

Water Pinch Analysis – An Innovative Approach Towards Water Conservation In Pulp And Paper Industry



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ABSTRACT

The growing stringent environmental norms and the economic considerations force industry for the reuse of process water. Recycling of the process water thus can substantially save energy & reduce effluent volumes. Analysis indicates that the fresh water consumption in the Indian Pulp & Paper Mills varies depending on large & varied requirement such as type of fibrous raw material, paper varieties produced, technological level of manufacturing processes, site of the mill, its age, availability of fresh water, degree of water recycling etc. The volume of water consumption in integrated and non-integrated mills varies both in terms of quantity and quality of the effluent generated. While in integrated mills, it varies from 60 to 125 m³/tonne of paper, in non-integrated mill it ranges from 10 to 50 m³/tonne depending the type of paper produced by the mill. When compared to mills in developed countries, the consumption is on higher side.

Water pinch is a concept of process integration for minimizing the fresh water consumption. This method based on the principle of pinch analysis shows graphical representation of targeting and design of water networks with minimum fresh water consumption and maximum reuse of water considering constraints of water quality affecting reuse & recycling within the processes. Water pinch analysis offers scope for water conservation in the pulp & paper industry and mills in developed countries have adopted this tool for optimization of water consumption. This concept is new to Indian paper industry and an effort has been made by CPPRI to create awareness about water pinch analysis. A few studies have been conducted in selected integrated pulp and paper mills to demonstrate the saving potential by using this technique. Present article highlights the concept of water pinch analysis and scope of savings by using water pinch analysis in selected mills. The case study conducted in integrated wood based mills is an example to demonstrate saving potential by using water pinch approach. Similar exercises can also be replicated in non-integrated paper mills to achieve the water conservation targets.

Introduction

The pulp and paper industry is one of the major water consuming industries. Water is used for a variety of processes such as preparation of raw materials and

chemicals, development of fibers for papermaking properties, transportation and dilution of pulp, formation and consolidation of paper web, cleaning of parts of paper machines and accompanying equipment. Additionally, water is also used for cooling, sealing, lubrication, heating (in the form of steam) etc. During the above operations, water gets

contaminated by processing with raw materials, byproducts, residues and pulp processing. The amount of water consumed in integrated and non-integrated mills varies significantly due to different processes used for pulp and paper manufacturing. The effluent generated in integrated mills, varies from 60 to 125 m³/tonne of paper, while in non-integrated mills it ranges from 10 to 50 m³/tonne depending the type of paper produced by the mill.

The analysis of demand for fresh water in each stage of paper production (newsprint and writing printing paper) in a recycled fiber based mill shows that the highest amount of water is consumed during the paper manufacture in the paper machine (Fig 1).

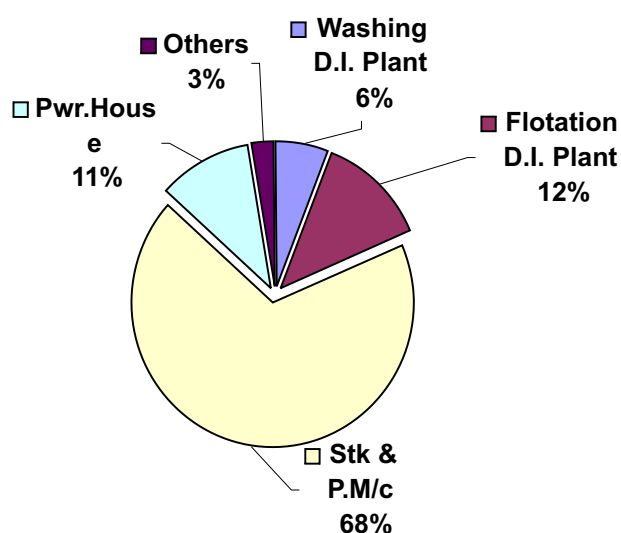


Fig. 1 Water Consumption in RCF mill producing Newsprint and WPP paper

Treatment of the contaminated waste water has always been an expensive & technically challenging subject. Since water and energy are closely integrated as 98% of the streams have water content higher than 50% (1) therefore water conservation has gained significant importance.

The adoption of water minimisation techniques can effectively reduce the fresh water demand of water-using processes considerably and subsequently reduce the amount of effluent generated. This may result in both, reduced cost in use of fresh water and the cost involved in the treatment of effluent streams. Important methodologies that have been applied for minimisation of water use and effluent generation have been listed by Klemeš and Perry (2) as;

- The minimisation of water consumption by the efficient management and control of process operations.
- The optimisation of material and energy balances of processes by the application of advanced optimisation

strategies aiming at waste reduction.

