Application of Unit heat integration in VFY unit –A case study

Ilayaraja Palani[1], Atul Joshi [2]

[1] General Manager, Corporate Technical &Energy services, Aditya Birla Science & Tech Pvt Ltd, Navi Mumbai, 410208, India
[2] Manager, Corporate Technical & Energy services, Aditya Birla Science & Tech Pvt Ltd, Navi Mumbai, 410208, India
Ilayaraja.palani@adityabirla.com[1], atul.joshi@adityabirla.com[2]

Abstract

Background/Objectives: Energy efficient technology selection for all the individual in site does not guarantee optimized energy consumption for total site. Synergy exist between two different technologies for heat recovery. Application of inter unit Pinch analysis opens up opportunities for step reduction in Energy consumption
Methods/Statistical analysis: Viscose Filament Yarn process was chosen to demonstrate application of inter unit pinch analysis. Chlor-alkali units are integral part of viscose process units. Significant steam is consumed in viscose units for spin bath at 50 deg C. High grade steam at 150 deg C is normally used in graphite exchanger. There is general belief that graphite exchanger is expensive and use of low grade heat like hot water is not economical as area of exchanger increased and there by cost. Scheme was developed to compare spin bath heating using steam and hot water. Aspen EDR was used to size the exchangers. Costing for the scheme was done for analysis of project economics.
Findings:

- Inter unit use of low grade unit for spin bath heating is an economically viable option. Payback is very attractive at 8 months though the capex is very high. Leverage is in the operating cost i.e. Steam Vs Waste heat.
- Heat transfer co-efficient in hot water heating decreases only by 16% with respect to steam heating. Hence hot water availability at 125 ºC would mean an increase in area only by 50% and not multifold.
- Reduction in water make up to cooling tower is additional benefit.

Improvements/Applications: Inter unit pinch analysis is applicable for any site having 2 or more process units.

Keywords: Heat integration, spin bath, low grade heat recovery, pinch analysis, energy reduction.

1. Introduction

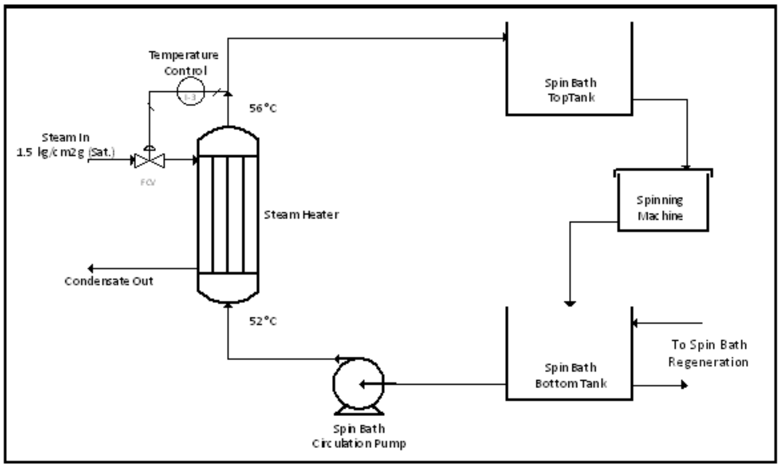
Spin bath' or 'Regeneration bath' has a vital play in the cellulose regeneration process. The viscose is forced through a spinneret, a device resembling a shower head with many small holes. Each hole produces a fine filament of viscose. As the viscose exits the spinneret, it comes in contact with spin bath solution containing sulphuric acid, sodium sulphate and zinc sulphate. [1]
Temperature and immersion depth affects the extent of regeneration, the later only to a small degree owing to the amount of spin bath liquor usually carried forward with the tow. Hence it is important to maintain the temperature of the spin bath. The desired spin bath temperature is 55-56 ºC. During the regeneration process, the spin bath temperature decreases due to heat loss to the surroundings, excess water addition in the process and due to low temperature mother liquor returning from crystallizer to spin bath tank. Currently steam heaters are employed to maintain the temperature of the bath. To meet duty at low grade at 55 ˚C hot water at 80 ˚C with an approach of 10 ˚C would be sufficient. Currently to reduce the cost of graphite exchanger steam is being used.
This case study explores the economic viability of using hot water for spin bath heating by utilizing waste heat from neighboring unit i.e. Chlor-Alkali unit. Use of waste heat not only reduces energy consumption but reduces water consumption, otherwise rejected through cooling tower.

