

Selection of Optimal Storage Strategy for Reduction in Fresh Water Intake and Waste Water Generation for Multipurpose Batch Plant

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ABSTRACT

In this work an optimum storage strategy is proposed for fresh water and waste water minimization in multipurpose batch plants. Three intermediate storage strategies considered for cost comparison. The graphical approach of representation of water composite curves and the concept of water surplus which is similar to the grand composite curve in heat pinch analysis is applied here for targeting fresh water and wastewater minimization. Analysis of results reveals that intermediate storage strategy helps in reuse of low COD wash water for further washings. This strategy reduces fresh water intake by approximately 40% for the industrial case study under consideration.

Keywords: Intermediate storage, water reuse, mass exchange networks, pinch analysis, resource reduction

I.INTRODUCTION

In recent years, with increasing population the demand for fresh water has increased. Process industries, which includes chemicals, petrochemicals, petroleum refining, pharmaceuticals, pulp and papers and certain food and consumer products, represents a major portion of the world economy, use huge quantity of fresh water. Significant quantity of water is used as process water and for the purpose of washing in batch process industries. Even though washing and cleaning operations produce most of the waste water generated in a typical plant, these operations have traditionally been considered of secondary importance in the production cycle [1]. Water consumption and wastewater discharges have become restrictive factors in the profitability and feasibility of certain industrial processes due stringent regulatory norms. Regulatory agencies are emphasizing the need for resource conservation and reduction of effluent generation. In this context, reuse of wash water is considered

as an important option[2]. Minimization of fresh water requirement can be done by proper scheduling of batch processes [3]. Scheduling is concerned with allocation of resources over time so as to execute the processing tasks required to manufacture a given set of products [4]. Minimization of wastewater is achieved by improving recycle and reuse opportunities [5][6]. The reusable stream is the stream that is reused or that is sent again to the process along with fresh water stream. This reusable stream contains fresh water with significantly low quantity of contaminants. Hence, when both of the streams are combined together there can be reduction in the ideal use of fresh water intake[7][8]. Mass exchange networks attracted considerable attention in the recent past to determine minimum resource requirement and waste generation. Synthesis of water network is considered either on fixed load (mass transfer based) or on fixed flow rate (non-mass transfer based) basis[9]. With the help of some preliminary data related to contaminant concentration and flow rate pinch analysis is used to determine minimum target of fresh water consumption and waste water generation prior to detailed network design[9]. This also provides the base line for synthesizing any water network. Pinch analysis can be performed either using graphical method or by using numerical method. Graphical method is more favorable to industrial practitioners as it provides physical insight to the problem and it is easily understandable [10]. On the other hand numerical method provides more algebraic accuracy and is easily accessible to computer programming[10]. Graphical method is considered in the present work.

II. PROBLEM STATEMENT:

In multipurpose batch plants, process equipments are used repeatedly for the production of same product or different products. Washing of process equipments is necessary to avoid contamination. The problem considered in this case can be stated as optimization of water consumption and waste

water discharge from such plants. This includes the determination of a) maximum storage required for water reuse b) maximum quantity of water which can be recycled or re-used and finally c) minimization of fresh water intake.

III. METHODOLOGY:

Mass balance is applied for determination of contaminant concentration in the outlet. Minimum water required and waste water generation is determined using Graphical pinch analysis method. Three storage strategies are evaluated for their suitability using graphical pinch method. Three storage strategies considered for the purpose are a) without using any intermediate storage b) using two bigger intermediate storage tanks and c) using four smaller intermediate storages tanks. Economic evaluation of the strategies is performed to reduce the cost. Contaminant concentration in the outlet is determined for number of cycles changing from one to ten. Detailed calculations and their corresponding results are shown for first two cycles. Ten washes are considered using 1000 Lt Fresh water for each cycle is considered to clean the contaminant mass load present in the tank. Results of first two cycles (each of 10 washes) are shown in Table (1-2). The graphical approach of representation of water composite curves and the concept of water surplus of pinch analysis is applied. The value of outlet concentration of each wash is taken as basis to decide, whether the outlet water is to be used for recycle or not for the second cycle. The main objective this problem is to minimize the waste water and optimize the re-cycle or reused water so it would ultimately reduce the total fresh water intake and lessen the waste water generation.

