Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2014, 6(5):34-41

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Chlor-alkali industry production scheduling algorithm research based on adaptive weight PSO

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ABSTRACT

First of all, in view of the process industry production scheduling system, the mathematical model of the process industry production scheduling was established. Secondly, the shortest maximum completion time was taken as the goal, process industrial production scheduling algorithms based on particle swarm optimization (PSO) was proposed. Finally, the specific production tasks of propylene oxide (PO) and polyvinyl chloride (PVC) of a chlor-alkali enterprises was taken as the research background, four production scheduling tasks of two products was realized. The simulation results demonstrate the effectiveness and superiority of the proposed algorithm, and it provided a certain reference value for improving the production efficiency and resources utilization, also for further improving the profit of enterprise.

Key words: Particle swarm optimization algorithm; Process industry; Chemical enterprise; Production scheduling; PO; PVC

INTRODUCTION

Chlor-alkali industry belongs to the process industry, has many characteristics, such as complexity, multi-objective, multi-constraint, multi-resources, etc. In the process of production, due to the time and resources sharing between the different products or the same production batches of the product, it's prone to conflict. Production scheduling is the command center of production running, good production scheduling can realize scheduling optimization, improve the production efficiency of enterprises, so as to achieve the aim of increasing profits. Therefore, looking for effective production scheduling algorithm has a great application value on improving the production efficiency and resource utilization, enhancing enterprise's competitive ability.

Particle Swarm Optimization (Particle Swarm Optimization, PSO) algorithm is put forward by Kenndy and Eberhart in 1995[1]. Because this algorithm has many advantages, such as less parameters, don't need gradient information, good generality and easy to implement, so it can effectively solve the problem of global optimization, and can effectively avoid the disadvantages of some other optimization methods [2].Since have been proposed, it has caused the wide attention of scholars in many areas at home and abroad, and some research achievements have been made. Parsopoulos [3], Zhang H [4], Bian Pei-ying [5], respectively apply PSO to solve multi-objective optimization problem, resource constrained project scheduling problem and AGV dynamic scheduling problem. Angeline Peter J[6], Li Bin-bin[7], Jia Zhao-hong[8] respectively apply different hybrid PSO algorithms to no wait limit stochastic flow operation problem, multi-objective replacement line production scheduling problem and the flexible job shop scheduling problem; Pisut Pongchairerks[9] proposed three heuristic algorithms based on PSO to solve job-shop scheduling problem. Zhang Jun[10]proposed improved PSO algorithm based on the combination of adaptive index inertia weight coefficient and the genetic algorithm (GA), Wang Jun-nian[11]applied A stochastic multi-objective PSO algorithm to realize optimization scheduling of time-sharing power supply in zinc electrolytic process. Peng

Wu-liang [12] proposed PSO based on vector similarity theory, and applied it to solve the resource-constrained project scheduling problem; the current application researches laid foundations for further PSO algorithm application to production scheduling problems.

In this paper, with the maximum completion time shortest as the goal, PSO algorithm was applied to chlorine balance system of chlor-alkali industry, a chlorine balance system production scheduling algorithm based on PSO was proposed. A chlor-alkali enterprises propylene oxide (PO) and polyvinyl chloride (PVC) specific production task was taken as the research background, two products four tasks of production scheduling was realized, and the simulation results verify the effectiveness and superiority of the proposed algorithm.
Process

INDUSTRY PRODUCTION SCHEDULING MATHEMATICAL MODEL ESTABLISHMENT

PROCESS INDUSTRY PRODUCTION SCHEDULING SYSTEM DESCRIPTION

Assume that there is a processing system contains m equipments and n products for processing, among them, each product processing have one process at least, every procedure processing can be done in many different equipments, and the processing time changes with the performance of the equipments, as shown in figure 1. Scheduling goal is to make scheduling scheme according to the constraint of product and resource conditions, to select the most appropriate equipment for each procedure, to determine the best processing sequence and starting time of each process on each device, and to make sure the circulation time shortest in the system.

