ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 2, March 2013

Batch Scheduling By Evolutionary Algorithms for Multiobjective Optimization

Charmi B. Desai, Narendra M. Patel
L.D. College of Engineering, Ahmedabad

Abstract - Multi-objective optimization problems are the problems having multiple conflicting objectives which need to be optimized. Batch scheduling of multiproduct plant falls under this category. For solving such problems, Multi-objective evolutionary algorithms (MOEAs) which are currently gaining significant attention from researchers in various fields due to its effectiveness and robustness, are applied. Specific methods are used for finding multiple solutions and the optimized solution. Dominated Sorting Genetic Algorithm-II (NSGA-II) is one of the methods that is used for solving multi-objective problems and specifically it is applied because it has capability to achieve fine tuning of variables in determining a set of non dominating solutions distributed along the Pareto front in a single run of the algorithm. One study example is also discussed to describe the effectiveness NSGA-II.

Index Terms- **Batch Scheduling, Evolutionary Algorithms, Multiobjective Optimization, NSGA-II.**

I. INTRODUCTION

Most real-world engineering optimization problems are multiobjective in nature, since they normally have several (possibly conflicting) objectives that must be satisfied at the same time. Multiobjective optimization has been applied in many fields of science, including engineering, economics and logistics where optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives. Here, instead of aiming to find a single solution, we will try to produce a set of good compromises or trade-offs from which the decision maker will select one. The presence of multiple objectives in a problem, in principle, gives rise to a set of optimal solutions largely known as Pareto-optimal solutions, instead of a single optimal solution. The plot of all such solutions which are non-dominated, constitute the Pareto front. In the absence of any further information, one of these Pareto-optimal solutions cannot be said to be better than the other. This demands a user to find as many Pareto-optimal solutions as possible. In this paper batch scheduling problem is considered as multiobjective optimization problem. In recent years, batch processes have been getting more attention due to their suitability for the production of small volume, high value added products, which are becoming increasingly important with fast market change. The flexibility of batch plants allows the production of different products within the same facility. This makes plant scheduling a challenging task. In speciality chemicals and pharmaceuticals production customers require smaller amounts of product orders, faster delivery times and on demand production. Additionally, the decision-making process may often involve several and usually conflicting objectives concerning economy, client satisfaction, environmental impact, etc. which should be satisfied simultaneously. Some of the tasks which are closely related to industrial problems of batch processing can be solved by help of optimization techniques. Much research has focused on developing optimization techniques for scheduling batch plants with the aim of reducing the time required to attain an optimal objective value such as MILP model, MINLP model, simulated annealing, tabu search, genetic algorithm, etc. Wellons et al. (1988) describe the production line scheduling problem by MINLP formulation [6]. Mah et al. (1991) proposed a heuristic procedure using Simulated Annealing (SA) is developed for the preliminary design of multiproduct batch plants [5]. Wang et al. (2000) proposed a genetic algorithm for online-scheduling of a multi-product polymer batch plant. Cavin et al. (2004) proposed a flexible met heuristic algorithm, Tabu Search (TS) for optimal designs of a chemical batch process [10]. Usage of such methods allows for faster screening of production capacities, plant line selection for given product, decision making, planning and assessment related to the plant and process. This paper describes scheduling of batch plant by multiobjective optimization evolutionary algorithm NSGA-II (Non-Dominated Sorting Genetic Algorithm-II).

II. MULTIOBJECTIVE OPTIMIZATION

When an optimization involves more than one objective function, the task of finding one or more optimum solutions is known as multi objective optimization. Most real world search and optimization problems naturally involve multiple objectives. Multiobjective optimization has been applied in many fields of science, including engineering,

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 2, March 2013

economics and logistics where optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives [1]. A multiobjective optimization problem involves a number of objective functions which are to be either minimized or maximized. As in a single objective optimization problem, the multiobjective optimization problem may contain a number of constraints which any feasible solution must satisfy. Since objectives can be either minimized or maximized, we state the multiobjective optimization problem in its general form:

Minimize/ Maximize $f_m(x)$, $m = 1,2,\ldots,M$;
Subject to $g_j(x) \geq 0$, $j = 1,2,\ldots,J$;
$h_k(x) = 0$, $k = 1,2,\ldots,K$;
$x_i^{(L)} \leq x_i \leq x_i^{(U)}$, $i = 1,2,\ldots,n$.

