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# Multi-product Pipeline Scheduling Based on Adaptive Genetic Algorithm

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**Abstract: Scheduling is of great importance to multi-product pipeline of batch transportation. Optimizing scheduling plan and pump distribution program as a whole, considering the balance of energy supply and hydraulic condition, a mathematical model of optimal operation condition was developed by employing the principle of minimization of the power consumption. Adaptive genetic algorithm was used to solve the model. The optimized scheduling plan and the pump distribution program can be obtained after calculation. By using this program, optimized scheduling plan and pump distribution program can be made automatically.**

**Keywords: Adaptive Genetic Algorithm, Multi-product pipeline, Optimization, Scheduling.**

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## I. INTRODUCTION

In recent years, the construction of multi-product pipeline is in high speed development period in China. As the pipelines going into operation, more attentions need to be given to their optimal operation problems. How to guarantee the pipeline's safe and economic operation, how to increase the efficiency of pipeline transportation and reduce the cost, is becoming more and more serious.

Generally, optimization of pipeline operation refers to under the circumstances of the definite pipeline project, through the reasonable configuration of pump operation plan, to achieve the purpose of reducing energy consumption.

But, in fact, once the scheduling of multi-product pipeline is determined, the space of optimization is limited.

If the scheduling plan is not reasonable, the further calculated pumping scheme optimization on the basis of this plan is also unhelpful.

Multi-product pipeline optimization problem should start from the overall situation, but not from some processes. In the process of making the scheduling plan, optimization problems should be considered at the same time. Optimal operation problem of product oil comes down to the process of scheduling plan optimizing. Considering the balance of supply and hydraulic condition, a mathematical model of optimal operation condition was developed by employing the principle of minimization of power consumption. The optimized scheduling plan and the pump distribution program can be output after calculation.

Making the plan of oil transportation scheduling, the oil supply volume at the first station should be known. Under this situation, use the minimum operating cost as objective function, to realize the optimal scheduling plan.

So, the process of programming scheduling plan is actually a process of optimization pipeline plan formulation, which rely on manual processes is obviously unrealistic, must use computer aided.

## II. GENETIC ALGORITHM USED FOR PIPELINE SCHEDULING PLAN

Genetic algorithm including coding the implementation of the process of calculating fitness, replication, exchange, mutation operations such as generating initial population and is a reference for biological natural selection and natural genetic mechanism of the random search algorithm.

Genetic algorithm is used for pipeline scheduling plan. A set of scheduling plan is generated according to certain principles, as the initial population.

Through the pump distribution module, for each scheduling plan, their optimum pump distribution solution is determined, and their energy consumption value is returned to the main program. According to the fitness function the main program compares one scheduling to another, (carry on the comparison to the scheduling plan) and judges whether meet the termination conditions. If the termination conditions are not satisfied, new individuals are generated by genetic operations, and the process is repeated, as shown in figure 1.