- The integration of optimisation and production planning techniques in conjunction with real-time plant measurements and control for product quality and minimisation of losses.
- The use of Process Integration techniques based on Pinch Analysis and Mathematical Optimisation.

The process integration techniques offer scope for reducing not only effluent discharge volume but also fresh water requirement. Processes integration has been identified as a potential method for energy as well as water conservation. Application of mass integration tools based on water pinch analysis, developed for targeting with a consideration of reuse, regeneration – reuse & regeneration – recycle of various process water streams, has yielded significant water conservation options for paper industry and has provided ways to move towards objective of zero effluent discharge. Use of state of art technologies in paper industry has shown a progressive reduction in the water consumption.

In present article a review of status of developments in the field of water pinch analysis for pulp & paper industry with its limitations and efforts made by CPPRI for application in Indian paper industry are highlighted.

Process Water Integration

The possibility of selectively reusing wastewater within pulp, paper making and utilities is a very attractive option for pulp and paper industry. The wastewater reuse / recycling can be performed with or without intermediate treatment. This would have a significant impact on overall fresh water usage as well as in the effluent generation and waste water treatment.

Water pinch analysis offers an approach & methodology for targeting fresh water usage and minimization. The technique is similar to thermal pinch analysis and utilizes concept of water surplus diagram. This method provides valuable information about process modification leading to wastewater recycling and minimization of fresh water use by developing network design to satisfy the targets.

Smith & Wang (3) initiated water targeting & designing of water network with the idea from heat integration developed in 1970's. The method of limiting composite profiles known as water pinch analysis used graphical approach for analyzing water networks & reducing water requirement for processes.

Limiting profiles constructed by specifying the maximum allowable inlet & outlet contaminant concentrations for each operation was used to combine and form a limiting composite curve against which a supply line was matched. The inverse of the slope of the line gives the target for fresh water and

wastewater. The point limiting the slope of the line was termed as water pinch. Approach used advanced algorithms to identify & optimize the best water reuse, regeneration & effluent treatment opportunities. This method had some disadvantages as it could not be applied to fixed flow rate problems like reactors, cooling towers etc and it was found that targets may not be true solutions as they largely depend on the mixing pattern of the process streams.

Dhole & Coworkes (4) suggested a method by plotting all water source & demand curves against water flow rate instead of contaminant mass load. The source and demand composite curves were plotted on the same axis & shifted together so that they touch. The overlap between the composites shows the potential for water reuse by dividing into two regions, one above the pinch & one below pinch. In order to achieve targets, fresh water below pinch be used and sources above the pinch should not be discharged as wastewater. However the disadvantages of this method were that there were many local pinch points and mixing of the sources can change the shape of the source composite & the targets. Hallale (5) presented a new graphical method for targeting fresh water and minimizing wastewater by using concept of water surplus diagram analogous to the grand composite curve (GCC) in thermal pinch analysis. This method has been found to be very useful for considering process modification & water regeneration by overcoming limitations of earlier concepts. However there are some drawbacks observed in this method as it requires transferring data from one plot to another and is based on trial & error procedures. Agrawal & Shenoy (6) have proposed a new targeting approach for fixed flow problem. This is based on a non iterative approach and gives absolute targets with reduced conceptual efforts. In this approach fixed flow problem are recast to be equivalent to fixed contaminant problems. Limiting composite curve is plotted for both demand & sources with contaminant concentration placed on vertical axis and cumulative mass load on horizontal axis. The fresh water line (horizontal axis) is rotated with the origin as a pivot until it touches the limiting profile. The inverse of the slope of this line gives minimum fresh water requirement.

To develop the water reuse network for meeting the targets, the loop breaking proposed by Wang & Smith is rather difficult to implement for large system because of no clear criteria of which is the loop that needs to be broken at each step. The nearest neighbors algorithm proposed by Prakash & Shenoy (7) can be easily used to develop water networks. This algorithm satisfies the conditions like no water transferred across the pinch & inlet as well as outlet concentration have to reach their maximum values to achieve the minimum water target. It allows the use of slightly cleaner & slightly dirtier sources to satisfy the demand.