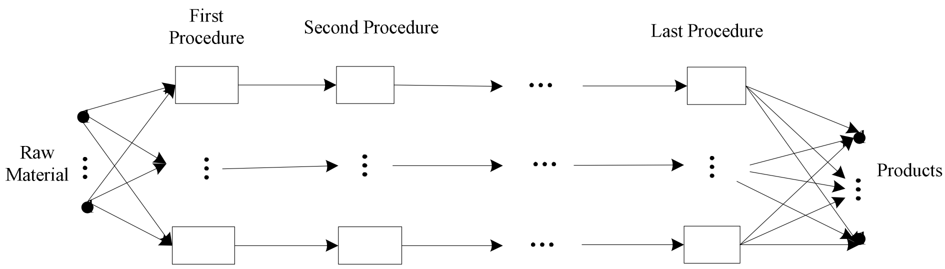

Fig.1 The process industry production process simplified chart

SCHEDULING MODEL VARIABLES DEFINITION SCHEDULING MODEL EXPRESSION

m: The number of devices;
n: The number of Production tasks;
Ji: The processing procedures number of product i;
Sijk: The start time for processing procedure j of product i in device k.
Eijk: The completion time for processing procedure j of product i in device k.
Tijk: The processing time for processing procedure j of product i in device k.
Ek: The completion time for all products in device k.
E: The final completion time for all products.

SCHEDULING MODEL EXPRESSION

(1) The objective function

Scheduling goal is to make the production time of all procedure shortest, it can be expressed as:

$$\min(E)=\max_{k=1,2,\dots,m}(E_k) \quad (1)$$

(2) Constraints

Equipment constraint: each device one can only process one kind of product. Formula expressed as:

$$E_{efk}-E_{ijk}\geq T_{efk} \quad (2)$$

Sequence constraint: the adjacent processing procedure order of same products between must be insured. Formula expressed as:

$$E_{ijk}-E_{i(j-1)m}\geq T_{ijk} \quad (3)$$

Time constraint: completion time minus the start time of any procedure not less than the processing time. Formula expressed as:

$$E_{ijk} - S_{ijk} \geq T_{ijk}, \forall J \quad (4)$$

ADAPTIVE PSO ALGORITHM

PSO algorithm[13-14] is a kind of bionic algorithm which simulates bird flock foraging, the principle can be simply presented as: Based on each bird (particles) in their optimal position which track finitude a neighbor in the optimal position now, close to the food step by step near the target position. PSO is initialized with a group of random solution, and then find the optimal solution through iteration. Particles update themselves through tracking two “extreme values”. The optimal value found by particle itself is called individual extreme value, and found by the entire population is called global extreme value. In a D dimensional space; generate population which is made up of N particles. $X = \{x_1, \cdots, x_i, \cdots, x_m\}^T$, ith particle position is $X_i = \{x_{i1}, x_{i2}, \cdots, x_{im}\}^T$, velocity is $V_i = \{v_{i1}, v_{i2}, \cdots, v_{im}\}^T$, $V_{\max}$ is the maximum velocity, which determines largest move distance of particles in an iteration, individual extreme value is $P_i = \{p_{i1}, p_{i2}, \cdots p_{im}\}^T$, the global extreme of entire population is $P_g = \{p_{g1}, p_{g2}, \cdots, p_{gm}\}^T$. According to the principle of following the best particle, velocity and position of particle update formula is:

$$v_i^{k+1} = v_i^k + c_1 r_1 \left(p_i - x_i^k \right) + c_2 r_2 (p_g - x_i^k) \quad (5)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (6)$$

r1, r2 are random numbers between 0 and 1. c1、c2 are the learning factor, generally, c1 = c2 = 2.

In order to improve the basic PSO algorithm shortcomings which are prone to premature convergence and global convergence, enhance algorithm proficient performance, standard PSO algorithm is proposed by Shi and Eberhart [15], introduced the inertia weight, revised velocity updating formula is:

$$v_i^{k+1} = w v_i^k + c_1 r_1 \left(p_i - x_i^k \right) + c_2 r_2 (p_g - x_i^k) \quad (7)$$

Inertia weight is a scale factor related to the last speed, used to control the influence that the previous generations' velocity takes on the particle current speed. Through the study found that the larger can strengthen the global search ability, and smaller could strengthen the local search ability.

In order to balance the global search ability and local improvement ability, nonlinear dynamic inertia weight PSO algorithm was proposed, its expression is as follows[16]:

$$w = \begin{cases} w_{\min} - \dfrac{(w_{\max} - w_{\min}) * (f - f_{\min})}{(f_{avg} - f_{\min})}, f \leq f_{avg} \\ w_{\max}, f > f_{avg} \end{cases} \quad (8)$$

$w_{\max}$ and $w_{\min}$ respectively represent the maximum and the minimum of w, f represent particle current objective function values, f_{avg} and $f_{\min}$ respectively represent the current average target value and the minimum target of all particles. In the type, the inertia weight change automatically as the objective function value, so called adaptive weight[17-18].