CASE (I). WATER WASHING OPERATION WITH FOUR INTERMEDIATE STORAGE TANKS

Four intermediate storage tanks have been considered for holding the water which would have low outlet concentration and can be considered for reuse or recycle water:

Objective function:

$Z_{min} = M_f$ Where, $M_f =$ mass of fresh water

Constrains:

1. $M_i = M_r + M_f$ Where, $M_i =$ Mass of water in $M_r =$ mass of water recycle

- 2. $M_i = M_o$ Where, $M_o =$ mass of water out from the unit j
- 3. $M_o = M_{f1} + M_e$ Where, $M_e =$ mass of effluent. $M_{f1} =$ mass of floor washing
- 4. $C_o = M_w / M_i$ Where, $M_w =$ Mass of waste present in the tank
 $C_o =$ concentration of outlet stream
 $C_o = I = C_{omax}$ Where, $C_{omax} =$ maximum outlet concentration
- 5. $M_i = I = W_{max}$ Where, $W_{max} =$ maximum water requirement
- 6. $M_r = I = M_{rmax}$ Where, $M_{rmax} =$ maximum water recycle

Table 1. 1 cycle of water washing of tank

No Of Washes	Mass present before Wash in (Kg)	outlet water in (liters)	outlet conc. in ppm	Water Purity for outlet
1	50	980	45918.37	0.95408163
2	5	1004	3984.06	0.99601594
3	1	1004	796.81	0.99920319
4	0.2	1003	139.58	0.99986042
5	0.06	1003	29.91	0.99997009
6	0.03	1002	14.97	0.99998503
7	0.015	1001	7.49	0.99999251
8	0.0075	1001	3.75	0.99999625
9	0.00375	1001	1.87	0.99999813
10	0.00188	1001	0.94	0.99999906
Total				

The results for the first cycle of 10 washes presented in Table 1 shows that first two washes have very high outlet concentration and the outlet concentration is getting reduced for subsequent washes. The graphical approach of representation of water composite curves and the concept of water surplus which is similar to the grand composite curve in heat pinch analysis is applied here for targeting fresh water and wastewater minimization. This example has ten water outlet streams and ten water source streams and the relevant data are presented in Table 1. The first

step is to plot composite curves of purity of source to outlet purity for the first cycle corresponding data is depicted in Table 1. Note that we consider purity of water rather than contaminant concentration. Purity is easily calculated from the contaminant concentration because by definition, the concentration of pure water is 1 million ppm. The fractional water purity of a contaminated stream is, therefore, defined as:

$$\text{Purity} = (1000,000 - C) / 1000,000$$

Where *C* is the contaminant concentration in ppm.

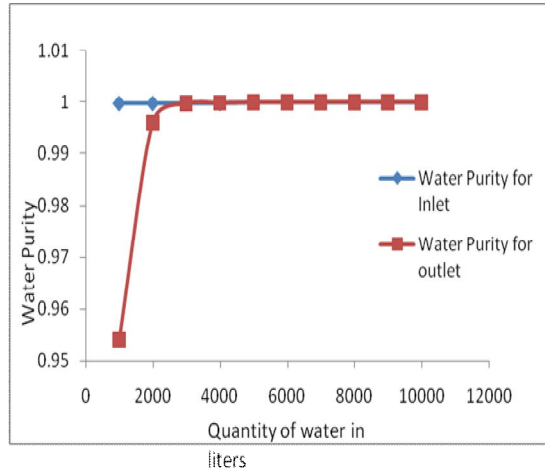


Figure 1. Composite Curve for I cycle

From the Figure 1 of composite curve it has been noticed that last eight washes have perfect pinch region where they purity strictly match with the purity of fresh water so these 8 washes can be considered for further use on the other hand first two washes are below the pinch region or the purity is well below the required purity so they can't be considered for further use. Based on the above results it has been decided to consider last 8 washes should be used for second cycle washes so total four intermediate storage tanks are considered, each tank would hold two consequent washes. Each holding tank would hold the water based on outlet concentration and they would be labeled accordingly. The second cycle of 10 washes result has been evaluated and presented in Table 2. Water stored in holding tanks are used for first 8 washes in the order of their decreasing concentration. We use fresh water for last two washes. Water from 3rd and 4th washes of 1st cycle is considered for 1st and 2nd wash of 2nd cycle, same way 5th and 6th of first cycle is utilized for 3rd, 4th wash of 2nd cycle, 7th, 8th of 1st cycle is used for 5th, 6th of 2nd cycle and 9th, 10th of 1st cycle is utilized for 7th, 8th washes of 2nd cycle.

