JEB
Journal of Environmental Biology
Journal Website : www.jeb.co.in
E-mail : editor@jeb.co.in
ISSN: 0254-8704 (Print)
ISSN: 2394-0379 (Online)
CODEN: JEBIDP

Research on the optimal energy consumption of oil pipeline

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Publication Info

Paper received:
17 June 2014

Revised received:
30 September 2014

Re-revised received:
01 January 2015

Accepted:
07 February 2015

Abstract

Most of the Chinese crude oil is easy to curdle and has high viscosity, so heating transportation is usually selected. Energy consumption by this method mainly comes from furnaces and pumps. Currently, operating parameters of these pipelines were determined according to experience of dispatch. It cause high energy consumption and high cost of pipeline running, so it could not adapt to energy conservation policy. The present study focused on consuming lowest energy to operate oil transportation line. To begin with, several optimization variables were set which included pump combinations, suction pressure, discharge pressure, and station temperature. Then constraint conditions were set to establish an optimal mathematical model of running transportation line. Furthermore, genetic algorithm was used to solve the model, in meantime, selection operation, cross operation and mutation operation in the genetic algorithm were improved. Finally, a crude oil pipeline running optimization software was developed. Through optimal analyzing, S-L transportation line and contrasting with the actual working conditions, it was found that optimal operation scheme could reduce energy consumption by 5% ~ 9%. In addition, optimal operation scheme also considered the effect of seasons and flow on energy consumption of S-L transportation line.

Key words

Energy consumption, Genetic algorithm, Model, Oil pipeline, Optimization

Introduction

Oil pipeline running is a very complex process and is restricted by many factors such as outbound temperature, environmental conditions along the pipeline, relationship between viscosity and temperature of oil, rheological characteristics and energy supply characteristics of pumping stations along the pipeline. Different operation plans consume different energy, so it is necessary to adopt optimization method to realize the lowest energy consumption and optimization pipeline operation.

Gopal *et al.* (1980) came up with an optimizing way for pumping station. This method used integer programming method to determine opened combination of pumps in order to get minimum total energy costs. East Texas Oil Pipeline Company adopted power optimization software to solve pump combinatorial optimization problems, and to reduce pipeline operating costs (Kurak, 1989). Camacho *et al.* (1999) optimized Spain Kansapu oil pipeline in order to achieve minimum energy consumption cost. This method introduced some new optimization methods of decision-making, such as Behrman's optimizing principle and heuristic rules. Manzhai *et al*. (1993) did experimental researches and field tests on how to reduce the power consumption of oil pipeline. A series of pipeline optimal operation ways, were introduced which provided technical guarantee for pipeline safety and economic operation.

Jokic *et al.* (2001) optimized oil transportation line network by using nonlinear programming methods, which aimed at achieving lowest cost of the whole system running, inorder to obtain the best operation scheme.

A nonlinear programming and each station technology calculation method was used to optimize oil pipeline (Meng *et al.*, 2002). As a result, they had got the operating method of each pump and furnace station in the pipeline, heating temperature and discharge pressure under a given flow. Xu *et al.* (2002)

considered object function of pipeline optimal operation, complex constraint conditions, and continuous variables and discrete variables in mathematical model. Further, mixed discrete variable combination method (MDCP) was selected to the solve mathematical model of optimal operation. The method outstanded fast solving speed and high success rate, so that it gained satisfactory results in practical application.

On the basis of analyzing operation characteristics of crude oil long-distance pipeline, optimal operation model was established by using simulated annealing algorithm. The result showed that the simulated annealing algorithm was broader than the dynamic programming algorithm (Song *et al*., 2007; Zuo *et al*., 2008; Zhang *et al*., 2012). Liu et al. (2014) introduced production unit consumption indicators to establish an objective function for achieving the goal of lowering energy consumption. By using a dynamic programming method for solving the model and preparing calculation software, the solution process was quick and efficient. Artificial neural network was introduced to forecast the daily electricity consumption of a multiproduct pipeline, which was used to drive oil pumps. Results showed that artificial neural network had high accuracy for prediction (Zeng *et al*., 2014) .

In view of the above, the present study aimed at investigating the cost of minimum energy consumption of pipeline running according to the characteristics of oil pipeline operation and management. An optimal operation model of crude oil pipeline was established and genetic algorithm was used to solve the model, and gained optimal running program of oil pipeline, as well as minimum energy consumption.

Through optimization research, energy consumption of pipelines and can be reduce greenhouse gas emissions, thereby reducing the greenhouse effect of the atmosphere, and achieve the purpose of protecting the environment.