When the target value of each particle consistent or tending to local optimum, the inertia weight increase, and When the target value of each particle is dispersed, the inertia weight reduce. For the objective function value is superior to the average of the target particles, their corresponding inertia weights are smaller, thus protecting the particles; On the other hand, for the target value of the objective function value is inferior to the average of the target particles, their corresponding inertia weights are bigger, makes the particles to better search area.

THE PROCESS INDUSTRY PRODUCTION SCHEDULING SIMULATION BASED ON PSO

PRODUCTION SCHEDULING CASE DESCRIPTION

In this paper, a chlor-alkali chlorine balance system was taken as the research background, Chlorine gas is produced by raw salt electrolysis, Chlorine gas react with lime and propylene to produce PO, react with ethylene to produce PVC. Based on PO and PVC production scheduler instance, it was verified that the PSO algorithm application in the process industrial production scheduling and its efficacy. The simplified production process flow chart for two products is shown in figure 2.

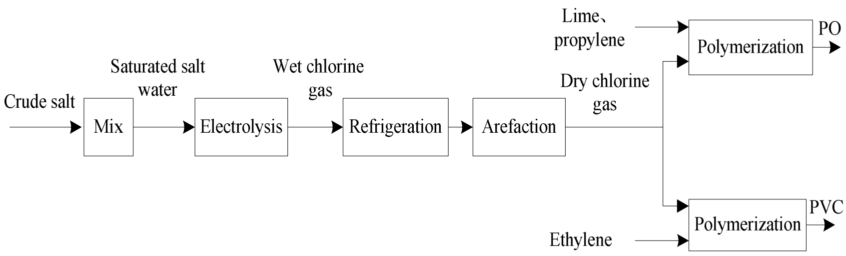

Fig.2 The process industry production process simplified chart

Hypothesis based on this production scheduling model:
1) Equipments are qualified and ready for production;
2) Equipments meet the constraints between adjacent process production sequences of same products;
3) Each device once can only conduct one production processes of some product;
4) This production process must be in the last process is completed;
5) Materials of Each processing batches are constant, regardless of the material balance problems;
6) There are no other resource constraints in addition to equipment conditions;
7) Regardless of the material transfer time and loss in the equipments;
8) Storage material by infinite intermediate storage strategy;
9) There are no successively constraints between different product processing steps;
10) Processing time of each processing procedure is certain; equipment preparation time is included in the processing time;
11) In any procedure, completion time minus the start time not less than the processing time.
12) Scheduling goal is to make the total production time shortest of all product in system.

Equipments of PO and PVC Production are numbered as follows: three electrolyzers {R11, R12, R13}, cooling tower {R2}, two drying a towers { R31, R32}, drying b tower {R4}, two polymerizers {R51, R52}, recovery tower {R6}. Product processing equipments situation is shown in table 1, and the basic features of PO and PVC production is shown in table 2.

Table 1 Product processing equipment

Devices	Quantity	Devices number	Production time(h)	Production capacity(t)
Electrolyzer	3	R11	5	5
		R12	5	8
		R13	5	5
Cooling tower	1	R2	5	10
Drying tower a	2	R31	8	10
		R32	8	10
Drying tower b	1	R4	3	5
Polymerizer	2	R51	5	8
		R52	5	10
Recovery tower	1	R6	6	8

Table 2 Basic features of products processing

Products	Production steps	Production procedures	Devices	Products	Production steps	Production procedures	Devices
PO	1	Electrolysis	Electrolyzer	PVC	1	Electrolysis	Electrolyzer
	2	Refrigeration	Cooling tower		2	Refrigeration	Electrolyzer
	3	Arefaction	Drying tower a		3	Arefaction	Drying tower a
	4	Colation	Drying tower b		4	Polymerization	Polymerizer
	5	Polymerization	Polymerizer		5	Recovery	Recovery tower

The required time and processing task quantity for four tasks of PO and PVC production are shown in table 3.