Table 2. II cycle of water washing of tank where four intermediate storage tanks are considered

No Of Washes	Quantity of Water for Next Cycle	Inlet conc. in ppm	Water Purity for inlet	Mass present before Wash in (gm)	outlet conc. in ppm	Water Purity for source for Demand
1	From 3 rd to 4 th	468.20	0.999531803	50	45918.85	0.95408115
2			0.999531803	5	3984.53	0.99601547
3	From 5 th to 6 th	22.44	0.99997756	1	796.84	0.99920316
4			0.99997756	0.2	139.60	0.9998604
5	From 7 th to 8 th	5.62	0.999994381	0.06	29.92	0.99997008
6			0.999994381	0.03	14.98	0.99998502
7	From 9 th to 10 th	1.40	0.999998595	0.015	7.49	0.99999251
8			0.999999063	0.0075	3.75	0.99999625
9	Fresh water	0	1	0.00375	1.87	0.99999813
10			1	0.00188	0.94	0.99999906
Total	8000					

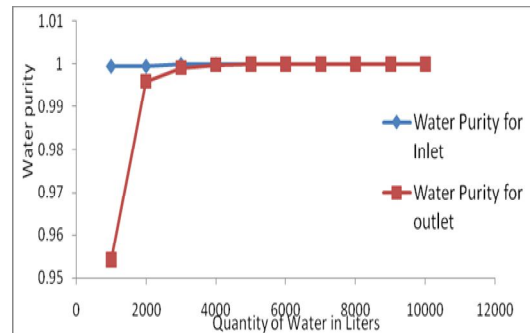


Figure 2. Composite Curve for II cycle

These results from Figure 2 shows that out of 10 washes of second cycle, two washes purity is well below the pinch region and remaining seven eight follow the perfect trend of pinch region so they can be considered for further use. From both cycle each of ten water washes and their corresponding composite curve suggests that total fresh water required is 12000 liters, so saving of 8000 liters of fresh water. The same procedure can be continued for further washes without compromising the process requirements of the plant.

I.1 Cost Calculations of holding tanks:

So the Capacity of each tank would be 2000 litres = Approximate 2500 liters

$$\text{Volume: } V = \pi r^2 h = 2 \times (1.4 \text{ times}) \text{ m}^3$$

$$\text{So } r = 1.5 \text{ m and } h = 1.65 \text{ m}$$

Base Area of Each tank

$$A = \pi r^2 = 1.77 \text{ m}^2$$

Rate of Tank $20 \times 2500 \text{ litres} = 50000/-$

Installation cost 30%

So total cost Rs.65000/-

Case II. Water Washing Operation with Two Intermediate Storage Tanks:

Same problem is now handled by using two intermediate storage tanks for holding the water which would have low outlet concentration and can be considered for reuse or recycle water. 1st cycle of water washing of tanks presented in Table 3.

Table3. I Cycle of water washing of tank with two intermediate storage tanks

No of Washes	Mass present before Wash in (gm)	out let conc. in ppm	Average Effluent in ppm	Quantity of Water for Next Cycle
1	50	45910	45910	From 3 rd to 6 th
2	5	3984	3984	
3	1	791	243.7	
4	0.2	139		
5	0.06	29.9	243.7	From 7 th to 10 th
6	0.03	14.9		
7	0.015	7.48	3.29	Fresh water
8	0.0075	3.74		
9	0.00375	1.87		
10	0.00188	0.095		Fresh water
Total				8000

The results for the first cycle of 10 washes presented in Table 3 shows that first two washes

have very high outlet concentration and the outlet concentration is getting reduced for subsequent washes. The fresh water intake for first cycle remains same for all three cases. From Table1 or Table 3 and Figure 1 of composite curve we noticed that last eight washes have perfect pinch region where the purity of wash water meets the requirements of intake water so these 8 washes can be considered for further use. First two washes are below the pinch region or the purity is well below the required purity so we avoid further use of this water. Based on the above results it has been decided to consider last 8 washes should be used for second cycle washes so total two intermediate storage tanks of bigger size are considered, each tank would hold four washes. Each holding tank would hold water based on outlet concentration and they would be labeled accordingly. The second cycle of 10 washes result has been evaluated and presented in Table 4. Here for last two washes fresh water has been considered for first eight washes the recycle water from first cycle which is stored in holding tanks has been considered. The water from 3rd, 4th, 5th & 6th washes of 1st cycle is considered for 1st, 2nd, 3rd & 4th wash of 2nd cycle, same way 7th, 8th, 9th and 10th of first cycle is utilized for 5th, 6th, 7th & 8th wash of 2nd cycle.

