343013	405168	15.3
232327	240347	284544	15.5

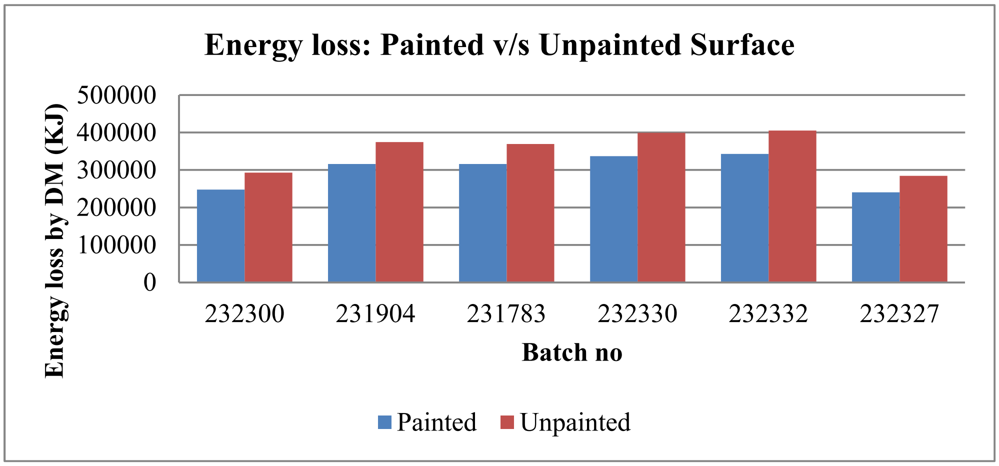

Figure 5: Theoretical energy loss

Energy losses are expected to reduce by approximately 15 % with the application of the paint. The paint supplier maintained that with 3 coatings, the energy losses would decrease by around 40%. The results appear promising especially since only one coating (thickness of paint=0.0002m) was applied on the DM[4]. Additionally the least decrease in temperature has been taken into consideration and so a higher reduction in energy losses can be expected.

The change in the energy consumption is was as tabulated:

Table 10: Percentage energy savings

Batch no	Total theoretical energy required		% Theoretical energy savings
	Painted	Unpainted	
232300	844704	895961	5.72
231904	917492	972065	5.61
231783	909117	962296	5.53
232330	629015	691358	9.02
232332	680050	742204	8.37
232327	580912	625109	7.07

The average theoretical savings on total energy consumption that was made is 6.9%. This means that energy usage decreased by this amount when the paint has been applied on the DM. A maximum average steam economy of 0.08 Kg/Kg fabric is possible as can be observed from table 4.

This economy may not seem attractive when compared with the overall energy consumption. Nevertheless Carbon Trust (1997, cited in Hasanbeigi, 2010) reported that insulation can save up to 9% of the total energy required in high temperature/high pressure wet-processing machines. Contrasting the reported economy with that being made with the paint, it is seen that around 77% of the maximum possible savings has been achieved. Hence it may be inferred that a great deal of savings is possible with this insulation and opting for the paint will only benefit the user. Also it is seen that there is still room for reinforcement of insulation on DM to decrease the losses. The information in the above table along with the actual energy consumption is represented below.

