Waste Water Minimization of Starch Industry Using Water Pinch Technology

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Abstract

Water is a vital component for many industrial operations, and is utilized for a wide range of purposes in industrial processes. The rapid growth in population, coupled with industrialization and urbanization, resulted in an increased demand for water, leading to serious consequences on the environment. The cost and scarcity of water beside stricter regulations on industrial effluents have become a significant factor in commodity material manufacturing. In this paper sincere efforts had been put to demonstrate, the potential of water pinch technology at real world of industries. To explore the effectiveness of this technology a case studies from a Starch industry of India is under taken with an aim to reduce demineralised (DM) water flow rate and subsequently waste water flow rate. The problem is viewed as a single contaminant problem and all the three modes of water integration i.e. *re-use*, *regeneration-reuse*, *regeneration –recycle* are demonstrated. The DM water consumption is 50 tph before modification and after modification using water pinch it reduces to 31.9 tph *(reuse)*, 21.6 tph (*regeneration-reuse*) and 12 tph (*regeneration-recycling*). The results obtained from the present analysis are compared well with the results obtained from well established software ASPEN WATER which uses mathematical programming approach based on MINLP. The cost benefit analysis illustrates that the profit obtained in the case of reuse is 17, 63,914 INR per year and the payback period for the *regeneration-reuse* and *regeneration –recycling* are 1.8 and 1.1 months. A computer program is developed in MATLAB for analysis of the above case study using water pinch technology.

Keywords: *Waste water minimization, Water Pinch, Starch*

1.0 Necessity of water minimization

The rapid growth in population, coupled with industrialization and urbanization, has resulted in an increase in the demand for water leading to serious environment consequences. Several industrial processes, such as, stripping, liquid–liquid extraction and washing operations, among the many processes present in refineries and chemical plants, require extensive utilization of water. It may contain various hazardous or toxic pollutants that need to be strictly controlled [8,9]. Apart from waste water generation, the amount of water used in manufacturing varies significantly from industry to industry as well as process to process. As a rough estimate as noted by Alva-Argáez et al.[1], in chemical manufacturing, total process and cooling water usage is 0.0045-0.045 m^3 per kg of product. Scarcity of water and stringent regulations for industrial effluents has led to a paradigm shift in thinking about water usage. Further, the cost of water is becoming a significant factor in commodity material manufacturing. There are many types of technologies/methodologies available to save fresh water and reduce waste water generation. Water system integration, one of the important methodologies of wastewater minimization, treats the water utilization processes of an industry as an organic whole, and considers how to allocate the water quantity and quality to each water using unit, so that water reuse is maximized within the system and simultaneously the wastewater generation is minimized. This method shows excellent effectiveness in saving freshwater and reducing wastewater. Therefore, much research has been devoted to the three approaches on water system integration, including water reuse, regeneration-reuse and regeneration- reuse-recycle. The developing field of water-pinch technology evolved out of the broader concept of process integration [10].

2.0 Concept of Water Pinch Technology

Conceptually, water pinch technology is a type of mass exchange integration involving water-using operations; it does not, involve the same practical problems that hinder the real world implementation of mass exchange networks, simply because the water-pinch technology represents existing class of manufacturing operations.

3.0 Strategies for industrial water reuse and waste water minimization

The goals of conventional water-reuse projects are to reduce fresh water consumption, minimize effluent discharge, and achieve zero liquid discharge. Water –pinch technology can contribute significantly to the fourth step in conventional water-reuse design. The steps involved in applying water-pinch technology to industrial processes are (1) water use survey (2) data extraction, (3) targeting and design and (4) project economics and detailing. Process synthesis systematically guides the designer in the rapid screening of the various process options in order to identify the optimum or near optimum design. It also allows the assessment of the design possibilities before detailed design is initiated. The development of graphical approach has been started with work of Linnhoff and Flower [13]. They developed Pinch analysis for the optimization of heat exchanger networks. Linnhoff et al.[14] applied the proposed methodology to practical problems. Linnhoff *et al*. [15] developed a graphical approach was proposed in which a heat exchange system is represented by a plot of temperature as a function of enthalpy and developed a concept of pinch point. Wang and Smith [19,20,21,22] presented a conceptually based approach, in which targets are set that maximize water reuse. Both single and multi-contaminant cases were addressed, along with the identification of regeneration opportunities. Wang and Smith [20] presented a conceptually based approach of designing of distributed effluent treatment plant. In a later paper, Wang and Smith [21] discussed single and multiple operations with fixed flow rate and processes with multiple sources of water of varying quality. Olesen and Polley [18] reviewed the procedures introduced by Wang and Smith concerning single contaminants. Kuo and Smith [11,12] also recognized the complexity of the evolutionary design procedure proposed earlier by Wang and Smith [19]. Liu [16] presented a few interesting heuristic rules. Although some of them are incorrect, the solution procedure has remarkable simplicity and provides good sub-optimal (and sometimes optimal) solutions. In addition, Gómez, Savelski & Bagajewicz [6] provided an algorithmic procedure to address this matter. Mann and Liu [17] have found that when considering water regeneration recycling, some systems had another pinch point, regeneration pinch, which is higher than the normal pinch for freshwater targeting. They also introduced graphical techniques to determine minimum water flow rate in case of multi contaminant systems. Hallale N [7] introduced a new graphical targeting method for water minimization. Gomes *et.al* [6] presented a heuristic algorithmic procedure, water source diagram procedure (WSD), to synthesize water mass-exchange networks. Feng *et al* [4,5] introduced use of graphical method to determine the targets of single-contaminant regeneration recycling water systems, by analyzing the limiting composite curve of a single-contaminant water system. Dakwala et al.[3] used graphical techniques and demonstrated a case study of multicontaminant system for starch industries. The technology implemented successfully at plant level too.

