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MULTI OBJECTIVE OPTIMIZATION CONSIDERING ECONOMICAL AND ENVIRONMENTAL OBJECTIVES OF MULIPRODUCT BATCH PLANT: AN INDUSTRIAL CASE STUDY

Anand P. Dhanwani[1], Dr.Srinivasarao Meka[2]

[1]*Associate Professor, Department of Chemical Engineering, Faculty of Technology, Dharmsinh Desai University, Nadiad, Gujarat: India.* **apdhanwani.ch@ddu.ac.in**

[*2]*Professor, Department of Chemical Engineering, Faculty of Technology, Dharmsinh Desai University, Nadiad, Gujarat: India* **msrao@ddu.ac.in**

Abstract: *In chemical process industry maximization of production and minimization of waste generation is highly desirable. We propose to address this twin problem through optimal scheduling so environmental and economic objective functions are used simultaneously for a multi product batch plant in this study. We have chosen e-constraint method for solving our multiobjective optimization problems. Mixed Integer Non Linear multi objective problem is formulated and successfully solved in GAMS. The efficacy of the proposed method has been demonstrated with the help of an industrial process plant. The results obtained revealed that the number of batches within the same source of available resources can be increased by 12.4% and the profitability can be increased by 9.02%. On the other hand quantity of waste generation is reduced by almost 10%. We present a Pareto optimal solution by simultaneously considering environmental and economic objectives.*

Keywords: *Multi objective optimization, optimal scheduling, Maximum production, Waste generation, Pareto optimal curve.*

I. INTRODUCTION:

Multi-product batch plants are characterized by demand driven low volumes high value product. These plants generally face problems of strategic planning cycle, lack of efficient production planning and scheduling decisions and improper waste water handling. This environment often results in low productivity, huge waste generation, high inventory costs and low capacity utilization. Water is used extensively for running these multiproduct batch plants. This leads to waste water generation and this should be treated/regenerated, reused/recycled or discharged to the environment. Stringent environmental protection laws have made it mandatory to disclose the waste water within specified limits. So there is a great demand to develop proper methodologies which should improve production with special emphasis on waste water minimization. These methodologies should minimize the overall treatment cost and maximize net profit together during each production cycle. This involves trade-offs between number of conflicting objectives like production and wastewater generation simultaneously. Thus, a multi-objective optimization approach considering simultaneously economics and environment is needed for designing competitive and clean multiproduct batch plant.

The multi objective optimization problems including environmental and economical decisions can lead to sustainable development. It is observed that multi-objective optimization is becoming more popular in Chemical Engineering. Various techniques like Parametric Approach, simulated annealing (SA), Genetic Algorithm (GA), Approximation method, discrete-event simulator (DES), weighted sum method and ε-Constraint Approach are used to solve MOO problems. These techniques are generally used to obtain Pareto optimal solutions for complex chemical engineering problems.

Reference [1] suggested several process modifications to achieve twin objectives of decreasing waste generation and increasing economical efficiency. They have used Approximation method to solve multi-objective optimization problem. Reference [2] proposed a method to convert a bi objective optimization problem into a single objective optimization problem; the method considered the economic performance of the process and evaluates the environmental impact by simulated annealing algorithm. Reference [3] proposed an interactive design strategy that utilizes numerical simulation of wastewater treatment processes combined with an efficient interactive multi objective optimization method. This enables the designer to simultaneously consider the process from different perspectives and optimally balance the final design between different conflicting design criteria. The waste water treatment plant design has been previously considered by optimizing treatment cost.