Apart from the conceptual approach, the mathematical

programming has also achieved a certain degree of success in solving the problem of water targeting & recycling. The limitation of single contaminant in conceptual approach to handle targeting has been over come with advanced computational facilities allowing multicontaminant concentration. However introduction of mathematical programming does not necessitate abandonment of all conceptual approaches as they have some constraints of developing models for the problem. The combination of both the approaches to obtain the best out of both should be the direction of the future as better conceptual insight can lead to better mathematical formulations.

Application Of Water Pinch Analysis In Pulp And Paper Industry

The water pinch analysis concept is new to Indian paper industry and has not been tried in any of the mill for exploring the possibilities of water conservation through reuse and recycling of waste water streams. There is huge potential for water conservation in large and medium scale paper mills by understanding the utilization pattern and getting an idea about the contaminants limit in various inlet and outlet streams in processes amalgamated with pinch concept. It can provide a new insight on utilization of various waste water streams and has been initiated by Central Pulp and Paper Research Institute to find out the application of water pinch analysis in Indian paper industry for accessing the water conservation potential.

In the context of Water Pinch analysis, reuse means that the effluent from one unit is used in another unit and does not re-enter the unit where it has been previously used. On the other hand, recycle allows the effluent to re-enter the unit where it has been previously used. Besides, one may also utilise a regeneration unit (e.g. filter, stripper, etc.) to partially purify the water stream prior to reuse/recycle (3).

A typical Pinch analysis study consists of two stages, i.e. setting minimum fresh water and wastewater flow rates (often termed as targeting), followed by network design to achieve the targeted flow rates. It is worth mentioning that the focus on Water Pinch analysis is the targeting step. With targeting, we are able to set a baseline target to determine how well a reuse/recycle system can actually perform based on first principle. Knowing the targets ahead of design is possible to eliminate the query of "will there be a better design?" during any design exercise. Once the minimum flow-rate targets are established, a water network can be designed using any network design tools. An example of this approach was demonstrated by Thevendiraraj et al. (8). Various examples are published elsewhere (9).

To set the flow rate targets for water reuse/recycle, various graphical and tabulated targeting techniques may be

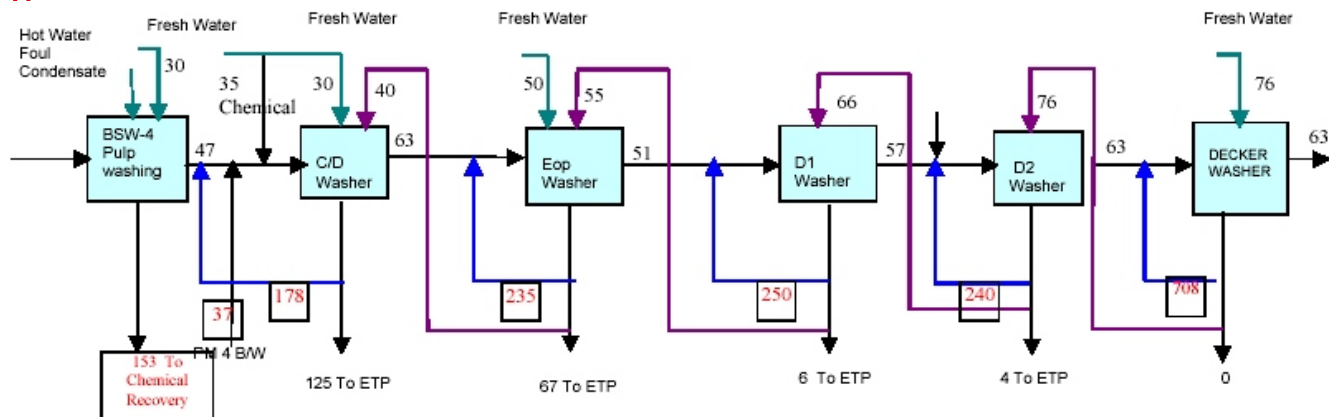


Fig. 2 Water Balance Flow Diagram for Mill-1

employed. These include the Limiting Composite Curves(3), Water Surplus Diagram (5), Material Recovery Pinch Diagram (MRPD) (10 , 7) Cascade Analysis technique (11) and Source Composite Curve (12). These graphical techniques are used to minimize the fresh water flow. Water surplus diagram are utilized to target the water requirements for;

- Fixed Contaminant (FC)
- Fixed Flow Rates (FF) and
- Mixed problems (FF and FC)

The overlap area of the demand (Sink) and Source Composite Curves represents the maximum water recovery among all sinks and sources. The point where the two Composite Curves touch is termed as the material recovery pinch, which is the bottleneck for maximum recovery. The segment where the Sink Composite Curve extends to the left of the Source Composite Curve represents the minimum fresh water (FFW) needed for the water network (to be purchased from external source); while region where the Source Composite Curve extends to the right of the Sink Composite Curve represents the minimum wastewater discharge (FWW) from the network (for waste treatment

before discharging to the environment). The minimum fresh water needed and the minimum wastewater generated by the network constitute the flow rate targets of the network, and are determined ahead of detailed design of the water network.