4.0 Objective of present study

To apply water pinch technology to determine water conservation opportunities in different sections of a Starch industry in the state of Gujarat, India. A case study has been viewed as a single and multiple contaminant systems. The aims of study is to minimize the consumption of DM water and the production of wastewater and to design optimal targets for water use so that the plant's outdated water network could be updated, while accounting for current economic and technical restrictions. The procedure presented in this paper for wastewater minimization, is based on the concentration interval diagram & concentration composite curve as introduced by Wang & Smith & explained in detail by Maan & Liu [13]. This paper discusses, with the help of case studies, various solution approaches such as (i) re-use; (ii) regeneration and re-use; and (iii) regeneration and recycling.

5.0 Brief Information about Starch Industries

Fig 1 represents the process flow diagram of starch manufacturing. [3]

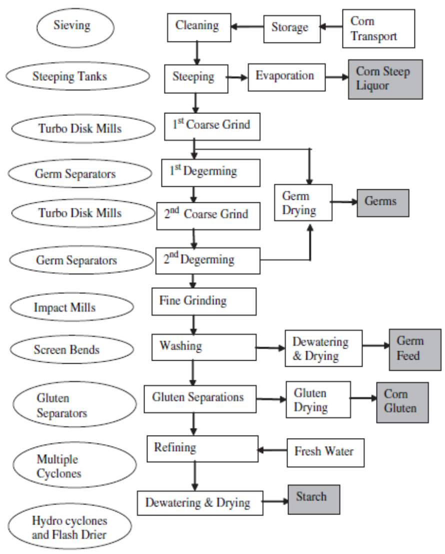


Fig 1 Process Flow Diagram of Starch Manufacturing [3]

6.0 Solution Methodology

The first step is to identify potential water consuming operations along with stream data including constraints for different water using operations. The next step is to analyze the system without any water reuse. And then different approaches of water pinch technology such as reuse, regeneration-reuse and regeneration-recycling should be investigated.

6.1 Minimum fresh water flow rate target for an integrated system with reuse

The key step in this type of process integration is to represent the individual water using operations on a single diagram and determining the minimum flow rate of fresh water for the entire system either by graphically through *concentration-composite curve* (CCC) or by tabular method through *concentration interval diagram* (CID).

6.1.1 Tabular Method: Concentration Interval Diagram

This process is very straight forward and more readily adapted to computer programming than the graphical method. The stepwise algorithm for this process is represented in Fig.2

6.1.2 Graphical Method-Concentration Composite Curve

Once the CCC has been established from the concentration interval diagram, the minimum fresh water flow rate can be obtained by drawing the water supply line on the CCC curve as detailed step wise in Fig.2. Fig.3 represents the algorithm for the program developed to construct CID & CCC using MATLAB.

6.2 Regeneration-reuse technique

The concept of *regeneration reuse* is divided in to four categories depending on water-using operations and is discussed in different sections. These are, *full regeneration & fresh water pinch*, *partial regeneration & regenerated water pinch*, *full regeneration & regenerated water pinch* and *Partial regeneration & fresh water pinch.* Fig.4 represents the general algorithm for selection and computation steps of different regeneration categories.