With regards to optimization of industrial water network system [4] used multi objective optimization strategy wherein fresh water, regenerated water flow rate and number of network connections were minimized. They used MILP formulation as the number of network connections is an integer variable and solved by the e-constraint method. Reduction in waste water generation and saving of both chemicals and freshwater can be achieved through multi-objective optimization in metal finishing systems [5] . They included potential environmental impact of the system into the multi-objective optimization formulation and thus generated reuse and recovery network that has better adaptability for dynamic behavior of ecological systems. Reference [6] proposed batch plant design, considering both investment cost and environmental impact minimization. An optimization scheme has been implemented using a multiobjective genetic algorithm (GA) with a discrete-event simulator (DES). The results show how the methodology can be used to find a range of trade-off solutions for optimizing batch plant design. Reference [7][8] have applied multi-objective optimization to consider trade-off between economics and environment by using weighted sum method, Goal Programming and Parameter Space Investigation methods. They have proposed Pareto curve as an ideal compromise solution set.

In the present work we propose to achieve twin objectives of increasing production and decreasing waste water generation through optimal scheduling of multi product batch plant. A Mixed integer non linear multi objective optimization problem is formulated by considering the e-constrained technique and solved by using GAMS solver. We consider waste water generation as an inequality constraint while optimizing the profit. We generate Pareto optimal solution by relaxing the environmental constraint. The upper limit for this environmental constraint is obtained through single objective profit optimization.

II. OPTIMAL SCHEDULING OF PRODUCT MIX TO DETERMINE UPPER LIMIT FOR WASTE GENERATION

We consider product optimization problem for four different plants having six products. Two of these plants are producing two products each. However, they produce single product at a time. We propose a general MINLP mathematical programming model for optimal scheduling of proposed MPBP. The proposed model is expected to maximize the overall production and minimize the quantum of waste water generation. We consider a case study of manufacturing unit producing pesticides located in GIDC Ankleshwar, Gujarat, India. The batch size, batch length and amount of waste water and COD loading per batch are collected from the commercial process plant.

Table (1): Production data collected from commercial complex consisting of four pesticide plants

Plant	Pro-duct	Batch Time (Hr)	Batch Size (T/B)	Max/Min (B/M)	Waste Water (Kg)	COD PPM
I	A	19.5	4.5	40/20	8000	9120
II-A	B	48	2.2	15/ 5	25481	4400
II-B	B1	24	0.98	30/15	12531	2000
III-A	C	48	0.37	15/ 5	9600	19660
III-B	C1	215	5	3/ 1	32000	123027
IV	D	8	1.6	100/50	5800	1500

2.1 Proposed Solution:

We have considered the number of batches for each product as a decision variable. Thus, there will be six decision variables; X_A is the variable for number of batches of product A produced from plant 1. X_B is the variable for number of batches of product B produced from plant 2. X_{B1} is the variable for number of batches of product B1 produced from plant 2. X_C is the variable for number of batches of product C produced from plant 3. X_{C1} is the variable for number of batches of product C1 produced from plant 3. X_D is the variable for number of batches of product D produced from plant 4.

2.2 Objective of the problem:

The main objective of this model is to determine the amount of waste water generation while achieving maximum overall production.

2.3 Constraints:

The main constraints for this model are total time available of each plant for producing these products, maximum and minimum numbers of batches of each product.

Table(2). Minimum and maximum numbers batches to be produced of each product, Batch length and batch size of each product

Variable	Lower bound	Upper bound	Batch Time (Hr)	Batch Size (T/B)
X_A	20	40	19.5	4.5
X_B	5	15	48	2.2
X_{B1}	15	30	24	0.98
X_C	5	15	48	0.37
X_{C1}	1	3	215	5
X_D	50	100	8	1.6

2.4 Mathematical Formulation

set j /A,B,B1,C,C1,D/ ;
Parameter a(j) /A 8000, B 25480, B1 12530, C 9600, C1 32000, D 5800/
c(j) /A 9120, B 4400, B1 2000, C 19600, C1 123027, D 1500/
Optimum Production $Z_{Pr} = \Sigma(j, x(j))$
Waste.. $Z_{ww} = \Sigma(j,a(j)*x(j))$
COD $Z_{cod} = \Sigma(j,c(j)*x(j))$

There are six products (j) labeled as A,B,B1,C,C1,D. Two parameters a and c; where a(j) represents the amount of waste generated per batch of each product j; and c(j) represents the amount of COD generation per batch of each product j. Z represent the optimum value; Z_{Pr} for optimum production of products j, Z_{ww} , Z_{cod} amount of waste generation and COD loading for optimum production respectively.