Materials and Methods

Crude oil pipeline system is complex and includes many parts such as pipelines, fluid, external environment and stations. In order to find minimum energy consumption issue of crude oil pipeline system, a corresponding mathematical model was established. Reasonable and perfect mathematical model was key of getting best result.

Objective function : Crude oil pipeline mainly had energy consumption from two aspects during running: power consumption of pump unit; fuel consumption of furnace. So the lowest energy consumption of crude oil pipeline was selected as objective function.

$$\min F = (Sp\omega_1 + S_h\omega_2) / T_{ur} \qquad (1)$$

Where, F was production unit consumption of pipeline (kgce. $(10^4$t. km$)^{-1}$); S_p was the power consumption (10^4kW.h); S_h was the fuel consumption (t); T_{ur} was turnover (10^4t.km); ω_1 was electric coal conversion coefficient (1229kgce. $(10^4$kW.h$)^{-1}$); ω_2 was oil coal conversion coefficient (1428.6 kgce. t^{-1}).

Power consumption S_p could be expressed as :

$$S_p = \sum_{i=1}^{Np} \frac{GH_i\, g\, t_p}{10^7\, \eta_{pi}\, \eta_{ei}} \qquad (2)$$

Where, N_p was number of pumping stations; G was mass flow of crude oil (kg.sec^{-1}); H_i was provided head by i-th pumping (m); g was acceleration of gravity (9.8N.kg^{-1}); t_p was pump running time (hr); η_{pi} was pump efficiency; η_{ei} was the motor efficiency.

Fuel consumption S_h could be expressed as :

$$S_h = \sum_{i=1}^{Nh} \frac{Gc\,(T_{ci} - T_{ji})\, t}{1000\, \eta_{hi}\, q} \qquad (3)$$

Where, N_h was number of thermal stations; G was the mass flow of crude oil (kg.sec^{-1}); c was specific heat capacity of oil; T_{ci} was outbound temperature of i-th station (ºC); T_{ji} was inlet temperature of i-th station (ºC); t was heating station run time (sec); η_{hi} was furnace efficiency of i-th station; q was low heating value of fuel (kJ. kg^{-1}).

Turnover T_{ur} could be expressed as

$$T_{ur} = 10^{-4} \sum_{i=1}^{n} Q_i L_i\, t \qquad (4)$$

Where, Q_i was mass flow of i-th section of pipeline (t. day^{-1}); L_i was length of i-th section of pipeline (km); t was delivery time (day).

Optimization variables : From the objective function of model, it was found that the energy consumption of crude oil pipeline was related to many parameters, such as energy consumption of crude oil pipeline, pump power, discharge temperature of furnace and so on. When pipe flow was constant, pump combination method, pump speed and discharge temperature would affect the energy consumption of oil pipeline directly. Therefore, optimal variables of optimal operation mathematical model of heated oil pipeline could be determined as pump combination way, pump speed and discharge temperature of heating station.

$$X = (C_{pi},\, n_i,\, T_{ci}) \qquad (5)$$

Where, C_{pi} was pump connections of i-th station; n_i was pump speed of i-th station; T_{ci} was outbound temperature of i-th station (ºC).

Constraint condition : In order to guarantee safe running of the whole pipeline and devices, both operation parameters of pipelines and devices should be with in the permitted range, namely the operation parameters include pressure, temperature, flow and power must be satisfied with a series of constraint conditions. Constraint conditions mainly included of pitted pressure constraint, discharge pressure constraint (pipeline strength constraint), hydraulic constraint of full pipeline, discharge oil temperature constraint, pitted oil temperature constraint, furnace heat load constraint and oil transfer pump power constraint.

Pitted pressure constraints : The suction pressure of pump should be greater than cavitations allowance, or it would not work properly. Thus, pitted pressure of pump station should be greater than that allowed minimum pitted pressure.

$$H_{ini} > H_{ini}\text{min} \quad (6)$$

Where, H_{ini} is pressure head of i-th station; H_{inimin} is minimum allowable pressure head pitted (m).

Outbound pressure constraints : Lift provided by the pump should not be less than the required pressure head of pipeline. But in order to ensure safe operation of hot oil pipeline, lift provided by pump station should be satisfied with strength requirement, namely, outbound pressure head of each pump station cannot be greater than maximum bearing capacity of pipeline.

$$H_{exi} < H_{dmax} \quad (7)$$

Where, H_{dmax} is maximum working pressure head of pipeline, m; H_{exi} is outbound pressure head of pipeline, m.