6.3 Regeneration-Recycling technique

Fig.5 shows the algorithm for regeneration-recycle techniques & how to select different categories of *regeneration –recycle.*

7.0 Existing Water Network

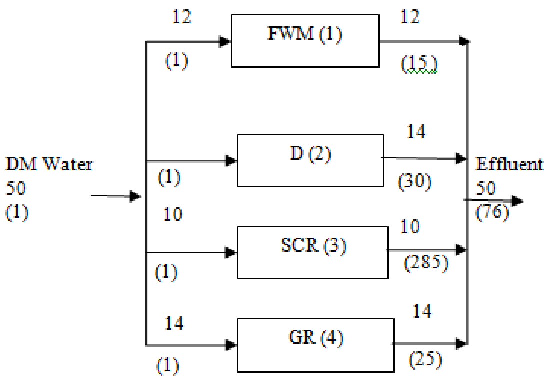


Fig.6 Existing water network

Note: *Values shown without brackets are flow rates of DM water in tph where as value within small brackets are concentration of contaminants in ppm.*

Fig 6 represents the schematic diagram of the water consuming units such as filter washing machine (FWM), Doroclones (D), Screens (SCR) and Grinder (GR) of a typical Chemical Industry producing starch. The Stream data is shown in the **Table 1** given below:

Table 1 Limiting Process data

Operation	**Limiting Water Flow rate f_i((tph)**	**Max. Limiting Inlet Concentration $C_{i,in}$ (ppm)**	**Max. Limiting Outlet Concentration $C_{i,out}$ (ppm)**
DM water using operations			
Primary Separators(PSI)	30	1 *	60
Primary Separators(PSII)	10	5	200
Process Reactor (R)	12	10	480
Dewatering section(DW)	12	15	350
Screen-4(S-4)	5	25	50

Fig. 7 shows the block diagram of the modified network which can facilitate DM water reuse to decrease the DM water consumption. The second step in the further reduction of DM water and waste water is to go for *full regeneration & regenerated water pinch.* Using Algorithm shown and program developed in MATLAB, the CID of DM water using operations has been generated which shows that the DM water flow rate can be further decreased to 34.5 tph. In this case also the DM water pinch remains at 60 ppm and regenerated water pinch occurs at 200 ppm. **Fig. 8** shows the block diagram of the modified network which can facilitate *full regeneration & regenerated water pinch* to decrease the DM water consumption. In the third step the DM water content is further reduced by using the concept of *regeneration-recycling.* Using Algorithm shown and program developed in MATLAB, the CID of DM water using operations has been generated which shows that the DM water flow rate can be further reduced to 24 tph. In this case also the DM water pinch remains at 60 ppm. **Fig. 9** shows the block diagram of the modified network which can facilitate *regeneration-recycle & regenerated water pinch* to decrease the DM water consumption.

8.0 Benefit Analysis

Table 2 represents the benefit of water pinch technology. It compares modified water using networks with that of existing ones for present case study. It also represents the net savings in water consumption. It can be observed that the water-pinch analysis reduced the consumption of DM water to a considerable extent.

Table 2 Benefits of water pinch technology

	Before Analysis	*reuse*	*regeneration-reuse*	*regeneration-recycling*
DM Water (tph)	69	59.83	34.5	30
% Savings in DM Water	--	13.3 %	50%	27.5%
Concentration of Solids (ppm)	76	225.8	351.76	296.4

9.0 Cost Analysis

The basis of costing is very important for carrying out cost analysis. **Table 3** presents the power comparison of different modified water network with existing water network. **Table 4** shows the cost of different modified water networks such *reuse*, *regeneration-reuse* and *regeneration-recycling* along with existing water network. **Table 4** represents the comparison of cost of water networks based on changes in flow rate of DM water, changes in pipe sizes and thus necessary cost associated with piping layout (i.e. civil, structural, erection and commissioning cost).

Further, it can observed that due to the decrease in flow rate of DM water consumption, load on DM water plant has also been decreased and this will result in decrease in operating cost of DM water plant. However the present problem is a retrofit case this decrease in fixed cost of DM water plant is not considered. **Table 5** illustrates the fixed capital investment , cost of additional equipment, profit incurred in operating cost in case of base case (existing network), *regeneration-reuse* and *regeneration-recycling.* For the case of *reuse* there is no extra fixed cost involved as it will use the hardware existing network. However, due to the changes made in the flow of water it will save an amount 17, 63,914 INR per year. From the **Table 5** it is clear that the computed payback period for the case of *regeneration-reuse* and *regeneration-recycling are* merely 1.8 and 1.1 months respectively which is very attractive.