2.5 Results & Discussion

We have solved the proposed model using GAMS solver. Optimal numbers of batches which can be produced per month are 157. The quantity and quality (COD) of waste water generated corresponding to optimal production are 42602 liters and 27650 ppm respectively. Comparison of optimization results obtained with commercial plant data is presented in Table (3) and Figure(1)

Table(3): Comparison of optimal numbers of batches of each product and waste generation with commercial plant data.

Product	Optimal Batches produced		Waste Water [Kg/Day]	
	GAMS DATA	Commercial plant data	GAMS DATA	Commercial plant data
A	35	32	8533	9333
B	7	18	15289	5946
B1	17	18	7519	6256
C	10	9	2880	3190
C1	1	1	1067	1057
D	87	62	11987	16820

TOTAL	157	140	47274	42602
Increase in production by 12.14%			**Reduction in Waste water generation by 9.88%**	

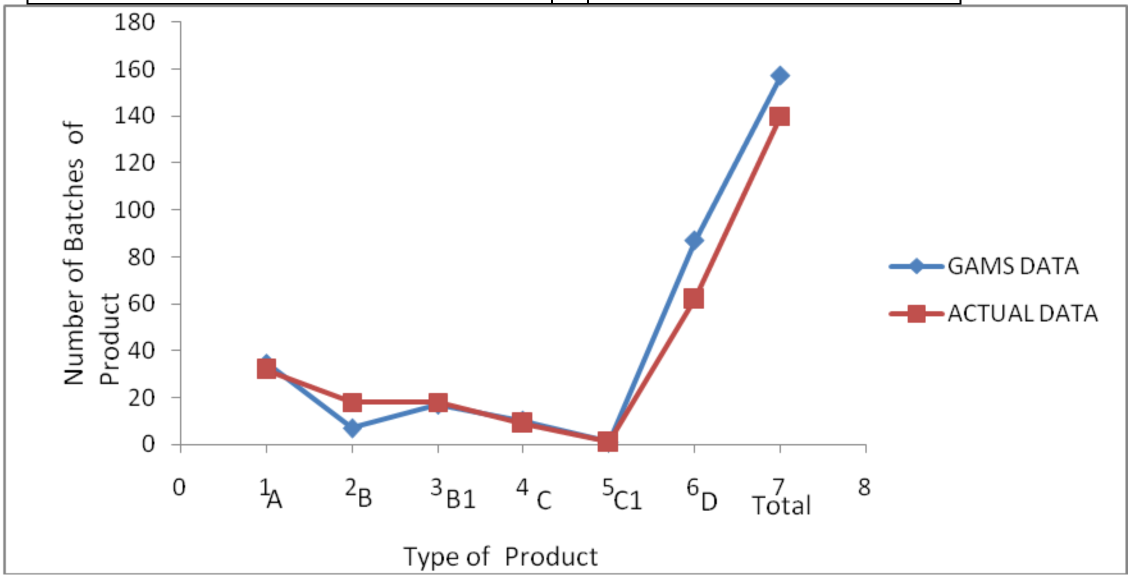


Figure (1): Comparison of optimal number of batches of each product with commercial plant data.

From the comparative results presented in Table (3) we observed that the production can be increased by 12.14% per month by optimal scheduling of batches. It is interesting to note that same constraints prevailing in commercial plant operation are considered in while simulating the results. The results presented in Table (3) also suggest optimal scheduling gives significant reduction in waste water generation. Amount of waste water generation in the present case is reduced by 9.88% compared with actual plant. This may be attributed to reduction in production of high effluent producing product. However, may not be always true if we do not consider waste water generation exclusively. Hence it is desirable to consider both objectives together while determining the optimal schedule for the given plant. The results presented gave upper limit for waste water generation for given optimal production. We consider the e-constraint method of multi objective optimization, where we include waste water generation as an inequality constraint. We propose to obtain pareto-optimal solution by considering production optimization with waste waster generation as constraint.