Various classical methods and evolutionary algorithm are developed for solve this type of optimization problem. Classical optimization methods (including the multi-criterion decision-making methods) suggest converting the multiobjective optimization problem to a single objective optimization problem by emphasizing one particular Pareto-optimal solution at a time. But now a day Evolutionary Algorithm is widely used to find out the best solution due to its effectiveness and robustness in solving multiobjective problem. There are various types of EAs available for MOOP. In this paper primary focus on the Non-dominated Sorting Genetic Algorithm-II (NSGA-II). Deb et al. (2002) reported NSGA-II as an improved version of the NSGA. In the NSGAII, for each solution one has to determine how many solutions dominate it and the set of solutions to which it dominates. The NSGAII does not use an external memory as the other MOEAs. Due to its clever mechanisms, the NSGAII is much more efficient than its predecessor, and its performance is so good, that it has become very popular in the last few years, becoming a landmark against which other MOEAs have to be compared [3]. Here, batch scheduling discussed with the help of MOEAs. In multiproduct batch plant, all batches are processed in the same production paths, and the processing sequences of batches in each unit are identical. However, in reality the multiproduct design problem can be formulated as a multiobjective design optimization problem in which one seeks to minimize investment, operation cost, and total production time, and, simultaneously, to maximize the revenue. Recall that not much work has been reported in the literature on the multiobjective optimal design of a multiproduct batch plant.

III. BATCH SCHEDULING PROBLEM

A. Description of Problem

Consider a multiproduct batch plant that consists of three processing stages: mixing, reaction and centrifuge separation. Two products A and B are to be manufactured in such a plant. The data for processing times, size factors for the units and cost data are given below. Determines the size of units required at each processing stage, as well as the number of units that ought to be operating in parallel to minimize the investment and operation cost and maximize the revenue [2].

B. Problem Formulation

The plant consists of a sequence of M batch processing stages that are used to manufacture N different products. At each stage j there are N_j identical units in parallel operating out of phase, each with a size V_j. Each product i follows the same general processing sequence. Batches are transferred from one stage to the next without any delay, that is, we consider a zero-wait operating policy. In the conventional design of a multiproduct batch plant, one seeks to minimize the investment cost by determining the optimal number, required volume and size of parallel equipment units in each stage for a specified production requirement of each product and the total production time [4]. However, in reality the designer considers not only minimizing the investment but also minimizing the operation cost and total production time while maximizing the revenue simultaneously,

Max Revenue = $f1 = \sum_{i=1}^{N} C_{Pi} Q_i = C_{PA} Q_A + C_{PB} Q_B$

Min Investment Cost = $f2 = \sum_{j=1}^{M} N_j \alpha_j V_j^{\beta_j}$

$$f2 = 250\, N_1 V_1^{\,0.6} + 500\, N_2 V_2^{\,0.6} + 340\, N_3 V_3^{\,0.6}$$

Min Operation Cost = $f3 = \sum_{i=1}^{N} \sum_{j=1}^{M} C_{Ej} \frac{Q_i}{B_i} + C_{Oi} Q_i$

$$f3 = \frac{Q_A}{B_A}(C_{E1}+C_{E2}+C_{E3}) + \frac{Q_B}{B_B}(C_{E1}+C_{E2}+C_{E3}) + C_{OA}\, Q_A + C_{OB}\, Q_B$$

Min Total Production Time = f4 = H

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 2, March 2013
The constraints are expressed as follows:
(1) Volume constraints: Volume Vj has to be able to process all the products i:
Si j Bi ≤ Vj , i = 1, . . . ,N; j = 1, . . . , M.
(2) Time constraint: The summation of available production time for all products is not more than the net total time for production.

$$\sum_{i=1}^{N} \frac{Q_i}{B_i} T_{Li} \leq H$$

(3) The limiting cycle time for product i:

$$\frac{\tau_{ij}}{N_j} \leq T_{Li} \quad i = 1, \dots, N; \quad j = 1, \dots, M.$$

(4) Dimension constraints: Every unit has restricted allowable range,

$$V_j^L \leq V_j \leq V_j^U, \quad j = 1, \dots, M.$$

$$B_j^L \leq B_j \leq B_j^U, \quad j = 1, \dots, N.$$

So, the multiobjective problem consists of determining the following parameters:
1. N_j the number of parallel units in stage j
2. V_j the required volume of a unit in stage j
3. Bi size of the batch of product i at the end of the M stages
4. T_{Li} the cycle time for product i
5. Q_i the production requirement of product i and
6. H the total production time

Table 1: Data used in Problem [2].