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[4] DM: Dyeing Machine

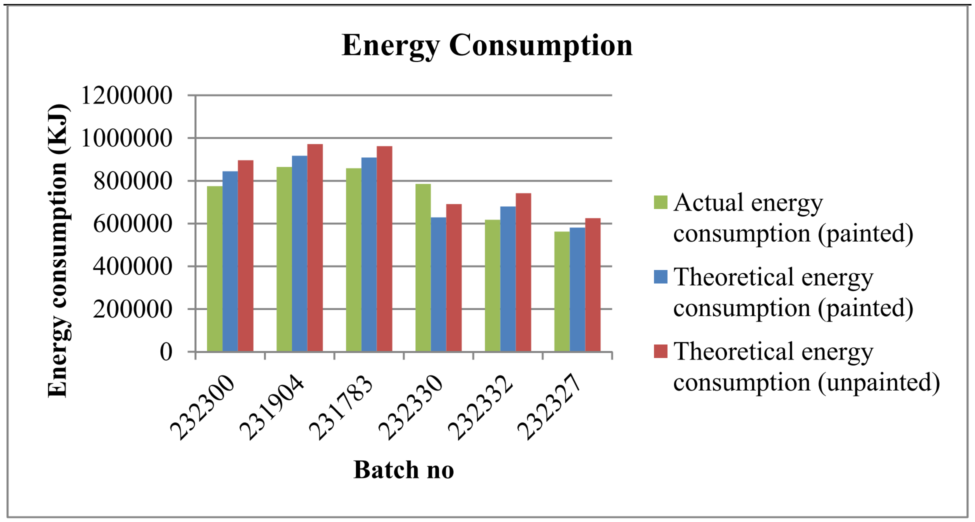

Figure 6: Energy consumption by dyeing process

The actual steam consumption is simply found by multiplying the steam enthalpy with actual steam consumption. Actual energy utilization is higher than both the theoretical use (painted and unpainted surface) for batch 232330. As previously mentioned, this might be due to varying temperature of water or stoppages which therefore resulted to an increase in energy consumption. The remaining batches followed the same tend of energy consumption, i.e. theoretical consumption with unpainted DM is highest followed by theoretical and actual consumption with painted DM.

3.7 Economic savings

A **simple payback period** of around 11 months for this study has been obtained. This tallies with the reported payback period (6-18 months) estimated by supplier. The **discounted payback** method gave a result of 10-11 months as well. This implies that as from the eleventh month to the twenty-fourth month, the company is expected to make profit over this investment. As mentioned in the literature, the NRDC[5] (2013) asserted that insulation of DM[6] can have payback period of 6-10 months which is lower than that obtained. However theses payback period cannot be contrasted since the investment costs are not the same.

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[5] NRDC: National Research and Development Centre

[6] DM: Dyeing Machine

The NPV[7] and IRR[8] methods measure the profitability of the investment. **NPV** obtained is greater than 0. This implies that the expected gains would exceed the initial investment and hence the project can go ahead. The **IRR** is around 80.44 %. This high rate of return suggests that this project is very profitable. The IRR usually overstate the returns since it does not take into consideration factors like size of project. Also it should be noted that both methods did not take into consideration that the efficiency of the paint would decrease with time. Degradation of the paint would indubitably lower monthly savings. They however provide a sufficiently good estimation for evaluating the feasibility of the project. Finally both methods suggest that the project is economically feasible.

4. CONCLUSION

The results obtained were deemed sound to use for comparison since theoretical deviation from actual process was 6.4%. The outcome of the calculation revealed that with one coating of the insulating paint, losses would be mitigated by at least 15%. When this savings were linked to the total amount of energy saved during the process, it was found that energy recuperation amounted to 6.9 %. On basis of steam usage, the latter dropped by an average of 0.08 Kg/ Kg fabric. This demonstrates that energy losses have been mitigated to certain extent by usage of this paint. The study also shows that more effort should be laid to minimize energy losses from the DM[9].

The economic analysis gives a favorable result for this project. The payback period showed that within 11 months the company will already recuperate the initial costs. The NPV[10] being positive and the rate of return high show that the project is profitable. The usage of the paint hence does seem pleasing especially since cash economized after the 2 years is Rs 2411.07 per DM.

The usage of the paint did certainly not completely solve the problem of high energy losses from the machines yet it has lessened the impact of this issue. It should not be forgotten that Energy Optimization does not necessarily engender enormous savings. The small savings when coupled together can create a huge

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[7] NPV: Net Present Value

[8] IRR: Internal Rate of Return

[9] DM: Dyeing Machine

[10] NPV: Net Present Value

difference on the bills. Furthermore a small saving is better than no saving at all. Given that the project is economically feasible, it can be concluded that this paint may be used on other DM in the company.

Moreover, this recuperation can indeed be improved if more coatings were applied given the high rate of heat loss by the machines. Supplier claims that 24 coatings are the best but this necessitates further investigation of whether the project will be beneficial or not.

5. ACKNOWLEDGEMENTS

Sincere thanks are extended to personnel of the dyehouse who provided all necessary information for the completion of the research work.

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