2. Conventional System

2.1. *Spin bath Heating system* & Composition

The schematic diagram (fig 1.) explains the conventional spin bath heating system where saturated steam at 1.5 kg/cm^2g is fed to the shell side of the exchanger to heat 1500 m^3/hr of spin bath from 52 ºC to 56 ºC.

Figure 1. Sketch of conventional spin bath heating system



Composition of the spin bath solution is as follows:[2]

1. H2SO4 - 137 gpl
2. ZnSO4 - 15.5 gpl
3. Na2SO4 - 245 gpl
4. Specific Gravity - 1.35

2.2. Properties of Spin bath solution

Physical properties of the spin bath solution with above mentioned concentration at mean temperature of 54 ºC are as follows: [3]

1. Density (ρ) – 1350 Kg/m^3
2. Specific Heat (Cp) – 0.7 Kcal/kg ºC
3. Thermal Conductivity (k) – 0.5 Kcal/hr.m.ºC
4. Viscosity – 1.4 cP

Amount of steam required can be calculated using simple heat transfer equations

$Q= M.Cp.\Delta T = Ms.\lambda s.$

Where:

M is mass flow rate of spin bath in Kg/hr

Cp is specific heat of spin bath at mean temperature in Kcal/kgºC

ΔT is the temperature difference of spin bath solution across heat exchanger in ºC.

Ms is mass flow rate of steam in kg/hr

λs is the enthalpy of evaporation of steam in Kcal/kg

2.3. Heat Load Estimation

Exchanger duty is estimated [4] as given in Table 1.

Table 1. Exchanger heat load estimation[4]

Spin Bath	Values	Parameters
Flow rate	1500	M3/hr
Specific Gravity	1.35	
Mass flow rate (M)	2025000	Kg/hr
Specific Heat (Cp)	0.7	Kcal/ kg ºC
Temperature Difference (ΔT)	4	ºC
Heat Duty (Q)	5.67	M Kcal/hr
Steam (Saturated)		
Pressure	1.5	Kg/cm2 g
Enthalpy of Evaporation (λs)	520	Kcal/kg
Mass Flow Rate (Ms)	10904	Kg/hr

2.4 Operating cost estimation for steam heating

Operating cost is estimated and Table 2 shows the stimates of operating cost of current system

Table 2. Operating cost estimation [4]

Parameters	Unit	Values
Steam flow rate	Kg/hr	10904*
Annual operating hours	Hours	8400 #
Annual steam required	MT/ annum	91593.6*
Steam cost	Rs./ MT	650.0#
Annual operating cost	Lacs Rs.	595.4*

‘* - From calculation , #- Typical basis used in manufacturing industry

2.5 Exchanger design – Steam heating[5]

Exchanger was designed using Aspen EDR simulation software. Key parameters are tabulated Table 3 provides data sheet of exchanger using steam as heating media.

Table 3. Steam heating exchanger design data sheet [5]

Parameter	Unit	Graphite Heat Exchanger			
Heat Transfer Area	Sq.m.	74.43			
Heat Duty	Kcal/hr	5670000			
		Shell Side		Tube Side	
Fluid		Saturated Steam		Spin Bath	
Mass Flow	Kg/hr	10904			
Temperature (In/Out)	ºC	128.73		52	56
LMTD	ºC	74.71			
Inlet Pressure	Kg/cm^2 g	1.5		3.0	
Pressure Drop (ΔP)	Kg/cm^2 g	0.024		0.13	
Fouling Factor	$hr.m^2.ºC/Kcal$	0.0001		0.0003	
HTC Overall	$Kcal/hr.m^2.ºC$	1120			

2.6 Heat Integration Opportunity [6]

2.6.1 Waste Heat Sources

In viscose fiber plant waste heat is available from multiple sources like [1,2,3]

- Vapors from evaporators of caustic/flaker unit which are condensed in the condenser.
- Condensate from process heating/evaporators.
- Hot steam vapors to surface condensers in MFSE in fiber unit.