Table 3 Production tasks

Mask number	Products	Mask arrive time(h)	Mask quantity(t)
1	PO	0	15
2	PVC	0	15
3	PVC	5	8
4	PO	10	8

PRODUCTION SCHEDULING ALGORITHM DESIGN BASED ON PSO CORRESPONDING PARAMETERS SELECTION

Each parameter of PSO algorithm in birds feeding problems and process industry production scheduling problem are compared, and the meaning of the corresponding parameters is shown in the table 4 below:

Table 4 PSO algorithm parameters contrast table

Parameters	Birds feeding problem	Scheduling problem
Particle position x	Each bird	The production process of each product
Particle dimension D	The scope of flying direction	The number of the process used in a production task
Particle velocity maximum Vmax	The maximum speed of birds to fly	The number of equipment combination used in Each process
Inertia weight w	Ability affected the global search and local search	Ability affected the global search and local search
Learning factor c1、c2	Cognitive factor	Cognitive factor
Adaptive values fitness	The distance from food	The production time of task
Individual extreme values pbest	A single bird to find the location of the closest to the food	Equipment combination To make a minimum procedure time
Global extreme values gbest	The entire population to find the location closest to the food	Equipment combination to make a minimum makespan
Target	To find the recent distance from food	To Minimize the makespan

ALGORITHM IMPLEMENTATION STEPS

According to the characteristic of chemical production scheduling problem, this paper adopted a hybrid particle coding method based on PPS particle position (particle position sequence, PPS) - particle position integer operations (particle position rounding, PPR) ,which was put forward in literature [19], namely the coding method based on the PPS - PPR.

Based on PPS - PPR hybrid particle coding method can be used to map the solution space of scheduling problem that need to consider both the production operation sequence and machine distribution, that is, as a process of a product can be done in different machines, the scheduling scheme, consider the allocation problem of product on different machines in addition to the operation sequence.

Assume that the number of total procedure is n, number of total machines is m, mark different machines with natural number 1, 2,... , m. Establish a three-dimensional particle, length is n, the first dimension represent process, mark different process using natural number 1, 2,... , n, the second dimension is particle position xi, used for mapping work order, and the third dimension is particle position yi, used for mapping the machine allocation. The three-dimensional particle can be represented as:

Production procedures	1	2	…	j	…	n
Particle position (xi)	xi1	xi2	…	xij	…	xin
Particle position (yi)	yi1	yi2	…	yij	…	yin

When decoding, the position vector-value of particle was sorted, at the same time to exchange the position of the vector-value operation in the positions of the particles, resulting in an orderly operation sequence of the equipments scheduling.

It can be seen that the particle coding method and the way of scheduling updated particle position vector by position-velocity model in PSO algorithm, which ensures the operation sequence constraint in the process of production. At the same time, due to the random position vector-value particles, also ensures the diversity of generation scheduling scheme.

ALGORITHM IMPLEMENTATION STEPS

Implementation steps for adaptive weight PSO algorithm:

Step 1 Particle population and parameters initialization. Random generating 20 particles, particle position of each

dimension is limited within the range of the particle position values; the maximum velocity of particles is limited between 0 and 1;
Step 2 Adaptive values Calculation of each particle new position.
Step 3 Individual extreme values and global extreme values update.
Step 4 update particle's position、velocity respectively and inertia weight according to the formula (6) (7), and (8), and make the judgment of the updated velocity, if it is greater than the maximum velocity, we make them equal to the maximum velocity;
Step 5 Go to the end if achieve maximum iterations, or go to Step2;
Step 6 Optimization algorithm is ended.

ALGORITHM DESIGN

Scheduling goal is to make the minimum makespan of the production task, the particle's position represents a processing task, its length is processing task step number, particle position of each dimension is rounded, and they respectively mean the equipments used in processing steps, such as the value is 1 when Numbers 1 equipment is used, the value is 2 when Numbers 2 equipment is used. Because each processing step of the available equipment might be different, so the particle position in each dimension has a scope, which present the combinations of equipments in processing tasks. After Particle movement, take integer operations on particle position of each dimension, and according to the values resulting from the integer to determine the use of equipment.

SIMULATION RESULTS AND ANALYSIS

This example choose adaptive weight PSO algorithm, the selection of its parameters: population $N = 20$; maximum number of iterations $M = 500$; particle dimension $D = 5$; learning factor $c_1 = c_2 = 2$; $w_{\max} = 0.9$; $w_{\min} = 0.4$; PO production task particle position of each dimension value range $[1\text{-}7,1,1\text{-}3,1,1\text{-}3]$; PVC production task particle position of each dimension value range $[1\text{-}7,1\text{-}7,1\text{-}3,1\text{-}3,1]$; PO production particle velocity maximum $V_{\max}1 = [7,1,3,1,3]$; PVC production particle velocity maximum $V_{\max}2 = [7,7,3,3,1]$.