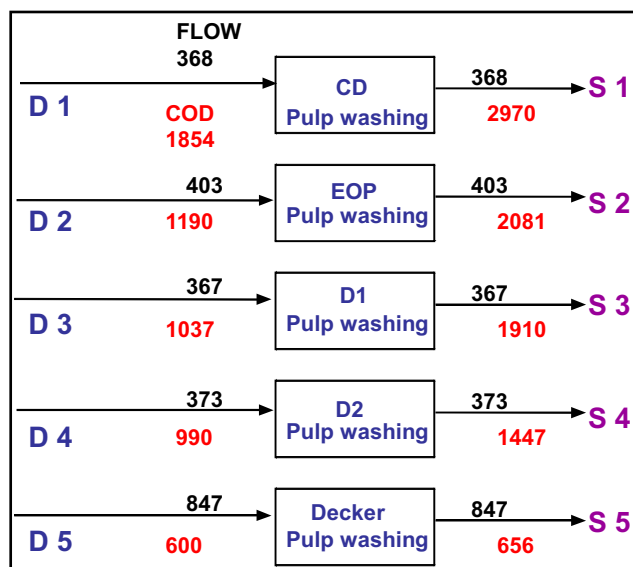


Fig. 3 Data extraction Diagram for Mill-1

Table-1 Flow Rate and Contamination Data for Mill-1

S.No	Detail of Streams	F _{in} m3/hr	C _{in} max		F _{out} m3/hr	C _{out} max	
			TS ppm	COD ppm		TS ppm	COD ppm
1	C/D Washer	368	4457	1854	63	8797	2970
2	EOP Washer	403	3827	1190	51	6982	2081
3	D1 Washer	367	3683	1037	57	5674	1910
4	D2 Washer	373	3134	990	63	5063	1447
5	Decker washer	847	2617	600	63	2617	656

Table-2 Composite Table Algorithm (CTA)

	Flow	Concentration, ppm	Net Flow, t/hr	Load Kg/hr	Cumulative Load, kg/hr (m)	Slope
d	847	600	0	0	0	0
s	847	656	847	47.4	47.4	72.3
d	373	990	0	0.0	47.4	47.9
d	367	1037	373	17.5	65.0	62.6
d	403	1190	740	113.2	178.2	149.7
s	373	1447	1143	293.8	471.9	326.1
d	368	1854	770	313.4	785.3	423.6
s	367	1910	1138	63.7	849.1	444.5
s	403	2081	771	131.8	980.9	471.4
s	368	2970	368	327.2	1308.0	440.4
		3000	0	0.0	1308.0	436.0

. d=demand and s=source

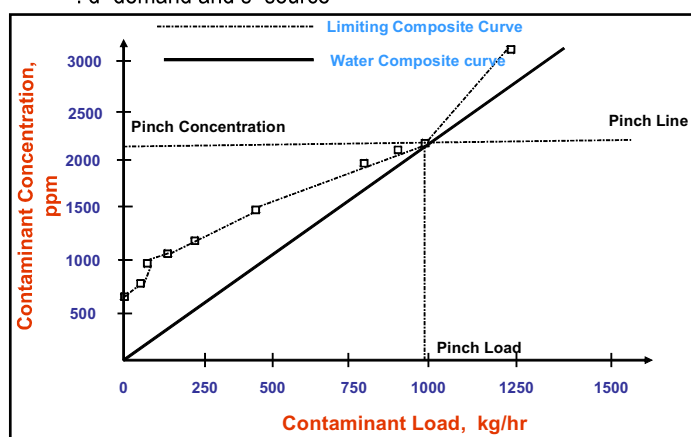


Fig. 4 Limiting Composite Curve for Mill-1

The basic principle of NNA in its simplest form may be stated as: "To satisfy a sink, the sources to be chosen are the nearest available neighbors to the sink in terms of its quality level". In other words, two sources that are having quality level just higher and just lower than the sink are mixed to satisfy the flow rate and load requirements of the latter. In this case, the required amounts of the two neighbor sources are dictated by the material balance equations. If the required flow rate of a source is not sufficient, then the total flow rate of that source is used completely and the next neighbor source is considered to satisfy the sink.