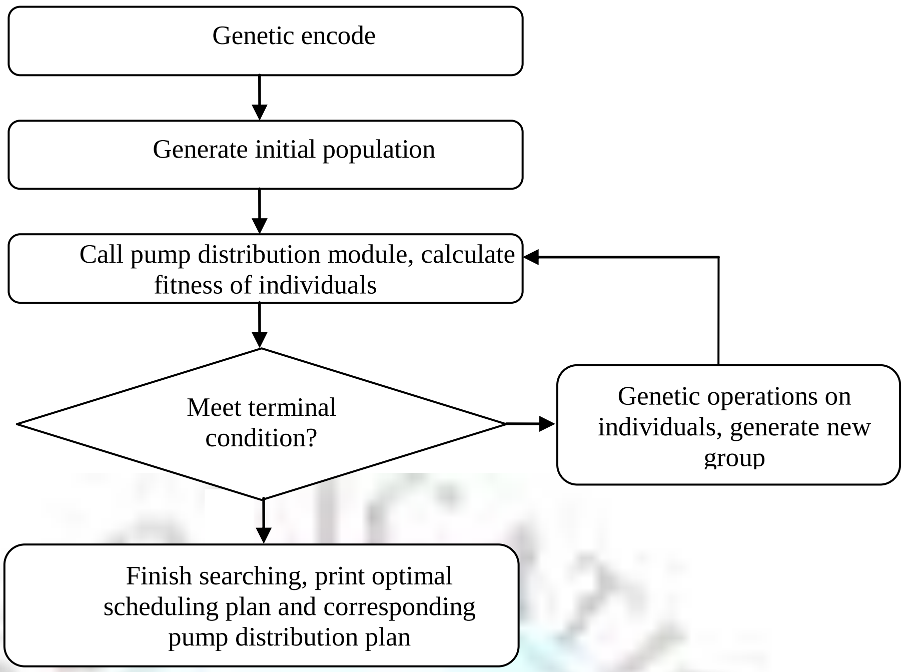


**Fig1: The flow chart of Genetic Algorithm**

A. **Genetic encode**

The genetic algorithm does not act directly on the parameters itself, but the optimization of some encoding of Problem parameters. So, when we use this method to solve the optimization problem, firstly, you need to adopt the appropriate encoding method to represent the best optimum result of the problem as the chromosome.

At present, real number coding system is mostly applied for genetic algorithm to solve the problem. This approach is also used in this article.

If there are S distribution stations, each station has B kinds of products to distribute, parameters of each batch include the start time to end time and the throughput of each point, if the throughput of each point is given, and two other parameters need to be solved.

Connect genes of all stations in regular sequence in order to form a chromosome, whose total length is L = 2 BS.

B. **Determine the initial population**

Genetic algorithms are random search algorithm, the initial value has great influence on the number of optimizing times, and therefore, it is important to determine the initial population.

In order to improve the quality of the initial population, and reduce frequency of search, this article combines planning experiences and constraints and other factors, according to the following steps to set up the initial group (as shown in figure 2):

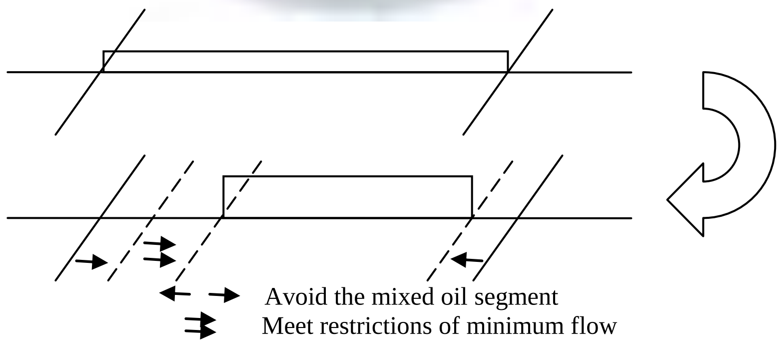


**Fig2: Schematic diagram of initial scheduling plan**

(1) firstly average distributing way is used in all stations , that is, once the batch interface enter the station, the mission to distribute oil is carried on until other batch interface reach this station, according to the total throughput and start-stop time the throughput of each product is calculated.

(2) The stations in the middle pipeline should avoid the batch interface, and adjust the start-stop time and throughput of each product.

(3) Adjust the distribution flow in order to meet restrictions of minimum flow, and consider the principle of minimum quantity of mixed oil, the stop time should be fixed, the start time should be adjusted.

Many constraints should be satisfied in scheduling plan. For example:

(1) The constraints of station reserves: $vt_{p,s}^{\min} \le vt_{p,s,t} \le vt_{p,s}^{\max}$

$vt_{p,s,t}, m^3$ , represents oil reserves of P, the moment is t, the station is S.