	Processing Time, τ_{ij} (h)			Unit price for the product ($/kg)		
Product	Mixer	Reactor	Centrifuge	Product	Cp	Co
A	8	20	4	A	0.35	0.08
B	10	12	3	B	0.37	0.1
Product	Size factors, Sij (L/kg)					
A	2	3	4			
B	4	6	3			
	Cost of equipment ($, V in liters)					
	$250V^{0.6}$	$500V^{0.6}$	$340V^{0.6}$	Minimum size = 250 L		
	Operating cost factor (C_E)			Maximum size = 2500 L		
	20	30	15			

C. Result:

A four-objective optimization problem is considered. The set of decision variables consists of the batch size, the total production time, the number of parallel units at each stage, the cycle time for each product, and the required volume of a unit in each stage. Since the number of parallel units at each stage is an integer decision variable, we code this variable as a binary variable. All other decision variables are coded as real numbers. Thus, there are 3 integer variables and 10 real variables. In addition to the constraints, we consider bounds on objective functions as additional constraints to generate feasible no dominated solutions in the range desired by the decision-maker, to have 19 constraints in all. Then NSGA-II is employed to solve the optimization problem with the following parameters: maximum number of generation up to 200, population size 200, probability of crossover 0.85 & probability of mutation 0.1. The Pareto-optimal solutions are presented in Figure 1.1 (a), (b) & (c). The revenue (f1) increases with the increase in operation cost (f3) and investment cost (f2) decreases. Figure 1.1 (d), (e) & (f) presents the relationships between some chosen decision variables such as batch size and production requirement of both the product.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 2, March 2013

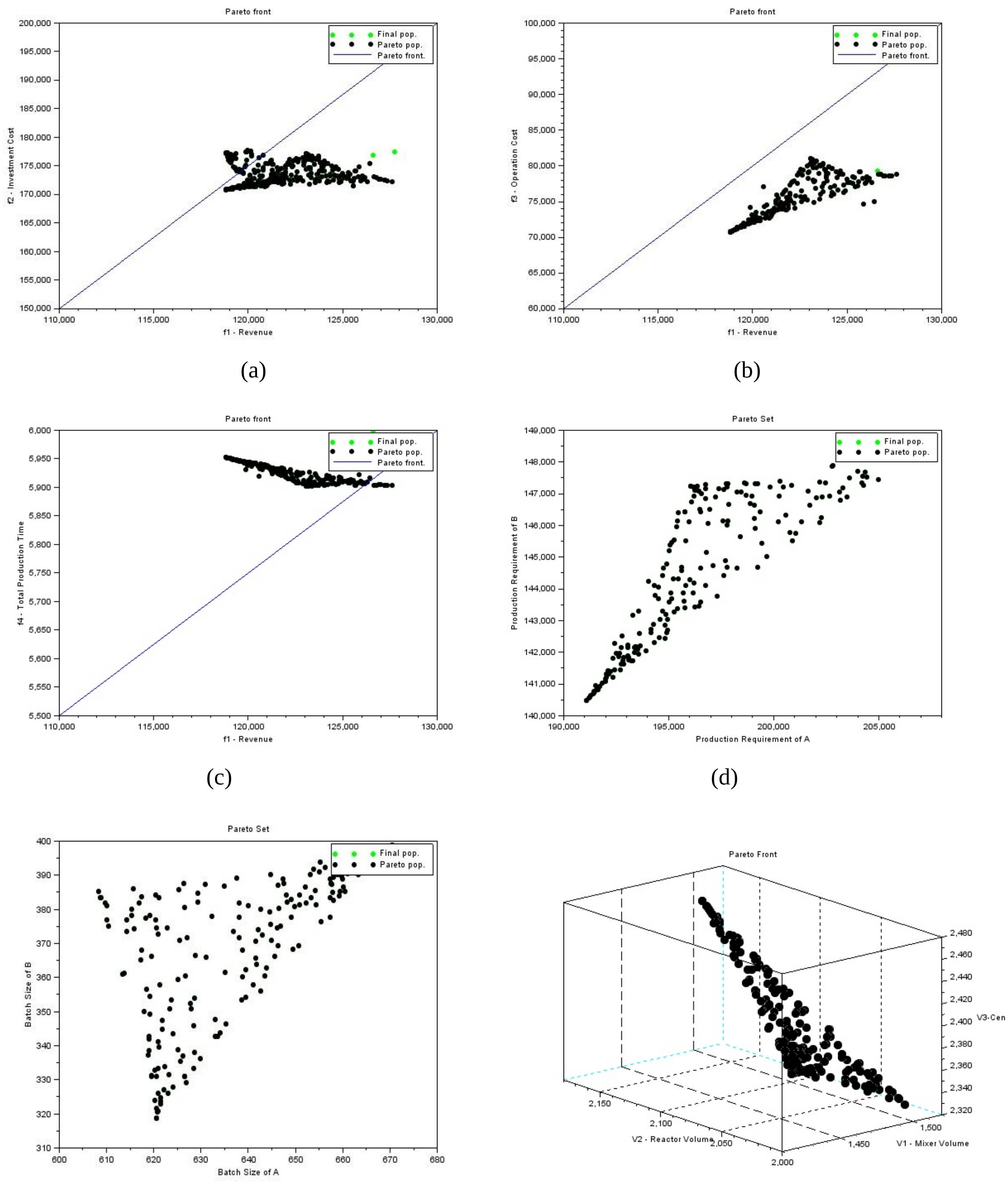

Fig.1 Pareto optimal solutions for given problem. (a) Revenue v/s Investment Cost (b) Revenue v/s Operation Cost (c) Revenue v/s Total Production Time (d) Production Requirement of A v/s Production Requirement of B (e) Batch Size of A v/s Batch Size of B (f) Mixer, Reactor and Centrifuge Volume