Hydraulic constraints : In order to ensure task flow, pressure head provided by pump station cannot be less than the pressure loss along the pipeline. Along the pipeline pressure loss included friction, local friction and depth displacement.

$$H_{total} \geq H_p \quad (8)$$

Where, H_p is pressure head loss along the pipeline (m); H_{total} is pumping head provided (m).

Outbound temperature constraints:

$$[t_{rmin}] \leq t_{ri} \leq [t_{rmax}] \quad (9)$$

Where, t_{ri} is the outbound oil temperature of the i-th station (ºC); $[t_{rmin}]$ is the lowest outbound oil temperature of the i-th station (ºC); $[t_{rmax}]$ is the highest outbound oil temperature of i-th station (ºC).

Inlet temperature constraints: To ensure safe operation of hot oil pipeline, generally pitted temperature should not be less than specified value, *i.e.,*

$$t_{zi} \geq [t_{zmin}] \quad (10)$$

Where, t_{zi} was inlet temperature of i-th station (ºC); was the minimum pitted temperature (ºC).

Furnace heat load constraints : If the actual furnace heat load was more than rating, it maybe endanger the production safety, leading to explosion. When actual heat load was low, the efficiency was very low. So it could not make full use of energy from the burning fuel oil. Furnace heat load constraint is given below :

$$Q_{min} \leq Q_{ri} \leq Q_{max} \quad (11)$$

Where, Q_{min} is the minimum heat load of furnace (kW); Q_{max} is maximum heat load of furnace (kW); Q_{ri} is actual heat load of i-th station (kW).

Pump power constraints : The power of each pump station is limited in a certain range, power constraints for pumping station is:

$$P_{min} \leq P \leq P_{max} \quad (12)$$

Where, P is pump power (kW); P_{min} is minimum power of pumps (kW); P_{max} is maximum power of pumps (kW).

The crude oil pipeline operation optimization mathematical model : The crude oil pipeline operation optimization mathematical model can be expressed as:

$$\min F\,(C_{pi}, n_i, T_{ci}) \quad (13)$$

$$\begin{aligned} s.t.:\quad & H_{ini} > H_{ini}\text{min} \\ & H_{exi} < H_{dmax} \\ & H_{total} \geq H_p \\ & [t_{rmin}] \leq t_{ri} \leq [t_{rmax}] \\ & t_{zi} \geq [t_{zmin}] \\ & Q_{min} \leq Q_{ri} \leq Q_{max} \\ & P_{min} \leq P \leq P_{max} \end{aligned}$$

The discharge temperature of each heating station (including heat pump station) in mathematical model was continuous variable while pump combinations of each station were discrete variables. Therefore, this problem belonged to non-linear mixed-discrete variable optimization design problem.

Model solution based on genetic algorithms : Based on the natural selection, mutation and genetic evolution in biological evolution process, Professor Holland and his coworkers of American Michigan University in 1975 developed a computational model, named Genetic Algorithms (Bin *et al.*, 2012). This model is widely used in optimization of various problems.

Genetic algorithm calculation flow : Coding is one of the most important processes of genetic algorithm, and the first problem needs to be solved. It affects the solution procedure and determines the search method of coding space, thus affecting the whole selection operation, crossover operation and mutation operation.

Initial production of bio-Group : In search space genetic algorithms set several individuals(namely the search points), and these individuals were made up of biological group. Usually, the initial biological group were randomly generated by using random function. Each biological group generated individuals for a total of N and produced groups counted as M (M=2N). Individuals generated were expressed as I(*i*, *j*) (*i*=1,2,…*N*; *j*=1,2,…*M*), while individual genotypes were expressed as *G*(*i*,*j*).

Calculated fitness for each group of biological : Fitness showed individual adaptation degree of the problem, which could be used to evaluate the pros and cons of the individual. Good individuals could adapt to better environment, so they had a better chance of inheritance to next generation; on the contrary, their genetic inheritance possibility was small, and slowly became extinct. This method simulated natural genetic phenomenon and evolutionary phenomenon, helping to find a good solution to algorithm. Using a function to express adapting degree, it was named as adaptive value function.

Eliminated proliferation : The possibility of selecting a biological group was defined as *P*(*j*), which was calculated by the following formula:

$$P(j) = \frac{f(X_j)}{\frac{1}{N}\sum_{i=1}^{M} f(X_i)} \tag{14}$$

The possibility of each biological group surviving in the next generation was in proportion to its adapting degree. Biological group was put according to the adapting degree of descending order, and unconditional eliminated a percentage of individuals, then made the rest of individuals to cross, to generate new genotypes, and to realize proliferation at last.