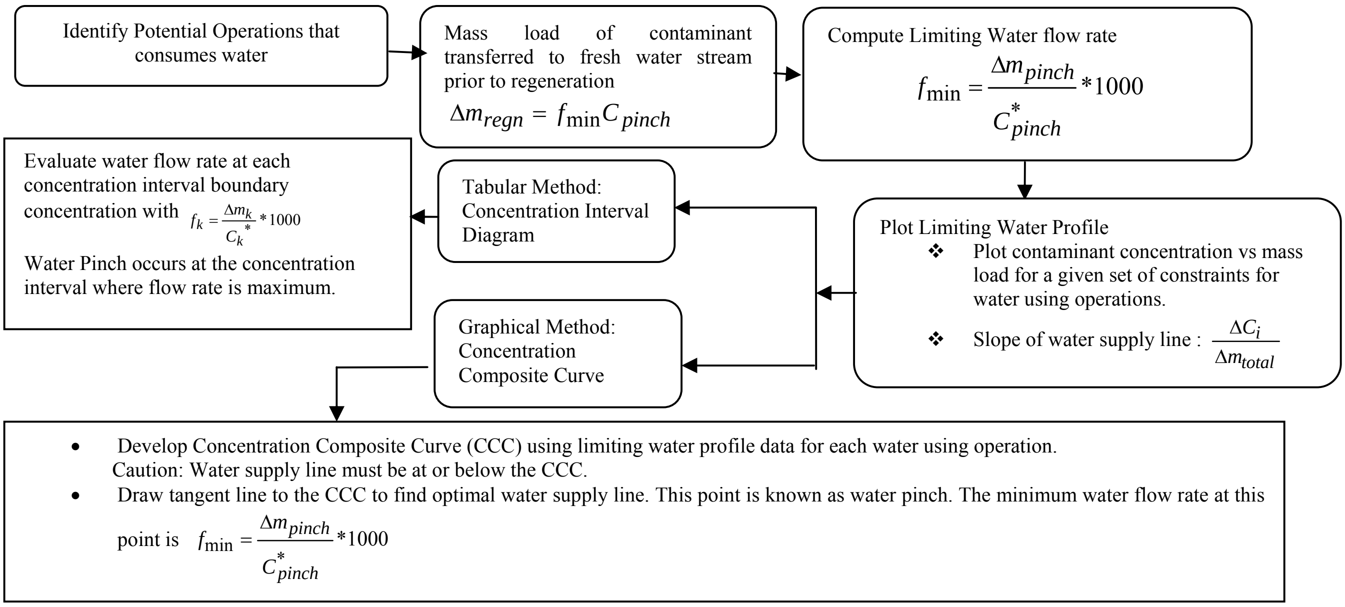


Fig 2. Flow chart to generate CID & CCC for single contaminant problem

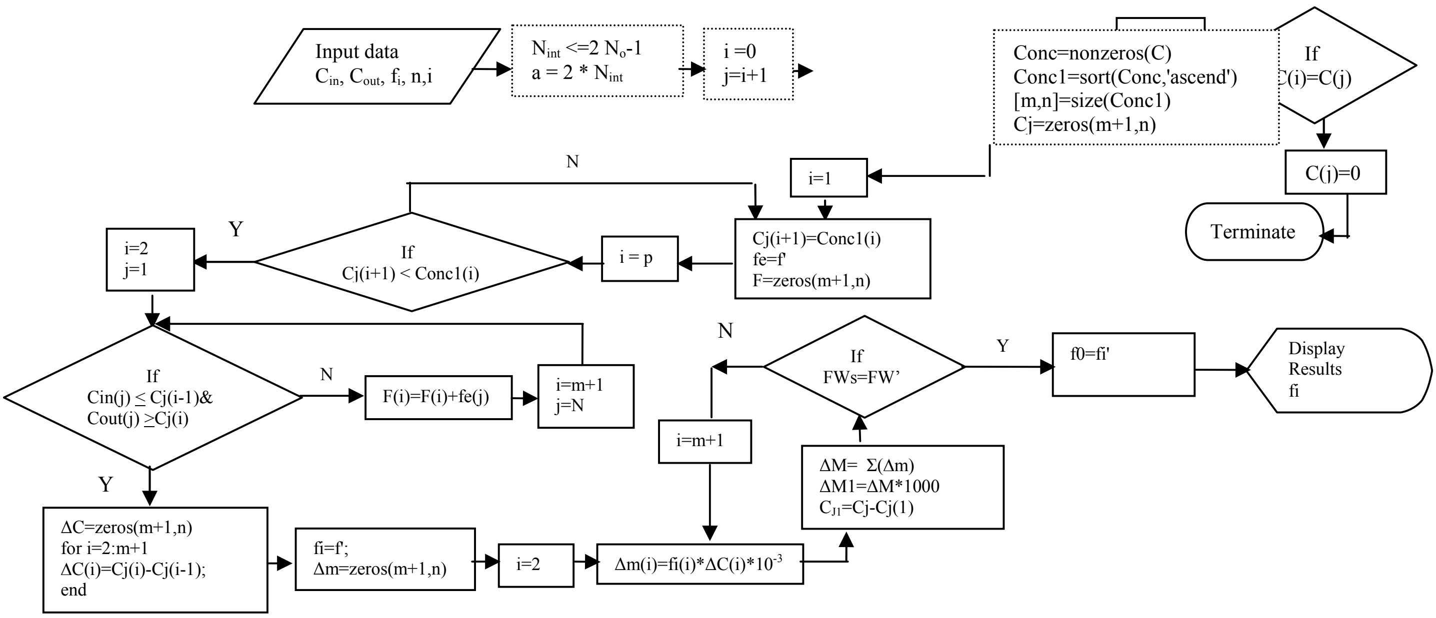


Fig. 3 Algorithm of program used to construct CCC & CID using MATLAB 7

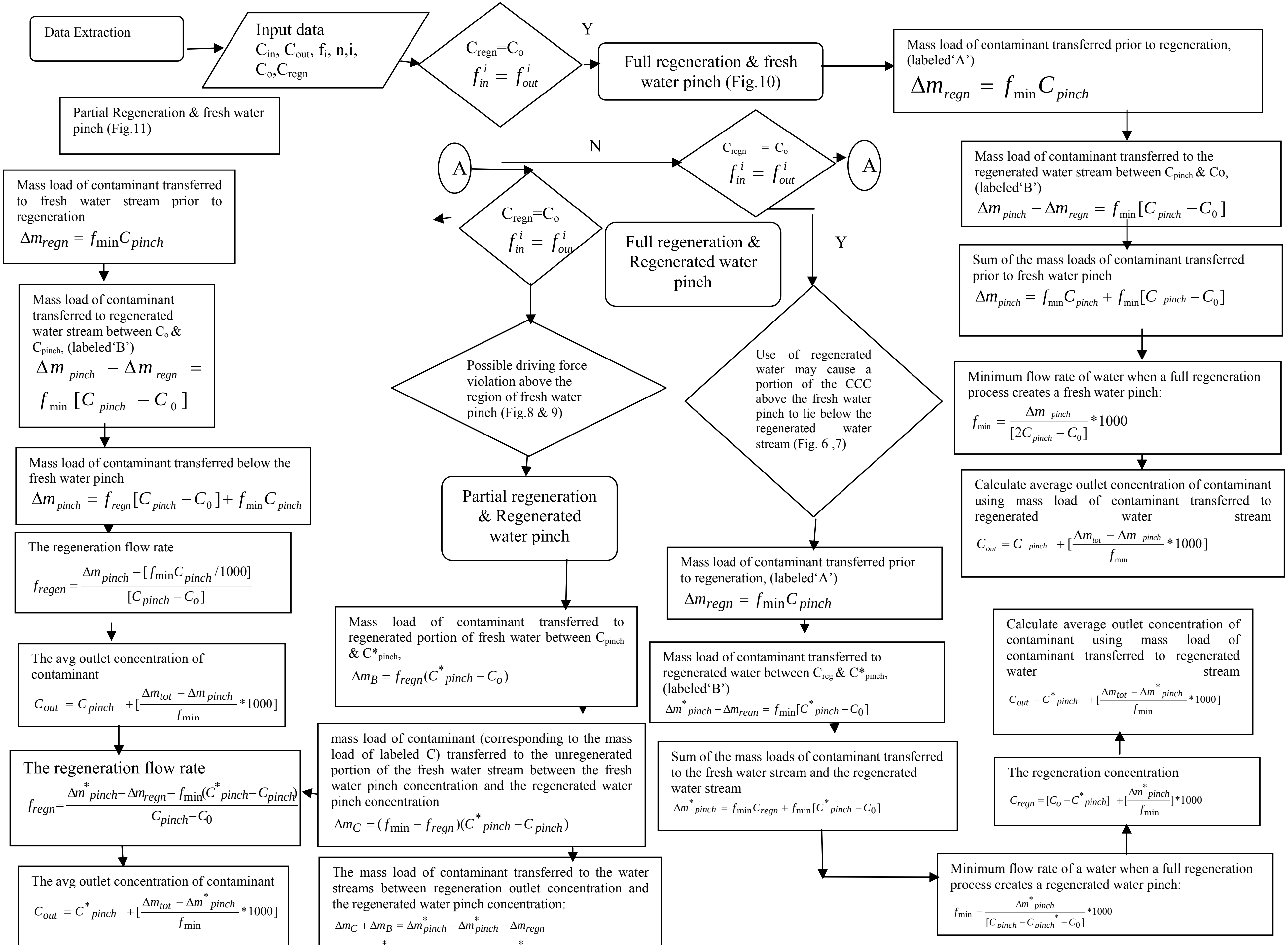


Fig.4 Regeneration Algorithm

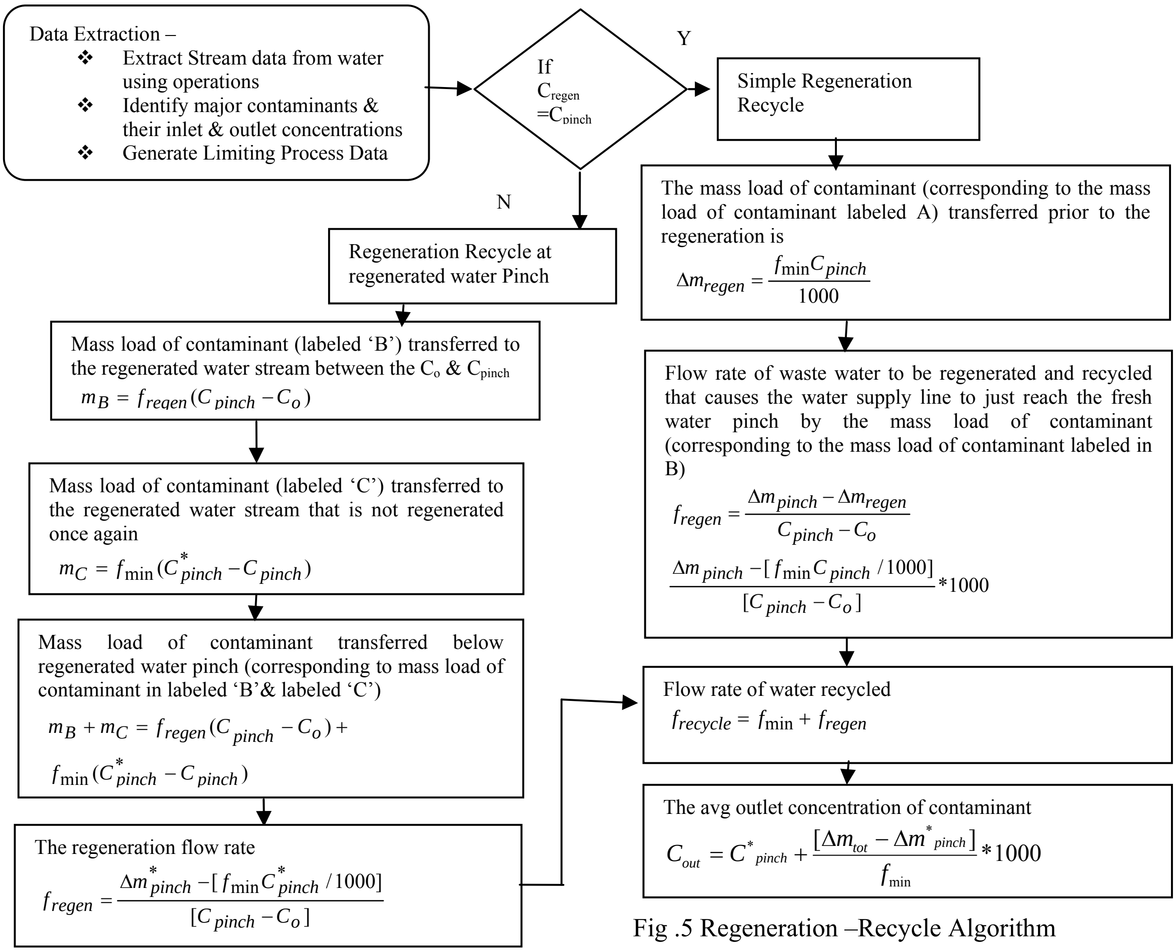