Above mentioned waste heat sources are available at or > 90 deg C. Same can be utilized to heat spin bath solution from 50 to 55 deg C.

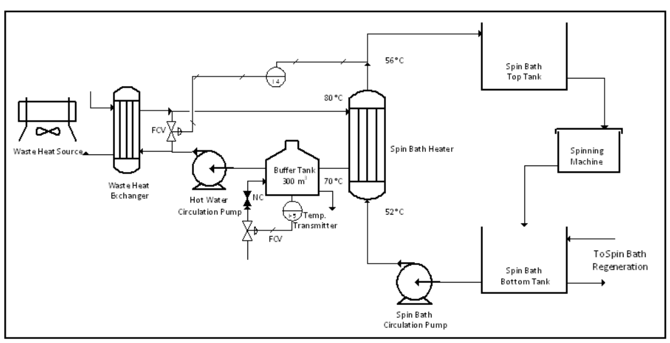
2.6.2 Heat Recovery Option

At site, spin bath heater and heat source would be at a distance of at least 500 m away. Pumping spin bath solution to pick heat from heat source would require large pumps. Steam vapors transportation to spin bath heater is not feasible as all the heat sources are at vacuum. Required pressure drop can't be met. However since the driving force between heat source and sink is large enough to introduce a circulating medium to pick up heat from heat source and transfer to spin bath heater. Water is chosen as circulating medium. This option will be evaluated with the following basis (Fig 2.) .

Basis of Calculation:

1. The waste heat source is at 1000 meter apart from the spin bath heat exchanger.
2. Equivalent length of piping considered is 2800 m.
3. Hot water generated from waste heat will be available at 80 ºC and
4. Hot water return temperature from spin bath heat exchanger is assumed 70 ºC.
5. Cost of steam considered is Rs. 650/ MT.
6. Power cost is considered as Rs. 5/ kWh.
7. The static head is considered as 16 m for selection of hot water circulation pump.
8. Discount Factor (for NPV) considered is 8%.

Figure 2. Proposed modified scheme for spin bath heating using waste heat



2.6.3 Circulating flow estimation

Amount of hot water required can be calculated using simple heat transfer equations

$Q = Ms.Cps.\Delta Ts = Mh.Cph.\Delta Th$

Where:

Ms is mass flow rate of spin bath in Kg/hr

Cps is specific heat of spin bath at mean temperature in Kcal/kgºC

ΔTs is the temperature drop of spin bath solution across heat exchanger in ºC

Mh is mass flow rate of hot water in Kg/hr

Cph is specific heat of hot water at mean temperature in Kcal/kgºC

ΔTh is the temperature drop of hot water across heat exchanger in ºC

Table 4. Circulating medium flow estimation using heat balance

Table 4. Circulating medium flow rate estimation[4]

Spin Bath	**Values**	**Parameters**
Flow rate	1500	M^3/hr
Specific Gravity	1.35	
Mass flow rate (Ms)	2025000	Kg/hr
Specific Heat (Cps)	0.7	Kcal/ kg ºC
Temperature Difference (ΔTs)	4	ºC
Heat Duty (Q)	5.67	M Kcal/hr
Hot Water		
Inlet Temperature	80	ºC
Outlet Temperature	70	ºC
Temperature Difference (ΔTh)	10	ºC
Specific Heat (Cph)	1	Kcal/kg ºC
Mass Flow Rate (Mh)	567000	Kg/hr
Volumetric Flow Rate	567	M^3/hr

2.6.4 Proposed Heat Exchanger Sizing[5]

Heat exchanger was sized to meet the required duty using hot water as heating medium. Design parameters are tabulated in (Table 5) – Data sheet of exchanger using hot water as heating media.