Genotype cross : Randomly K groups of two in pairs were choose from selected biological groups, paired corresponding individuals of each pair, and made each pair to cross. For example, genotype *G*(*i*,1) and *G*(*i*,2) were crossed to generate new individuals and formed new biological groups, and then calculated the adapting degree, in the end, saved the excellent biological groups.

Sudden variation : Determining sudden mutation genes of the genotypes in the existing biological groups according to the mutation rate. Then we calculated the adapting degree of mutated biological groups. Generally, sudden mutation rate was suitable to be 0.1%~0.5%.

Evaluation criteria : Making the largest adapting degree of biological group larger than the set value or making the evolution times to reach the set value.

Narrow space exploration : Genetic method explored in discrete optimization design space. Therefore, it had a

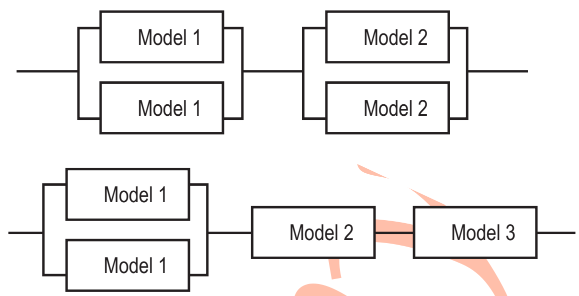

Fig. 1 : General combination of the pumps

shortcoming that even it explored somewhere near to the solution, it was hard to get more accurate optimization solution. If passing several generations of exploration, the smallest solution was still, we could set minimal solution as the center to narrow space to explore again in order to improve the exploration precision.

Improvement and application of genetic algorithms : Coding strategy: For the pump of crude oil pipeline operation optimization model, mostly real number encoding was used. For constant speed pump coding, some scholars came up with making each kind of pump schemes corresponding to real number encoding. But for long-distance pipeline, pump schemes of whole pipeline were so many, and it was only a mathematical mapping relationship between pump schemes and coding. However, coding itself had no actual clear meaning, so it would bring some inconvenience to the encoded genetic algorithm operation. Therefore, further study is required for reasonable way of coding for pumps of crude oil pipeline.

After studying pump combination methods of domestic crude oil pipelines, it was found that all of pumps in pump station had common combination law: different types of pumps were in series; same types of pumps were in series or in parallel, and its combining means were associated with pipeline flow and pump performance, which is shown in Fig.1.

For a pump station, there may be multiple types of pumps, and each type has number of pumps. Different types of pumps in station can be divided into no.1, no.2 and no.3 etc in turn. Therefore, the information contained in each type of pumps is the specific model of pumps, the number of pumps and series or multiple methods of pumps. For an oil pipeline, the specific type of pumps and the number of pumps in each station are certain, so are the combination methods of each type of pumps. So different number of open pumps determines the pump mode in the station, namely the pump coding of the station is the open number of each pump type. For example, in a station there are three types of pumps, named pump no.1, no.2, and no.3 respectively, and the number of the pumps are 3, 3, and 2 respectively. If their way of series-parallel is also known, the pump methods can be expressed as 332, 221 or 121, and so on. Matching each station in the pipeline by this method, such as 322-231-410-201, the pump mode of pump stations of the whole oil pipeline could be determined, which was the pump encoding strategy.

Inlet temperature coding : Temperature control of crude oil pipeline operation optimization mode was the control of pitted temperature of heating station generally, with a preference of real number coding to pitted temperature. In order to improve the precision of control, a double-precision floating-point coding could be used. Making combination of pitted temperature of stations along the whole pipeline can get pitted temperature coding, such as 44.3-35.4-26.8-25.5.

Combination of temperature coding and pump coding can result in an integrated optimization coding scheme. The coding represents an individual in the group. Integrated coding, such as 44.3-35.4-26.8-25.5-322-231-410-201, was good for reproduction, crossover and mutation of algorithm, improving the operation efficiency of genetic algorithm.

Constructor penalty function for objective function : To carry out penalty function on the objective function of crude oil pipeline optimal operation mode, a objective function was produced:

$$f = F + \gamma \times N \qquad (15)$$

Where, f is objective function with penalty; F is productive consumption of pipeline running; γ is punish coefficient; N is times of violating penalty.