Fig .5 Regeneration –Recycle Algorithm

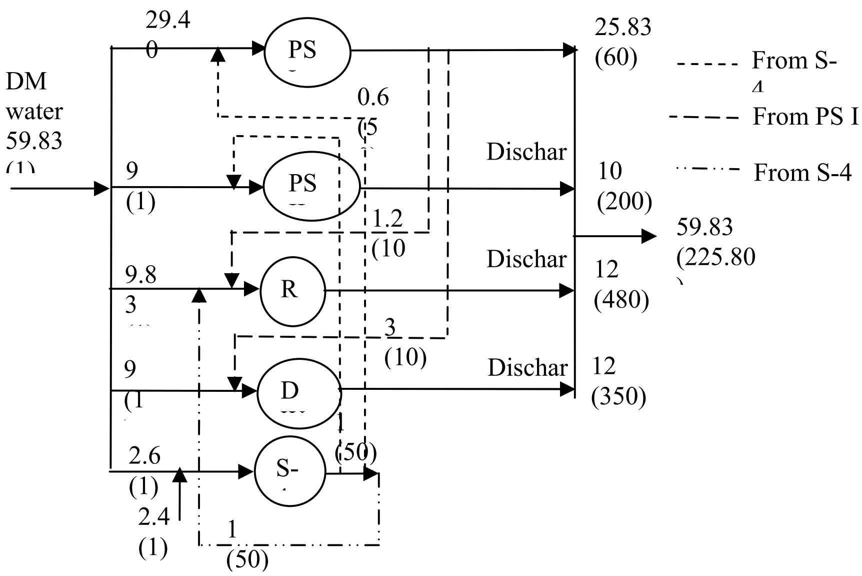


Fig. 7 Modified Water Network (*reuse* technique)

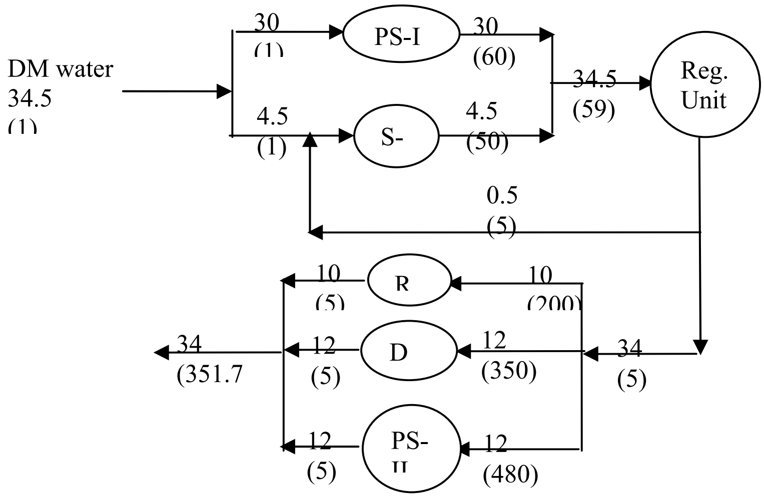
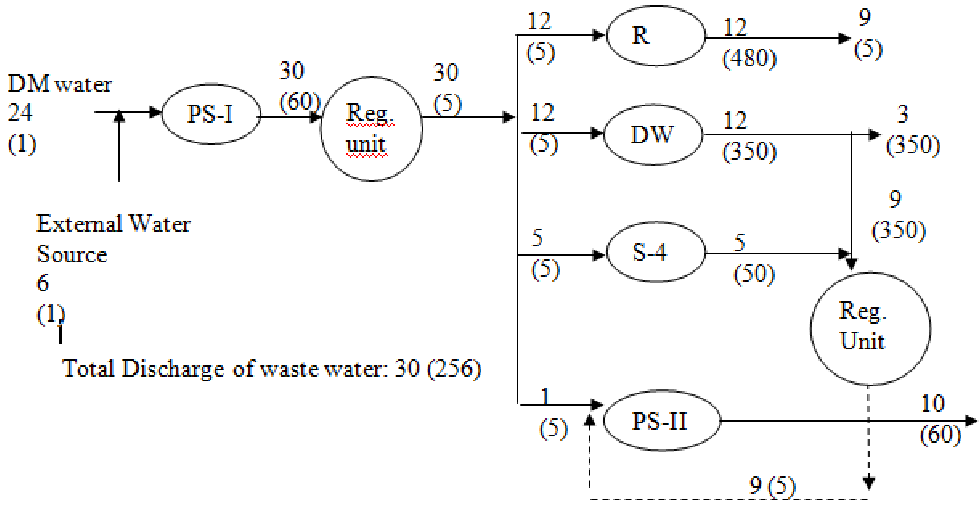


Fig. 8 Modified Water Network (*regeneration-reuse*



Note: *Values shown without brackets are flow rates of DM water in tph where as value within small brackets are concentration of contaminants in ppm.*

Fig. 9 Modified Water network (*regeneration-recycling* technique)

Table: 3 - Power consumption comparison of different modified water network with existing water network

Specifications	***Existing***	***Reuse***	***Regeneration-Reuse***	***Regeneration-Recycling***
Pump Capacity (delivered) (m^3/ h)	69	59	34.5	30
Pump Head (delivered) (m)	30	30	30	30
Efficiency of pump (%)	65	65	65	65
Power consumption (kW)	8.8	7.42	4.33	3.77
Motor efficiency (%)	90	90	90	90
Current drawn at full capacity (amp)	28	21	13	11
Power consumption (kW)	9.8	8.3	4.9	4.1
No. of unit per hour (kW-h)	9.8	8.3	4.9	4.1
Cost of power (INR / unit)	4	4	4	4