Table 5. Graphite Exchanger Data sheet[5]

Parameter	**Unit**	**Graphite Heat Exchanger**			
Heat Transfer Area	Sq.m.	322			
Heat Duty	Kcal/hr	5670000			
		Shell Side		**Tube Side**	
Fluid		Hot Water		Spin Bath	
Mass Flow	Kg/hr	567000			
Temperature (In/Out)	ºC	80	70	52	56
LMTD	ºC	20.8			
Inlet Pressure	Kg/cm^2 g	3.0		3.0	
Pressure Drop (ΔP)	Kg/cm^2 g	0.83		0.2	
Fouling Factor	$hr.m^2$.ºC/Kcal	0.0002		0.0003	
HTC Overall	$Kcal/hr.m^2$.ºC	940			

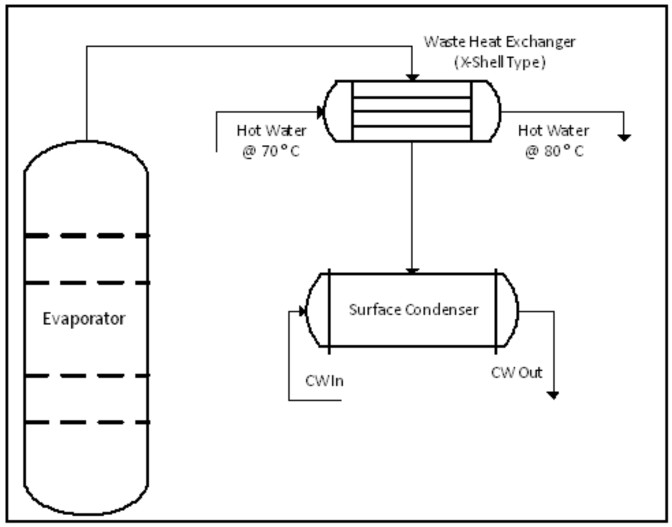
The exchanger sized with the help of Aspen Exchanger Design & Rating tool was then compared with the design proposed by a graphite exchanger manufacturer for its accuracy and the deviation was found to be < 5.0 %

2.6.5 Waste Heat Recovery Exchanger:

Waste heat exchanger will tap the waste heat from the source & will transfer it to the hot water. Here the waste heat source considered is the water vapours generated from the evaporators at 90 ºC. In normal operation these vapors are condensed by cooling water in the surface condenser to create vacuum.

The waste heat exchanger will be placed in series with the condenser at the upstream of condenser. Evaporation systems work under vacuum or at very low pressure and hence back pressure due to pressure drop from additional exchanger is envisaged. To negate or minimize the pressure drop X-shell type exchanger is considered. (Fig 3).

Figure 3. Waste heat recovery through an Exchanger



2.6.6 Heat Exchanger Sizing [5]

Table 6 shows the design details of the waste heat exchanger.

Table 6. Waste Heat Exchanger Data sheet[5]

Parameter	Unit	Waste Heat Exchanger			
Heat Transfer Area	Sq.m.	365			
Heat Duty	Kcal/hr	5670000			
		Shell Side		Tube Side	
Fluid		Water Vapors		Hot Water	
Mass Flow	Kg/hr	10421		567000	
Temperature (In/Out)	ºC	93.7	91.8	70	80
LMTD	ºC	17.1			
Inlet Pressure	Kg/cm^2 a	0.8	0.79	2.0	1.84
Pressure Drop (ΔP)	Kg/cm^2	0.01		0.06	
Fouling Factor	$hr.m^2.ºC/Kcal$	0.0002		0.0003	
HTC Overall	$Kcal/hr.m^2.ºC$	960.6			

Tapping the waste heat for the spin bath heating will conserve the steam however one need to consider the increase in operating cost for the proposed system. Operating Cost for the proposed system will be the cost of energy required to drive the circulating medium i.e. hot water.