III. MULTI-OBJECTIVE OPTIMIZATION

A Mixed integer non linear multi objective optimization model is proposed by considering the e-constrained technique and solved by using GAMS solver. We have considered upper limit of waste water generation as an inequality constraint while optimizing the profit. We generate Pareto optimal solution by varying the environmental constraint.

Table (4) Production data collected from commercial complex consisting of four pesticide plants

Plant	Product	Waste Water (Kg)	Profit in (Rs./Batch)	COD PPM
I	A	8000	60000	9120
II-A	B	25481	50000	4400
II-B	B1	12531	60000	2000
III-A	C	9600	70000	19660
III-B	C1	32000	300000	123027

IV	D	5800	40000	1500

3.1. Proposed Solution:

We have considered number of batches per month of each product produced as a decision variable. Hence, we have considered six decision variables. The main objective of this model is to optimize the profit simultaneously minimize the quantum of waste water generation based on multi-objective optimization.

3.2 Mathematical Formulation

set j /A,B,B1,C,C1,D/ ;
Parameter a(j) /A 8000, B 25480, B1 12530, C 9600, C1 32000, D 5800/
c(j) /A 9120, B 4400, B1 2000, C 19600, C1 123027, D 1500/
f(j) /A 60000, B 50000, B1 60000, C 70000, C1 300000, D 40000/
Optimum Production $Z = \Sigma(j, x(j))$
Amount Profit $Z_{Prof} = \Sigma(j,f(j)*x(j))$
Amount of Waste $\Sigma(j, a(j)*x(j))$ =L= different values of waste water
Amount of COD $\Sigma(j,c(j)*x(j))$ =L= different level of COD
There are three parameters; a(j) represents the amount of waste generated by batch each product, c(j) represents the amount of COD generation of each product, f(j) represents the profit earned by batch of each product. Z represents the optimum production in kg per month and Z_{Prof} represents the optimum profit in Rs per month.

3.3 Results and Discussion:

This is multiproduct batch scheduling MINLP model and solved by using GAMS solver for above given data of Table(4).We have considered waste water generation per day as major constraint so based on this the optimum numbers of batches which can be produced on monthly basis are calculated and presented in Table(5).

Table(5): Optimal number of batches by considering various limits of waste water.