Total cost of power consumption (INR per year)	3,43,392	2,90,832	1,71,696	1,43,364
Operating hours	24	24	24	24
No. of operating days	365	365	365	365

Table 4 - Cost comparison of different modified network with exiting network

Total Cost of network	Existing	Reuse	Regeneration-Reuse	Regeneration-Recycling
Total Cost of existing network (INR)	4,87,408	5,10,173	4,39,766	4,40,256
Cost of regeneration equipments(INR)	-		7,85,000	8,50,000

Table 5 - Fixed cost, operating cost, profits and payback periods of different modes of water conservation

Specifications	**Existing water network**	**Modified water network based on *regeneration-reuse* technique**	**Modified water network based on *regeneration-recycling* technique**
Fixed Capital Investments (INR)	81,71,363	32,51,297	27,85,893
Operating Cost per year (INR/year)	81,22,622	31,27,30	26,86,867
Service Life (years)	10	10	10
Total additional cost of capital investment due to installation of regeneration equipments (INR)	--	7,52,358	50,28,48
Total annual profit in operating cost per year (INR/year)	--	49,95,302	54,35,755
Payback period (months)	--	1.8	1.1

Conclusion

- The water pinch technology approach described in the present paper can be used for planning of water conservation in different water using operations and especially in the starch plant as can be seen from the case study. It is possible to save large amount of water by using different approaches of water pinch technology.
- The problem is viewed as a single contaminant problem and the DM water consumption is 69 tph before modification and after modification using water pinch it reduces to 59.8 tph *(reuse)*, 34.5 tph (*regeneration-reuse*) and 30 tph (*regeneration-recycling*). The cost benefit analysis illustrates that the profit obtained in the case of reuse is 17,63,914 INR per year and the pay back period for the *regeneration-reuse* and *regeneration –recycling* are 1.8 and 1.1 month.
- The Consumption of DM water reduced by 13.3 % (reuse), 50% (regeneration –reuse) and 27.5% (regeneration-recycling).

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Nomenclatures

$C_{i,in}^{lim}$ limiting inlet concentration of operation i ,ppm
$C_{i,out}^{lim}$ limiting outlet concentration of operation i ,ppm
$C_{i,in}^{w}$ water supply inlet contaminant concentration of operation i ,ppm
$C_{i,out}^{w}$ water supply outlet contaminant concentration of operation i ,ppm
C_{in}^{w} overall water supply contaminant concentration of operation i, ppm
C_{in}^{w} overall water supply outlet contaminant concentration of operation i, ppm

C^*_k	contaminant concentration at interval boundary k, ppm
C^*_{pinch}	contaminant concentration at each pinch interval boundary, ppm
f^{lim}_i	limiting flow rate ,tph
f_{min}	overall minimum fresh water flow rate ,tph
$f_{min,i}$	minimum fresh water flow rate for operation i ,tph
$\Delta m_{i,total}$	total contaminant mass load to be transferred from operation i, kg /hr
Δm_k	contaminant mass load to be transferred below the pinch interval boundary, kg /hr
Δm_{total}	total contaminant mass load transferred to all operation i, kg /hr
Δm_{pinch}	contaminant mass load transferred below the pinch interval boundary, kg /hr
$f_{i,k}$	fresh water flow rate to process i in interval k ,tph
$f_{i,k}^{total}$	total water flow rate to process i in interval k ,tph
$m_{i,k}$	contaminant Mass load transferred in process i in interval k, kg /hr
C_o	regeneration outlet concentration, ppm
C_{out}	average outlet concentration, ppm
C_{pinch}	fresh water pinch concentration, ppm
C_{regen}	regeneration inlet concentration, ppm
C^*_{pinch}	regenerated water pinch concentration, ppm
$f_{i,}^{lim}$	limiting flow rate, tph
$f_{min,j}$	minimum flow rate for operation j , tph
$f_{recycle}$	recycle flow rate, tph
$f_{regen,}$	regeneration flow rate, tph
$f_{unregen,}$	flowrate of water not regenerated, tph
Δm_{regen}	mass load of contaminant transferred prior to regeneration, kg /hr
Δm^*_{pinch}	mass load of contaminant transferred below the regenerated water pinch concentration, kg /hr
N_{int}	number of mass intervals in the CID
N_o	number of operations,
i	number of operations
tph	tones per hour
ppm	part per million
CCC	concentration composite curve
CID	concentration interval diagram

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