Table 4 Washing with two intermediate storage tanks for II Cycle

No Of Washes	Quantity of Water for Next Cycle	Inlet conc. in ppm	Water Purity for inlet	Mass present before Wash in (gm)	outlet conc. in ppm	Water Purity for source for Demand
1	From 3 rd to 6 th	243.7	0.9997563	50	45918.62	0.954090
2			0.9997563	5	3984.31	0.996016
3			0.9997563	1	797.06	0.999200
4			0.9997563	0.2	139.82	0.999857
5	From 7 th to 10 th	3.29	0.9999967	0.06	29.91	0.999967
6			0.9999967	0.03	14.97	0.999982
7			0.9999967	0.015	7.50	0.999750
8			0.9999967	0.0075	3.75	0.999750
9	Fresh Water	0	1.0000000	0.00375	1.87	0.999755
10	Fresh Water	0	1.0000000	0.00188	0.94	0.999756
Total	8000					

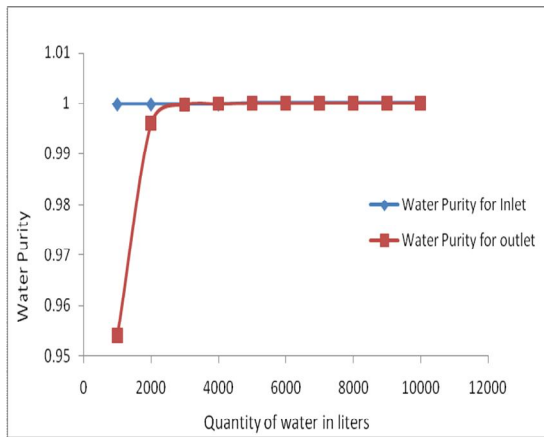


Figure 3. Composite Curve of washing with two intermediate storage tanks for II cycle

These results from Figure 3 shows that out of 10 washes of second cycle, two washes purity is well below the pinch region and remaining eight washes follow the perfect trend of pinch region so they can be considered for further use. From both cycle each of ten water washes and there corresponding composite curve suggests that total fresh water required is 12000 liters so saving of 8000 liters of fresh water.

So the Capacity of each tank would be 4000 litres = Approximate 5000 litters

$$\text{Volume} = V = \pi r^2 h = 4 \times (1.4 \text{ times}) \text{ m}^3$$

$$\text{So } r = 2.05 \text{ m and } h = 1.90 \text{ m}$$

Base Area of Each tank

$$A = \pi r^2 = 2.83 \text{ m}^2$$

Rate of Tank $15 \times 5000 \text{ litres} = 750000/-$

Installation cost 30%

So total cost Rs. 100000/-

Case III. Water Washing Operation without any Intermediate Storage Tanks:

Same problem is now handled with the methodology where we do not use any intermediate storage facility so for this case total two cycles of washing operation each cycle is considered for 10 washes of fresh water to clean the contaminant mass of load present in the tank. Fresh water requirement the first cycle is same for all three cases. However the fresh water requirement increases with each subsequent cycle.

Results and discussion

Results obtained from the above three cases are compared in terms of contaminant concentration in the discharge water. Two cycles are considered for the purpose of comparison. The results are presented in Table 5. From the results it can be seen that use of four storage tanks is more preferable compared to two storage tanks. It is also noted that use of two storage tanks is better than not using storage and reuse of water with respect to water consumption. The same analysis can be extended to n-x storage tanks where n is number of washes and x is number of washes that requires fresh water. However cost of storage tanks increases with increase in their number. Hence it is necessary to find an optimum number of storage tanks. Comparison of cost is also presented in the next section.

Table 5 Comparison of outlet contaminant concentration for all three cases after two cycles

No Of Washes each of 1000 lit.	Concentration In PPM			
	Without Storage		Four Intermediate Storages	Two Intermediate Storages
	I cycle	II Cycle	II Cycle	II Cycle
No Of Washes				
1	45910	45910	45918.85	45918.62
2	3984	3984	3984.53	3984.31
3	791	791	796.84	797.06
4	139	139	139.60	139.82
5	29.9	29.9	29.92	29.91
6	14.9	14.9	14.98	14.97
7	7.48	7.48	7.49	7.50
8	3.74	3.74	3.75	3.75
9	1.87	1.87	1.87	1.87
10	0.95	0.95	0.94	0.94

V. Cost calculation of ETP Plant:

ETP plants includes activities like excavation, plastering, brick work, plumbing, flooring etc along with the cost of construction material. The different items which are required for construction are walls of solid cement blocks with outside and inside plastering for water tightness, PCC base,

PVC pipes , baffle walls, gravel filter media, RCC slab, perforated slabs, vent pipes etc. The cost component pertaining to the construction and installation varies from city to city. Typically, for installation of a plant of 8-10KLD capacity would cost around Rs. 2.5 to 3.5 lacks at present market value.