$vt_{p,s}^{\min}, vt_{p,s}^{\max}$ , $m^3$ , respectively represent minimum and maximum oil allowable reserves of P, the station is S.

(2) Constraints of total conservation:

$$vt_{p,s,0} = \sum_{tt=0}^{t} vf_{p,s,tt} + \sum_{tt=0}^{t} vd_{p,s,tt} - \sum_{tt=0}^{t} vi_{p,s,tt} - \sum_{tt=0}^{t} vs_{p,s,tt} + vt_{p,s,t}$$

$$\sum_{s=0}^{S} vt_{p,s,t} = \sum_{s=0}^{S}\sum_{t=0}^{T} vf_{p,s,t} - \sum_{s=0}^{S}\sum_{t=0}^{T} vs_{p,s,t} + \sum_{s=0}^{S}\sum_{t=0}^{T} vi_{p,s,t} - \sum_{s=0}^{S}\sum_{t=0}^{T} vd_{p,s,t} + \sum_{s=0}^{S} vt_{p,s,0}$$

$vf$ , $vd$ , $vi$ , $vs$ , $vt$ , $m^3$ , within a certain time period ,respectively represent station's total production of P from oil refinery, the flow of distribution to pipeline used to receive the oil, total quantity of flow from injection pipeline, total quantity of flow sold , current oil reserves.

(3) Constraints of flow equilibrium: $q_{0,t} = \sum_{s=1}^{S} q_{s,t}$

$q_{s,t}, m^3/s$ , quantity of flow injected to S station or distributed from S station .

(4) Constraints of flow regime: $q > \dfrac{\mathrm{Re}_j \pi d_s v}{4}$

$\mathrm{Re}_j, d_s, v$ , respectively represent critical Reynolds number of Turbulent flow smooth area and steepening area, internal diameter of pipe, viscosity of oil.

(5) Constraints of arrival time: $ti_{b,s+1} = ti_{b,s} + \dfrac{V_s}{\bar{q}_{b,s}}$

$ti_{b,s}, s$ , the time of batch b to arrive station s.

$V_s, m^3$ , pipe capacity from station s to station s+1.

$\bar{q}_{b,s}$ , average capacity of batch b from station s to station s+1, $m^3/s$ .

(6) Conditional constraints of distribution flow: $q_{b,s} = \dfrac{Q_{b,s}}{te_{b,s} - tb_{b,s}}$ .

$q_{b,s}$ , $Q_{b,s}$ , $tb_{b,s}$ , $te_{b,s}$ respectively represent distribution flow of batch b from stations, total flow,the start time of distribution, the end time to arrive next station.

(7) Constraints of prohibition about distribution blending:

$$ti_{b,s} + \frac{m_{b,s}}{2\bar{q}_{b,s}} < tb_{b,s} < te_{b,s} < ti_{b+1,s} - \frac{m_{b+1,s}}{2\bar{q}_{b+1,s}}$$

$m_{b,s}$ , blending volume of batch b from station s, $m^3$

### C. The determination of fitness function

In situations where each scheduling plan is identified, mathematical model and constraint conditions compose of the fitness function, which evaluates the different standards of various pump schemes. In order to determine this function, establish mathematical model and calculate, The following assumptions are made:

(1) Multi-product pipeline is isothermal.

(2) The electricity price of each station remains unchanged during the research phase.

In pipeline transportation cycle, power consumption of all pump units is target function. We set the number of all stations along the line is $ns$ , and there are $np$ pumps in the $i$ station, then the target function is:

$$\min z = \int_0^T \sum_{i=1}^{ns} \left( c_i e_i \sum_{j=1}^{np} \frac{\alpha_{ij} \rho_i g q_{ij} h_{ij}}{3.6 \times 10^6 \eta_{ij}} \right) dt$$