In the following sections, the targeting technique of water pinch (10, 7) and Water Grid Diagram (3) as applied in bleaching section of two mills, is presented.

Case Studies

Water minimization study was conducted in two wood based mills to indicate the minimum water requirement within the bleaching section using limiting profile diagram. The study

focused on two contaminants (TDS and COD) in the pulp mill water for reuse & recycle options within the mill. A complete water balance of the pulp mills was prepared using online & portable flow meters. The water samples from various streams were characterized with respect to their pollution load.

The water balance flow diagram and data extracted and its evaluation for bleaching sections of these two mills is discussed below.

The water balance flow diagram for Mill-1 is shown in (Fig. 2).

From above water flow diagram the data extraction was conducted. For the analysis all operations were assumed to be fixed contaminant (FC) and fixed flowrate operations type. The limiting contaminant levels in this case was fixed at 10 % above the current values. Following restriction were imposed on re-use of water streams.

- All matches prohibited by pH were disallowed.
- Order and flowrate from one process to another was maintained.

The data extracted is shown in Fig. 3.

From above data the flow rate and Contamination Data was calculated for Mill-1. The data was used to generate the Composite Table Algorithm (CTA). The flow rate, contamination data and CTA are presented in Table-1 and 2 below.

In the CTA the formula used for calculation of Net Flow, Load and slope are ;

Table-3 Fresh water Matching Matrix Network before study

No	Streams	Flow (m3/hr)		C/D Washer	EOP Washer	D1 Washer	D2 Washer	Decker Washer	Extra
	Name	Available	Used	D1 {368}	D2 {403}	D3 {367}	D4 {373}	D5 {847}	
S1	Freshwater	191	191.0	65.0	50.0			76.0	0.0
S2	B/W from PM 4	37	37.0	37.0					0.0
S3	Feed from BSW	47	47.0	47.0					0.0
S4	C/D Washer B/W	304	179.0	179.0					125.0
S5	EOP Washer B/W	351	275.0	40.0	235.0				76.0
S6	D1 Washer B/W	311	305.0		55.0	250.0			6.0
S7	D2 Washer B/W	310	306.0			66.0	240.0		4.0
S8	D.W. B/W	784	784.0				76.0	708.0	0.0
P1	C/D Washer	63.0	63.0		63.0				0.0
P2	EOP Washer	51.0	51.0			51.0			0.0
P3	D1 Washer	57.0	57.0				57.0		0.0
P4	D2 Washer	63.0	63.0					63.0	0.0
P5	Decker Washer	63	0.0						63.0