2.6.7 Pump Sizing:[4]

Table 7. Pump sizing for hot water circulation

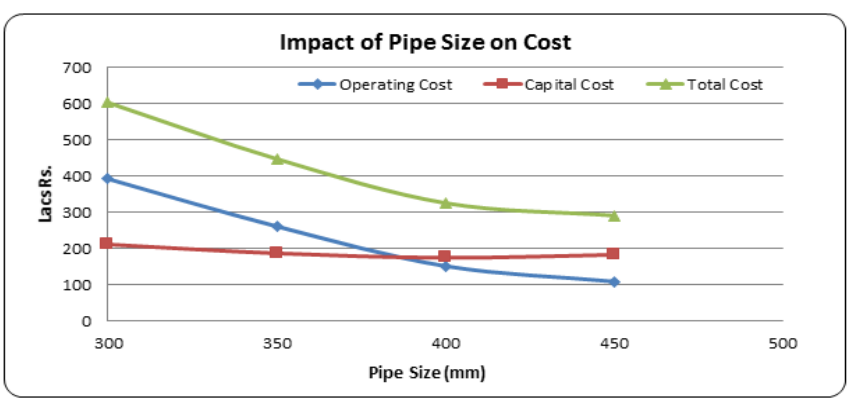
Table 7. Pump sizing Calculation sheet [4]

Parameters	Unit	Values	Remark
Hot water flow rate	m^3/hr	567	
Pipe size (D)	M	0.40	Carbon Steel,Sch 40, DN 400.
Equivalent length of pipe (L)	M	2800	
Water velocity (v)	m/s	1.3	
Water density (ρ)	Kg/m^3	971.6	@ 80 ºC
Dynamic viscosity (μ)	Kg/m.s	0.000355	@ 80 ºC
Reynolds's Number (Re)	-	1442052	
Absolute surface roughness (ε)	-	0.00375	
Darcy friction factor (fd)	-	0.037754	
Friction head loss (hf)	M	27.1	Darcy-Weisbach equation
Static head	M	16.0	Assumed elevation of 2 floors
Head loss in HE-1	M	0.8	from design data of HE
Head loss in HE-2	M	0.5	from design data of HE
Total head loss	**M**	**44.5**	
Pump for Given Duty	(η=84%), Impeller ø380 mm		
Pump efficiency	%	80	De-rated efficiency for calculations
Motor efficiency	%	95.4	IE 3, 4 Pole, 3 ø, 110 kW, 415 V, 50 Hz
Power required	kW	90.0	
Power cost	Rs./ kW	5.0	
Annual operating hours	Hours	8400	
Annual operating cost	**Lacs Rs.**	**37.8**	

2.6.8 Pipeline sizing [4]

The cost benefit analysis was carried out to decide the economic diameter of the pipe. (fig 4)

Figure. 4. Optimum Pipeline dia from cost anaysis



** Operating cost: NPV calculated for 5 years at discount rate of 8%*

Cost benefit analysis revealed that 400 mm diameter pipe is the optimum pipe dia for the given case