In the formula, $T$ is the time of pipeline transportation cycle, $s$. $z$ is power consumption cost in pipeline transportation cycle, $yuan$ . $c_i$ is coefficient of station type, the coefficient of pressure reducing station is 0, the coefficient of pressure boosting station is 1. $e_i$ is the electricity price in $i$ station, $yuan/kwh$ . $\alpha_{ij}$ is the operating condition of $j$ pump in the $i$ station, *1* stands for operation, *0* stands for stop. $\rho_i$ is the oil density of $i$ station, $kg/m^3$ . $q_{ij}$ is flux of $j$ pump in $i$ station, $m^3/s$ . $h_{ij}$ is the pump head of $j$ pump in $i$ station, $m$ ; $\eta_{ij}$ is the $j$ pump efficiency in the $i$ station.

Hydraulic constraints: $p_{ij}^{in} + \sum_{p=1}^{i-1} h_p = h_{s1} + \sum_{p=1}^{i-1} \left( p_p^{out} - p_p^{in} - p_{mp} \right)$

$h_p$ is the frictional resistance between station $p$ and station $p+1$, $MPa$ . $p_{mp}$ is the internal friction of $p$ station, $MPa$ .

The process constraints:

$p_{ij}^{\min\_in} \le p_{ij}^{in} \le p_{ij}^{\max\_in}$, in the $i$ station, the inlet pressure of pump $j$ within the allowable range.

$p_{ij}^{out} \le p_{ij}^{\max\_out}$, the outlet pressure of pump $j$ is not higher than the maximum allowable discharge pressure.

Strength conditions:

$p \le p^{\max}$ , the pressure of pipeline at any point is lower than the maximum allowable operating pressure.

We transform the original minimum value of target function and constraints into the maximum function, which is the fitness function: $Z = \dfrac{1}{z + u_i \left| g_i(x) \right|}$

$g_i(x)$ is the constraint condition of $i$ , $u_i$ is the corresponding penalty factor.

### D. Genetic operator

Genetic operation are selection, crossover and mutation, which select the operation according to determine the proportion of fitness assignment method, the method of selecting the roulette.

The crossing-over rate $P_c$ and mutation rate $P_m$ are important for the genetic algorithm of scheduling. Srinvivas proposed an adaptive genetic algorithm, and pointed out two formulas which respectively represent the value of crossing-over rate $P_c$ and the value of mutation rate $P_m$ :

$$P_c = \begin{cases} k_1 \dfrac{f_{\max} - f'}{f_{\max} - f_{avg}'} & f' \ge f_{avg} \\ k_2 & f' < f_{avg} \end{cases} \qquad P_m = \begin{cases} k_3 \dfrac{f_{\max} - f}{f_{\max} - f_{avg}} & f \ge f_{avg} \\ k_4 & f < f_{avg} \end{cases}$$

In the formula, $f_{\max}$ represents the maximum fitness value in the population. $f_{avg}$ represents the average value of adaptation in every population; $f'$ represents the larger fitness value of two crossed individuals; $f$ represents the fitness value of mutating individuals, the value of $k_1 \sim k_4$ belongs to the range (0,1).

Compared with the standard genetic algorithm, the control parameters can improve the efficiency in the certain degree, but in the late evolutionary optimization of stagnant, efficiency is also not high. Considering the pipeline scheduling in the process of making law, a station scheduling plan, will affect the specific conditions of its follow-up on all stations. Therefore, the crossing-over rate and mutation rate are relevant to distance between distribution station and first station, that is, the individual controls parameter embody weight parameters. The closer the distance between distribution station and first station is, the lower the weight of controls parameter is, this can decrease the probability of crossover and mutation, keep the stability of evolution; the farther the distance between distribution station and first station is, the bigger the weight of controls parameter is, this can increase the probability of crossover and mutation, enhance the flexibility of evolution;