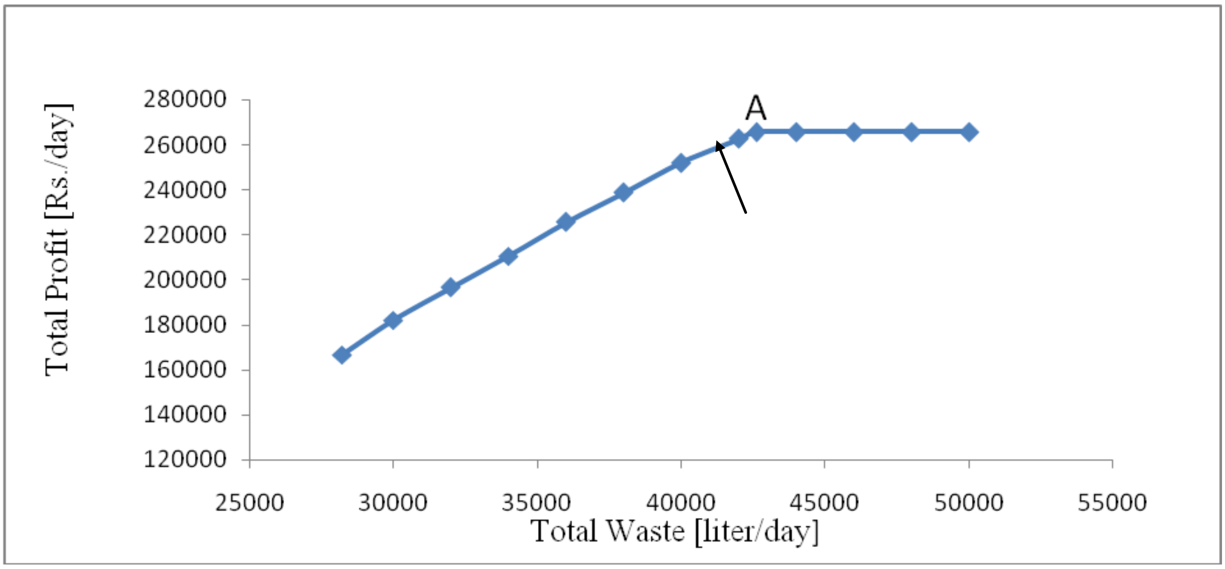
Type of product as variable	Optimal number of Batches produced for each product									
X_A	20	20	20	20	22	30	35	35	35	35	35
X_B	5	5	5	5	5	5	5	5	5	5	5
X_{B1}	15	15	15	15	15	15	15	15	19	19	19
X_C	5	5	5	5	5	5	7	10	10	10	10
X_{C1}	1	1	1	1	1	1	1	1	1	1	1
X_D	50	59	69	80	87	87	87	87	87	87	87
Total Batches	96	105	115	126	135	143	150	155	157	157	157
Total Waste [Lit./day]	28200	30000	32000	34000	36000	38000	40000	42000	42605	44000	46000
Total Profit [Rs./day]	16660	18200	196670	210670	225340	238670	252000	262670	265670	265670	265670

The optimum number of batches produced for each product depends on constraint of waste waster generation. Number of batches affects total production as well as profitability of the plant. We have estimated Monthly production, Monthly profit, Treatment cost, Net monthly profit, Net profit per Kg, Treatment cost per liter and waste generation liter per kg of production and presented in Table(6).

Table (6): Dependence of production, treatment cost and profitability on allowable quantity of waste water generation

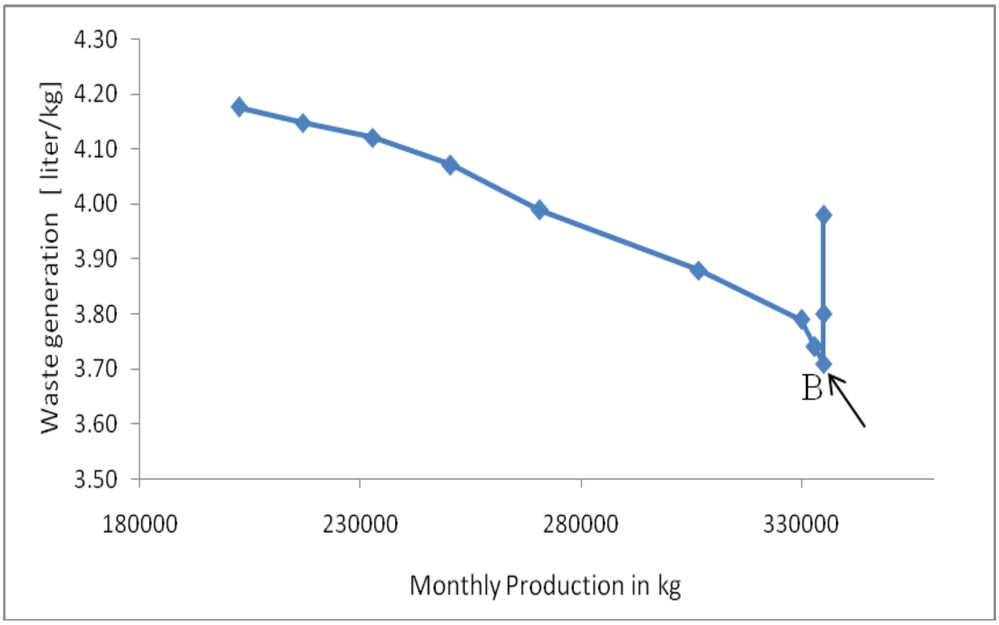
Total Waste Liter/day	Total Batches produced /Month	Monthly Production [KG]	Total Profit [Rs./day]	Total Profit [Rs./Month]	Treatment Cost [Rs/month]	Net Profit [Rs/Month]	Net Profit [Rs/Kg]	Treatment Cost [Rs/Lit]	Waste generation [lit/kg]
28200	96	202550	166670	5000100	1647292	3352808	16.55	1.95	4.18
30000	105	216950	182000	5460000	1747192	3712808	17.11	1.94	4.15
32000	115	232950	196670	5900100	1810192	4089908	17.56	1.89	4.12
34000	126	250550	210670	6320100	1867192	4452908	17.77	1.83	4.07
36000	135	270750	225340	6760200	1972192	4788008	17.68	1.83	3.99
38000	143	306750	238670	7160100	1849192	5310908	17.31	1.62	3.88
40000	150	329990	252000	7560000	1822192	5737808	17.39	1.52	3.79
42000	155	333060	262670	7880100	1909192	5970908	17.93	1.52	3.74
42605	**157**	**335020**	**265670**	**7970100**	**1935509**	**6034591**	**18.01**	**1.51**	**3.71**
44000	157	335020	265670	7970100	1996192	5973908	17.83	1.51	3.80
46000	157	335020	265670	7970100	2083192	5886908	17.57	1.51	3.98