3. Results and Discussion

3.1 Analysis on Increase In Exchanger Area

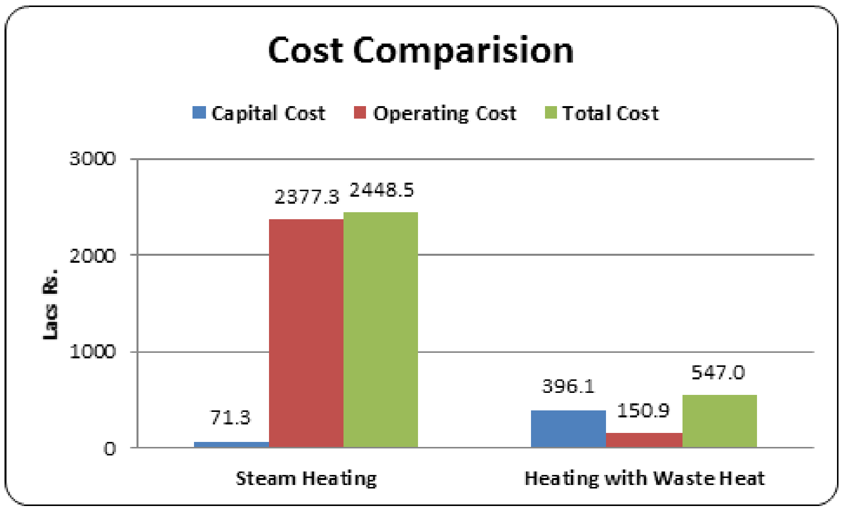
The size of the exchanger increased nearly 4.3 times. The reasons of increase in area is due to decrease in LMTD and heat transfer co-efficient. Interestingly, the heat transfer co-efficient decreased by only 16 %. In other words if hot water is available at 125 deg C and for a temperature range of 10 deg C, the exchanger area would have only increased by 50 %. In this case 370 % increase in area is attributed to lower LMTD in utilizing waste heat.

3.2 Cost Analysis: [4]

Cost Benefit Analysis: Steam Heating Vs Hot Water Loop.

This section compares the capital cost & operating costs for the above mentioned options. The spin bath circulation loop which is common in both the cases is not considered for costing. *(Table 8) Cost Calculation for Capex & Opex [4],* (Fig 5).

Figure 5. Capex/Opex cost comparision for steam & hot water heating system



* *Operating cost considered is NPV for 5 years at discount rate of 8 %.*

Table 8. Cost - Comparative Analysis[4]

Parameters	Steam Heating	Heating with Waste Heat
Capital Cost (Lacs Rs.)	**71.25**	**396.1**
Spin Bath Heater (Graphite Exchanger)	71.25	157.5
Waste Heat Exchanger	-	64.75
Pumps (2 Nos.)	-	122.0
Motors (2 Nos.)	-	9.84
Piping For Hot Water Circulation Loop		142.0
Operating Cost (Lacs Rs. Per Annum)	**595.4**	**37.8**
Steam For Heating	595.4	-
Pumping Power For Hot Water Circulation	-	37.8
Operating Cost (5 Year NPV @ 8% discount rate)	**2377.3**	**150.9**
Total Cost (Lacs Rs.)	**666.65**	**433.9**
Total Cost (Lacs Rs.) (NPV + Capital Cost)	**2448.5**	**547.0**

3.3. Simple Payback period: 8 months

 # Capital cost includes the cost of equipment, cost of installation and labor cost. Cost for waste heat exchanger, pumps, motors & piping was calculated based on the cost correlations developed from the past project data available with Corporate Technical and Energy services.

The investment required in the waste heat recovery system is almost 5 times that of conventional steam heating. The capital cost for waste heat recovery was dominated by the two components viz. cost of graphite heat exchanger &the piping cost.

However, the operating cost is significantly low for waste heat recovery system and pumping cost accounts for the same. Investment can get paid back in 8 months.

For retrofitting case the existing exchangers can be converted to hot water heating as spin bath will remain in the tube side irrespective of the heating medium.

4. Conclusion

1. Inter unit use of low grade unit for spin bath heating is an economically viable option. Payback is very attractive at 8 months though the capex is very high. Leverage is in the operating cost i.e. Steam Vs Waste heat.
2. Heat transfer co-efficient in hot water heating decreases only by 16% with respect to steam heating. Hence hot water availability at 125 ºC would mean an increase in area only by 50% and not multifold.
3. Reduction in water make up to cooling tower is additional benefit.

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