Two improved formulas for probability value:

$$P_c = P_{c0}\left(\frac{L_1}{L}\frac{f_{\max}-f_1}{f_{\max}-f_{avg}} + \frac{L_2}{L}\frac{f_2-f_{\min}}{f_{avg}-f_{\min}}\right) \qquad P_m = P_{m0}\left(\frac{L'}{L}\frac{f-f_{avg}}{f_{\max}-f_{\min}}\right)$$

In the formula, L is the length of pipe $Km$. $f_1$ is the larger fitness value of two crossing individuals. $L_1$ represents the distance between the corresponding distribution station $f_1$ and the first station, $f_2$ is the smaller fitness value of two crossing individuals. $L_2$ represents the distance between the corresponding distribution station $f_2$ and the first station. $L'$ represents the distance between the corresponding distribution station $f$ and the first station.

E. **The termination condition**

The difference value of twice total cost is less than the set limit of error: $\left|z^i - z^{i-1}\right| < \varepsilon$

In the actual implementation process, as the specificity of optimization process about the distribution pump, scheduling plan is adjusted for many times, but the pump distribution program retains the same, this situation is possible, therefore, we can put the continuous returned values within allowable error as the termination condition.

## III. EXAMPLES OF THE APPLICATION OF ALGORITHM IN LANZHOU - CHENGDU - CHONGQING PRODUCT PIPELINE

Lanzhou - Chengdu - Chongqing oil pipeline (referred to as the Lan-Cheng-Yu pipeline) is a national key project, which is the most representative of the multi-product pipeline project in domestic. The total length is 1250 km. The first station in Lanzhou is oil filling station, except terminal station in Chongqing, there are 14 distribution stations. The designed maximum throughput of pipeline is 5,800,000 tons, the delivery of three kinds of oil in batch pipelining are 90# gasoline 93# gasoline and 0# diesel oil, for now, the scheduling plan uses manual methods.

Combine the actual parameters of the pipeline, we establish mathematical model, besides the constraints listed above, according to the experiences of personnel who run the scheduling, the following supplementary are made:

(1) Limits of the distribution flow should be on the basis of empirical data in the dispatching operation;
(2) Each batch should distribute completely once in every station, without considering the multiple distribution case;
(3) Distribution of each station should be in sequence as far as possible, to reduce the frequency of operating change.

Take the Lanzhou-Chengdu-Chongqing pipeline transportation of 0# diesel and 90# gasoline as an example, to complete the 3 batches of periodic scheduling, initial mixed oil interface is located at 312.3Km away from the first station, after 124 iterations, the results reached a stable value, the total time is about 16 minutes. Convergence process of the arithmetic is shown in Figure 3, the obtained scheduling is shown in Figure 4, the pump scheme is shown in Figure 5.