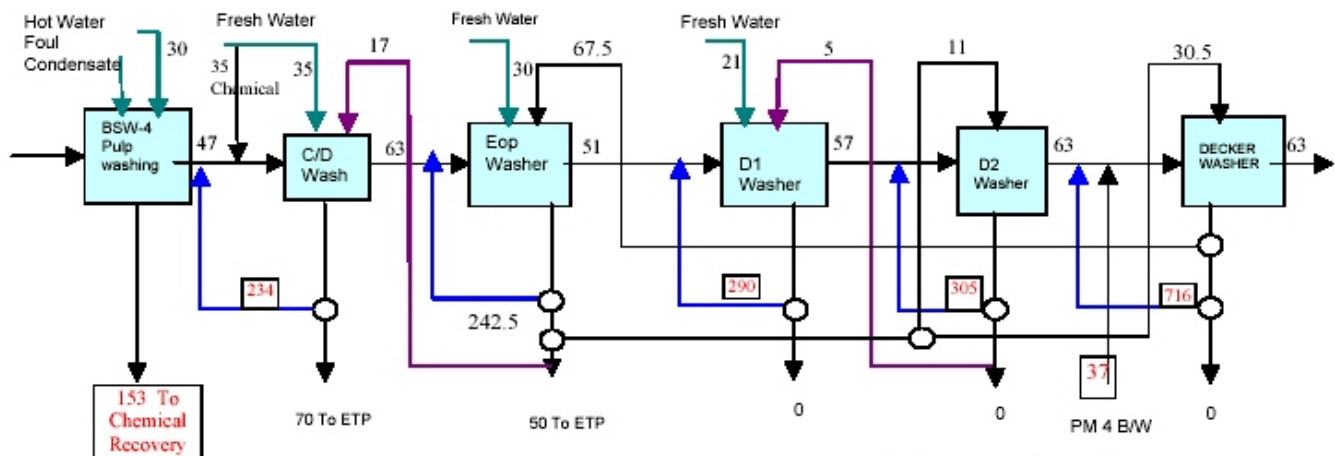


Fig. 5 Water Balance Network for Mill-1

Table -4 Fresh Water Matching Matrix Network After Study

No.	Streams	F (m3/hr)		C/D Washer	EOP Washer	D1 Washer	D2 Washer	Decker Washer	Extra
	Name	Available	Used	D1 {368}	D2 {403}	D3 {367}	D4{373}	D5 {847}	
S1	Freshwater	191	121.0	70.0	30.0	21.0			70.0
S2	B/W from PM 4	37	37.0					37.0	0.0
S3	Feed from BSW	47	47.0	47.0					0.0
S4	C/D Washer B/W	304	234.0	234.0					70.0
S5	EOP Washer B/W	351	301.0	17.0	242.5		11.0	30.5	50.0
S6	D1 Washer B/W	311	290.0			290.0			21.0
S7	D2 Washer B/W	310	310.0			5.0	305.0		0.0
S8	D.W. B/W	784	784.0		67.5			716.5	0.0
P1	C/D Washer	63	63.0		63.0				0.0
P2	EOP Washer	51	51.0		30.0	51.0			0.0
P3	D1 Washer	57	57.0				57.0		0.0
P4	D2 Washer	63	63.0					63.0	0.0
P5	Decker Washer	63	0.0						63.0

Table 5 Results for Mill I

Particulars	Min. Fw, m3/hr	
	Mill-1	Mill-2
Min. Fresh Water Consumption before PI	191	200
Min. Fresh Water after PI (considering TS and COD as contaminants)	121	171
Fresh Water Saving %	36	15

$$\text{Net Flow (t/hr)} = \sum \text{Flow} = \sum \text{Flow}_{\text{Demand}} - \sum \text{Flow}_{\text{Source}}$$

$$\text{Load (kg/hr)} = \sum \text{Flow} \times (C_{\text{out}} - C_{\text{in}}) / 1000$$

$$\text{Slope} = \text{cumulative load (m)} / C - C_{\text{min}}$$

The limiting composite curve is developed by plotting the contaminant concentration (ppm) against contaminant load (kg/hr). The same is shown in Fig.4.

Nearest Neighbour Algorithm (NNA) for Mill-1

In this approach, sources which are immediate higher and lower in concentration for a demand are mixed in ratio determined by mass balance to satisfy the demand. If the required flow rate is not available for a source, then whatever is available of that source is used completely & next neighbor is considered to satisfy the demand.

The mass balance equations used for NNA are-

$$F_{SK, DP} + F_{S(K+1), DP} = F_{DP}$$

$$F_{SK, DP} C_{SK} + F_{S(K+1), DP} C_{S(K+1)} = F_{DP} C_{DP}$$

Where;

F&C are flowrate & concentration

S_K & $S_{(K+1)}$ are immediate cleaner & dirtier sources (Nearest Neighbour)

DP is the particular demand.

For a plant having n consumers & m sources of water, possible numbers of match is (m x n). The possible number of matches are restricted by the constraint imposed by concentration criteria.

In order to satisfy a demand, the combined weighted concentration of all matches of the demand must be the same as the concentration of the sources. Thus the actual number of matches possible is less than (m x n) for m by n system.

By using the above NNA approach, the fresh water matching networks were developed for the bleaching process in mill-1. Table 3 and 4 present the fresh water matching networks before and after the study.

The proposed Water Balance Network for Mill-1 is presented in Fig. 5. Similar exercise was also conducted in Mill-2. The Table 5 shows the saving potential available in these mills by using the water pinch analysis in pulp and paper mills.

Conclusion

The study conducted in selected integrated mills in the bleaching section shows that water pinch analysis can be used as a valuable tool for water conservation. By conducting studies in other sections of the mill substantial water savings can be achieved by properly implanting water pinch analysis recommendations. The exercise can be extended and conducted in Recycled Fibre based mills and this segment of the industry can also get the benefits of the water pinch process analysis approach.

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