At different level of waste generation, total profit is calculated and presented in Table(6) and same has been represented in Figure(2).



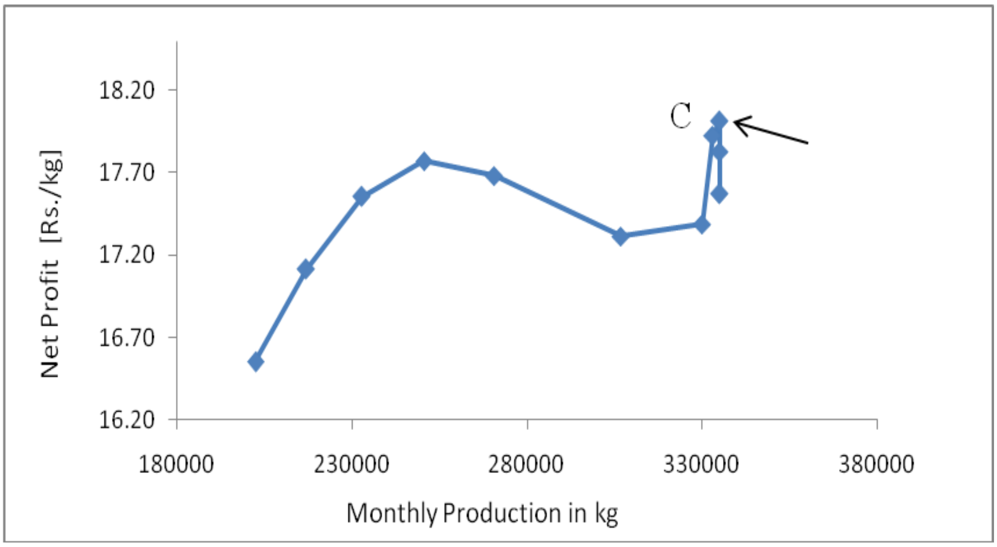
Figure(2): Pareto optimal curve for total profit against the waste generation.