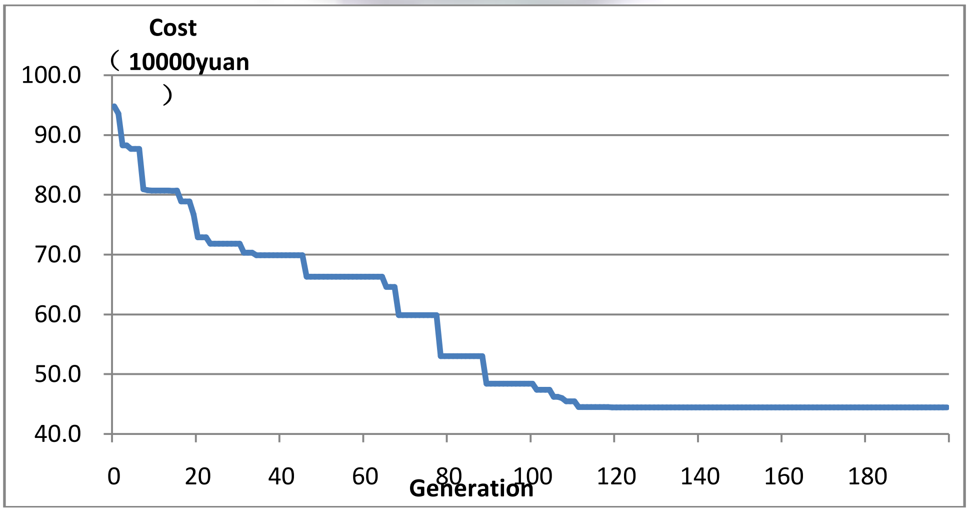


**Fig3: Schematic Diagram of convergence process**

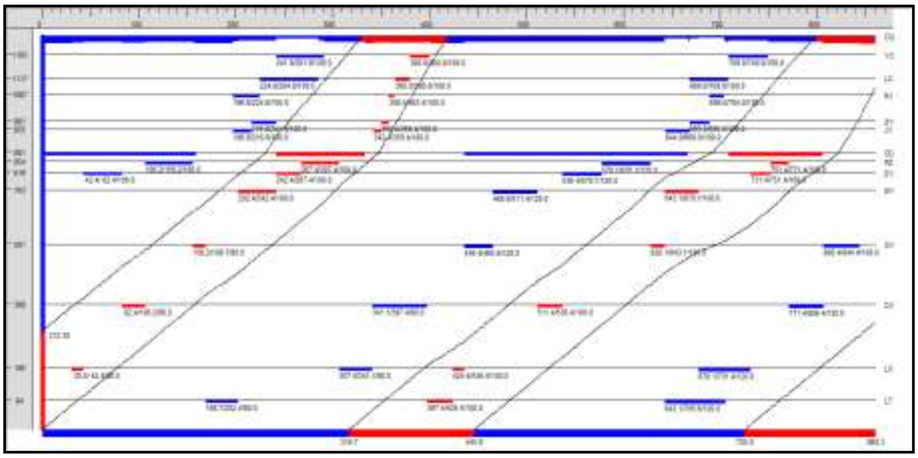

**Fig 4: Schematic Diagram of scheduling plan**

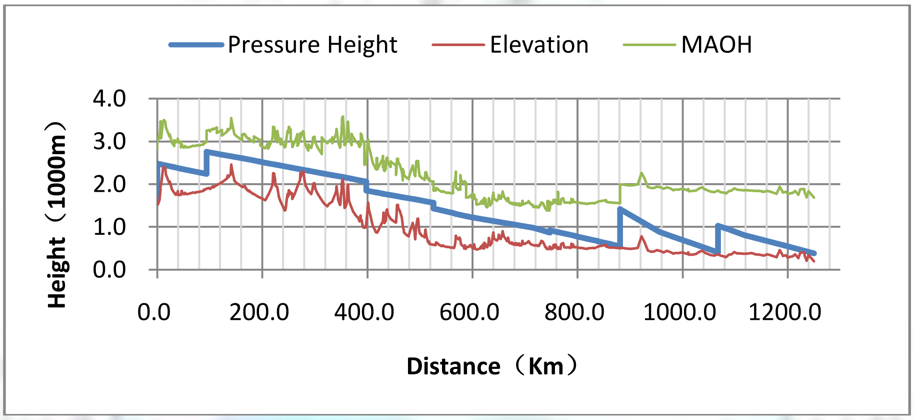


**Fig 5: Pressure distribution chart of the pipeline (t=0h)**

## IV. SUMMARY

Lan-Cheng-Yu pipeline example shows that, the adaptive genetic algorithm which is used for the automatic compilation process of scheduling plan is feasible. It can complete the whole optimization of scheduling and distribution pump scheme, and explore new ideas for pipeline scheduling automatic programming problem. It is instructive for the analysis of pipeline optimization problems.

Because usually there are multiple unloading stations on the multi-product pipeline, and multiple batches and various oil are transported at the same time, its computation is very large, it also takes rather long time to complete the simple calculation in the above example, we make through further research to improve the efficiency, to reduce the computing time, and to meet the needs of project application preferably.

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