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 2, March 2013

Table 2: Optimum Result by NSGA-II and MINLP method

Decision Variable	Case - 1	Case - 2	MINLP METHOD
f1 ($)	123266.57	126166.3	125500
f2 ($)	171789.76	172898.46	167427.64
f3 ($)	74882.523	78219.67	82133.3
f4 (h)	5925.592	5906.306	6000
Q_A (kg)	199251.6	204358.61	200000
Q_B (kg)	144671.63	147677.81	150000
V_1 (L)	1469.255	1503.68	1285.714
V_2 (L)	2018.66	2041.01	1928.571
V_3 (L)	2356.61	2347.34	2500
B_A (kg)	637.65	614.42	625
B_B (kg)	389.15	376.66	321.429
T_{LA} (h)	10.33	10.64	10
T_{LB} (h)	6.11	6.29	6

The large set of multiple optimal solutions provides the decision maker with immediate information about the relationship among the several objective criteria and a set of feasible solutions. Thus, it helps the decision maker to select a highly confident choice of solution. Some of the optimum value for the objective function and related decision variables are given in table 2 from the large set of multiple optimal solutions.

IV. CONCLUSION

Multiproduct batch plant scheduling is considered as multiobjective optimization problem. NSGA-II is developed to get an optimal zone containing solutions under the concept of Pareto set. NSGA-II capability has been proved to get the set of non dominating solutions along the Pareto front in a single run of the algorithm. It showed the satisfactory result in the case of the hypothetical problem. Similarly, this robust method would also be helpful in the industrial world for better solution.

V. NOMENCLATURE

Bi=Size of the batch of product i at the end of the M stages (kg)
C_{Ej} = Operation cost in stage j ($)
C_{Oi}=Operation cost of product i to be produced ($/kg)
C_{Pi} = Price of product i ($/kg)
H = Total production time (h)
M = Number of stages in the batch process
N = Number of products to be produced
N_j = Number of parallel units in stage j
Q_i = Production requirement of product i (kg)
S_{ij} = Size factor of product i in stage j (L/kg)
T_{Li} = Cycle time for product i (h)
V_j= Required volume of a unit in stage j (L)
τ_{ij} = Processing time of product i in stage j (h)

REFERENCES

[1] Multi Objective Optimization using Evolutionary Algorithms by Kalyanmoy Deb, John Wiley & Sons ltd.

ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 2, Issue 2, March 2013

[2] Systematic Methods of Chemical Process Design by Lorenz T. Biegler, Ignacio E. Grossmann & Arthur W.Westerberg.

[3] Kazi Shah & Nawaz Ripon, Real Jumping Gene Genetic Algorithm (RJGGA) for Evolutionary Multiobjective Optimization Problems, City University of Hong Kong, 2006.

[4] Diab Mokeddem and Abdelhafid Khellaf, Optimal Solutions of Multiproduct Batch Chemical Process Using Multiobjective Genetic Algorithm with Expert Decision System, Hindawi Publishing Corporation, 2009.

[5] A. N. Patel, R. S. H. Mah and I. A. Karimi, Preliminary Design Of Multiproduct Non-continuous Plants Using Simulated Annealing Department of Chemical Engineering, Northwestern University, Evanston, IL 60208-3120, U.S.A.

[6] M. C. Wellons and G.V. Reklaitis, Optimal Schedule Generation for a Single Product Production Line- Problem Formulation, 1988.

[7] Tsung-Che Chiang n, Hsiao-JouLin, A simple and effective evolutionary algorithm for multi objective flexible job shop scheduling, Int. J. Production Economics.

[8] Ming Pan, Xiuxi Li, Yu Qian, Continuous-time approaches for short-term scheduling of network batch processes: Small-scale and medium-scale problems, chemical engineering research and design, 2009.

[9] Qian Yu, Pan Ming and Huang Yacai, Modeling and Optimization for Scheduling of Chemical Batch Processes, Chinese Journal of Chemical Engineering, 2009.

[10] L. Cavin a, U. Fischer, F. Gloverb, K. Hunger Buhler, Multi-objective process design in multi-purpose batch plants using a Tabu Search optimization algorithm, 2003.

AUTHOR BIOGRAPHY

Charmi B. Desai, Chemical Department of L. D. College of Engineering, Gujarat Technological University, Ahmedabad, Gujarat, India.

N M.Patel is presently working as Asst.Professor and Head in department of Chemical Engineering in Vishwakarma Government Engineering College, Gandhinagar, India.