Four production tasks result based on adaptive weight PSO algorithm is shown in table 5.

Table 5 Scheduling results based on adaptive weight PSO algorithm

Production procedures Production course		1	2	3	4	5
Mask 1	Start time	0	5	15	23	32
	End time	5	15	23	32	37
	Device	R11+R12+R13	R2	R31	R4	R51+ R52
Mask 2	Start time	5	10	23	31	36
	End time	10	15	31	36	48
	Device	R11+R12+R13	R11+R12+R13	R31+R32	R51+ R52	R6
Mask 3	Start time	15	20	31	39	48
	End time	20	25	39	44	54
	Device	R12	R12	R31	R51	R6
Mask 4	Start time	25	30	35	43	49
	End time	30	35	43	49	54
	Device	R12	R2	R32	R4	R51

At the same time, in order to validate the effectiveness of the PSO scheduling algorithm, in this paper, the ant colony [20] scheduling and PSO scheduling was compared. Ant colony algorithm parameter selection: Ants' population ; pheromone initial value ; information heuristic factor ; expect heuristic factor ; balance factor ; total pheromone amount ; pheromone volatile coefficient ; and circulation coefficient . Scheduling result is shown in table 6.

Now, the proposed algorithm and ant colony algorithm scheduling results were compared, under same constraint, the production device utilization rate of two algorithms were calculated, computation formula is as follows.

$$\text{Device utilization rate} = \frac{\text{Time of device being used}}{\text{End time of device being used}} \tag{9}$$

It can be seen from scheduling simulation results, makespan based on the proposed scheduling scheme were 54 units, and makespan based on ant colony algorithm scheduling scheme were 69 units. Therefore, in accordance with the requirements of the production tasks, the production period based on PSO scheduling scheme was significantly shorter.

Table 6 Scheduling results based on ant colony system algorithm

Production procedures / Production course		1	2	3	4	5
Mask 1	Start time	0	10	20	36	54
	End time	10	20	36	45	64
	Device	R12	R2	R31	R4	R51
Mask 2	Start time	0	15	30	49	55
	End time	15	30	46	54	61
	Device	R11	R11	R32	R51+ R52	R6
Mask 3	Start time	10	15	36	44	49
	End time	15	20	44	49	55
	Device	R12+R13	R12+R13	R31	R51+ R52	R6
Mask 4	Start time	30	40	45	53	64
	End time	40	45	53	59	69
	Device	R11	R2	R31	R4	R51+ R52

In the related algorithm parameters and scheduling goal as the same case, the production equipment utilization rate of two algorithms is shown in table 7. The average equipment utilization rate based on PSO scheduling scheme is 58.897% on, higher than the average equipment utilization rate based on ant colony system scheduling scheme which is 48.37%.

Table 7 Production equipment utilization comparison of two scheduling algorithms

Production devices	Equipment utilization rate (%)	
	PSO	Ant Colony
Electrolyzer R11	100	100
Electrolyzer R12	100	100
Electrolyzer R13	100	50
Cooling tower R2	42.86	33.33
Drying tower a R31	61.54	60.38
Drying tower a R32	55.81	34.78
Drying tower b R4	30.61	25.42
Polymerizer R51	37.04	36.23
Polymerizer R52	27.78	21.74
Recovery tower R6	33.33	21.82
Average utilization rate	58.897	48.37

RESULTS AND DISCUSSION

Production scheduling is the core of process industry production management, PSO algorithm has been successfully promoted application in the field of production scheduling, and gradually shows its superiority. According to the characteristics of process industry production scheduling, a chlor-alkali enterprises PO and PVC production tasks were taken as example, the corresponding PSO model was adopted to realize four tasks of two products' production scheduling, and the results was compared with the ant colony algorithm results. Adaptive weight PSO algorithm scheduling time is shorter, faster, can get better scheduling scheme, production scheduling can be done in a short period, the resources were used and allocated reasonably, this provided some theory references for the enterprise decision makers.

Acknowledgements
This work was supported by the Key Program of National Natural Science Foundation of China (61034005), Project: Liaoning Fine Chemicals Collaboration Centre Innovation Team funded projects.

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