Figure 3 represents the optimal profit against the waste generation and Pareto optimal curve is established. The optimal values of profit are optimized values for given waste generation so we can vary our production schedule as per the waste restriction. The Point A can be considered the Pareto frontier point because the profit get stagnant for further waste generation or in other words this point dominates the all other point on above given Pareto optimal curve. So the optimum daily profit of Rs.2,65,670/- can be obtained against the total waste generation 42605 liter on daily basis.



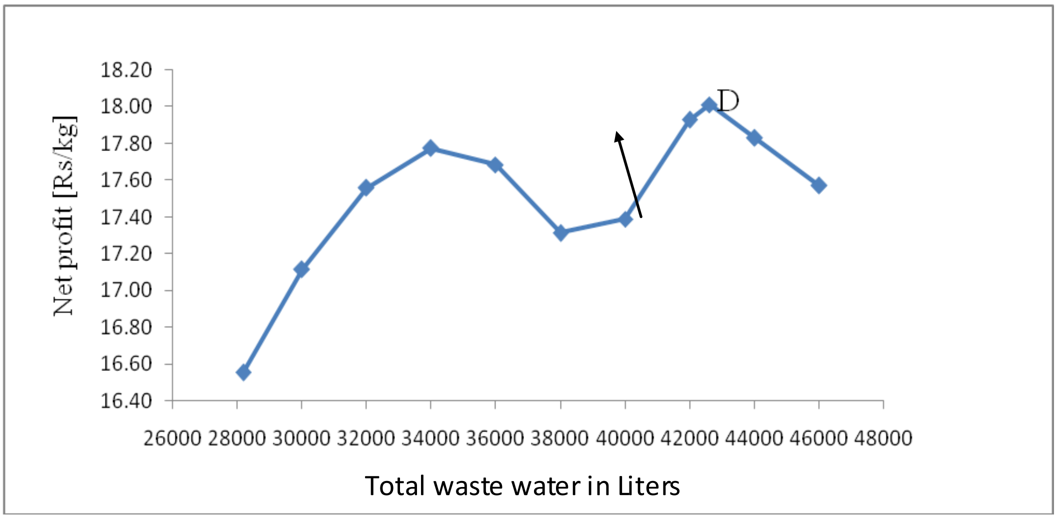
Figure(3): Waste water generation for optimal production.

From Figure(3) we can evaluate that if we increase the production the waste generation per kg of production would decrease. B is the point where we have maximum production and having the least value of waste generation in liters per kg of the production produced. So the optimum production is 33502 kg of production (157 Batches) against 42602 of waste generation and per kg waste generation is 3.71 lit.



Figure(4): Optimal net profit per kg of production.

From Figure (4) we have observed that net profit increases as production increases. This trend is clearly visible till point C. Beyond this point net profit suddenly reduced due to higher amount of treatment cost. So point C is maximum compare to all other options. This is the optimal feasible point where net profit is 18.01Rs./kg v/s production of 33502 kg (157Batches).



Figure(5): Optimal net profit per kg of production.

Figure (5) shows nonlinear nature of the relationship between waste generation and net profit. Point D shows maximum net profit as 18.01 Rs./Kg. Waste water generation at point D is same as waste water generation obtained with single objective optimization. Hence, optimal scheduling suggests that optimal production as 33502 kg/month (157 Batches)) and minimum waste generation as 3.71 lit /kg of product. The pareto optimal solution obtained through MOO can be used for production optimization in the presence of stringent environmental regulations.

IV. CONCLUSIONS

Optimal Schedule for MPBP for production optimization is done successfully using MINLP multi objective optimization model by considering the e-constrained technique and solved by commercial GAMS solver. The proposed model has increased the overall production by 12.14%, while profitability is enhanced by 9.04 %. On the other hand optimal scheduling has reduced the quantity of waste water generation by 9.88% compared to commercial operation. Pareto optimal curve has been established considering environmental and economic objectives. Efficacy of the proposed optimal solution is demonstrated with the help of net profit and waste waster generation per unit product produced. It has been observed the net profit values are the highest and waste water generation is the lowest for the optimal schedule obtained using the proposed model.

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