Cost calculation for the storage tanks required of all three strategies is presented in Table 6. which indicates that 1st policy(without storage) does not require any storage tank so cost of storage tanks is not applicable but for 2nd strategy where four intermediate storage tanks require and the cost of each tank would be Rs.65,000/- and 3rd strategy where two storage tanks require the cost of each would be Rs. 100.000/-

Table 6 Cost comparison of data for all three methodologies.

	Without Storage	Four Intermediate storage Tanks	Two Intermediate storage Tanks
Fresh water on daily basis	20000 liters	12000	12000
Reduction Of Fresh Water	0	8000	8000
Fresh Water Requirements on [yearly Basis in kilo liters]	7000	4200	4200
Cost Involve With Fresh water in Rupees	Rs.28,00,000/-	Rs. 17,00,000/-	Rs.17,00,000 /-
Water send to ETP on daily basis in liters	20000	8000	8000
Water Send to ETP on [yearly basis kilo liters]	7000	1400	1400
Cost Involve With ETP Treatme	Rs.70,00,000/-	Rs.21,00,000/-	Rs.21,00,000 /-

nt in Rupees.			
No of intermediate storage Tanks	-	4	2
Size of Each Tank	NA	2.9 M ³	5.8 M ³
Shipping & Operating Weight	NA	124 kg & 360 kg	215 kg & 600 kg
Base Area of Each Tank	NA	1.77 m ²	2.83 m ²
Cost of area occupied by of Each Tank in Rs.	NA	Rs.50,000/-	Rs.75,000/-
Cost of each Tank in Rupees.	NA	Rs.65,000/-	Rs.1,00,000/-

Fresh water requirement and amount of water send to ETP of all three strategies is calculated and shown in Table 6. The results clearly indicates proposed strategies reduces fresh water requirement and quantity of waste water treated in ETP. On the other hand storage strategies require additional storage tanks and space for mounting these tanks. Total cost for each of the strategies are estimated and compared,. Estimated cost presented in Table 7. The results suggest that storage strategy with two intermediate storage tanks is more economical compared to the other strategies under consideration.

Table 7. Fixed cost and total cost calculations for all three strategies:

	Without Storage	Four Intermediate storage Tanks	Two Intermediate storage Tanks
ETP Space and construction cost	Rs.5,00,000/-	Rs.4,00,000/-	Rs.4,00,000/-
Maintenance 15% of ETP	Rs.75,000/-	Rs.60,000/-	Rs.60,000 /-

4 operators would be required each having monthly salary of 10000/month 40000 x 12	Rs.4,80,000/-	Rs.4,80,000/-	Rs.4,80,000/-
Intermediate storages space and tanks cost		Rs.4,60,000/- [4 x 1,15,000/-]	Rs.3,50,000/- [2 x 100000]
Storage maintenance 15%		Rs.70,000/-	Rs.50,000/-
No operators and their monthly salary of 10000/month for handling storage	NA	Rs.4,80,000/- [4 operators]	Rs.2,40,000/- [2 operators]
Total Fixed cost	Rs.10,55,000/-	Rs.19,50,000/-	Rs.15,80,000/-
Cost Involve With Fresh water in Rupees	Rs.28,00,000/-	Rs.17,00,000/-	Rs.17,00,000/-
Cost Involve With ETP Treatment in Rupees.	Rs.70,00,000/-	Rs.21,00,000/-	Rs.21,00,000/-
Total cost	Rs.1,08,55,000/-	Rs.57,50,000/-	Rs.53,80,000/-
If this cycle continue for 10 years The total cost	Rs.9,90,55,000/-	Rs.3,99,55,000/-	Rs.3,95,80,000/-

VI. CONCLUSIONS

Two storage strategies are proposed and overall cost of these strategies per annum is estimated. Proposed strategies reduce fresh water consumption and waste water generation significantly. Reduction in water consumption is achieved through recycle of wash water. Each storage strategies save up to 40% fresh water compared to a strategy without storage. Overall cost including fixed and operating cost estimated

for annum has shown up to 50% reduction in total cost for the proposed strategy. The results will be more attractive if the length of operating period increases.

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