Crude oil pipeline optimal operation belonged to practical engineering problems, which had many constraints. Lack of knowledge to solution, it was difficult to determine the number of best solutions and possible distribution in space. Besides, the initial group of genetic algorithm was generated randomly usually, so it was hard to judge whether the individual in group was within the feasible space or not. Penalty function could transform constrained optimal problem into unconstrained optimal problem. Penalty function would punish solutions, which were not in feasible space, and eliminate these in the evolution process.

Fitness function: (1) Introducing a function of temperature: After optimized objective function was determined, fitness function could be determined by using the following formula:

$$fit_i = \exp\,[(f_{min} - f_i) / t] \qquad (16)$$

Where, fit_i is fitness of the i-th chromosome; f_{min} is minimum objective of contemporary group; f_i is objective function of the i-th chromosome; t is temperature function combined with the simulated annealing algorithm.

From the adjusted fitness function it was observed that, when copy or choice, if temperature was high, the calculated fitness differences among each chromosome in fitness function would be small, the same as the possible differences of being selected to copy. Thus, the problem of precocity convergence could be avoided. However, if temperature reduced, the fitness differences of chromosome, which was close to objective function, would increase. Thereby, the advantage of better chromosomes increased. And climbing characteristics of simulated annealing algorithm could be used effectively. What's more, the occurrence of evolutionary stagnation phenomenon was avoided.

Initial temperature and retreat temperature function : Firstly, objective function f of each chromosome (individual) was calculated in group. Then initial temperature was ensured according to objective function. So initial temperature $t1$ could be expressed as:

$$t(1) = (f^1_{min} - f^1_{max}) / \ln (f^1_{min} / f^1_{max}) \qquad (17)$$

Where, t(1) is initial temperature of anneal function; f^1_{min} is minimum objective function in the 1-th group; f^1_{max} is maximum objective function in the 1-th group.

Anneal function could be expressed as :

$$t\,(i+1) = m \times t(i) \qquad (18)$$

Where, $t(i)$ is anneal temperature of i-th generation; m is coefficient of anneal temperature, $0<m<1$.

Replication and selection policy : Roulette method was common mechanism of genetic algorithm replication and selection. However, when there were high species diversity and big individual difference, the selected ratio (namely selected pressure) between the best and worst individual would also be amplified exponentially. The survival possibility of the best individuals in the next generation would increase significantly, while the worst were opposite. The offsprings would then be filled with the best quickly, causing quick decrease of group diversity.

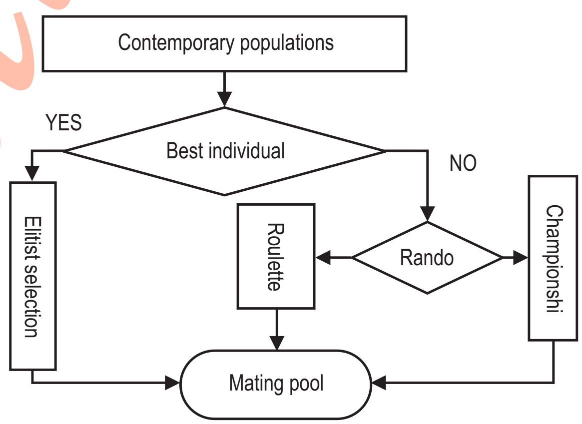

Fig. 2 : Hybrid selection operator process

Meanwhile, genetic algorithm would lose evolution capacity earlier. To avoid this situation, is the present study hybrid selection mechanism was used, which included Roulette, championship and elitist selection method.

The selection process of hybrid selection operator was to judge individuals in group in turn. If it was the best individual contemporarily, it would carry out elite selection; on the contrary, if it was not the best, it would carry out roulette and tournament hybrid selection. Process schematic diagram is shown in Fig. 2.

Crossover strategy : Cross operator included single-point crossover method, two-point crossover method and uniform crossover method and so on. Multi-point crossover was used mostly in practical application. Multi-point hybrid idea was done by selecting multiple cross point randomly, namely the hybrid position, of two given individuals to perform the crossover operation. Uniform hybridization method was based on same probability, taking uniform hybridization of each gene on chromosomes. Both hybrid methods had their advantages, so they were combined into mixed hybrid operator. The process of mixing hybrid operator was done in order to select individuals in two mating pools randomly, further, hybrid position and implemented uniform hybridization was selected. Process schematic diagram is shown in Fig.3:

Mutation strategy : Mutation operation was done in the auxiliary role of genetic algorithm, but its effect was significant. During the later period of genetic algorithm, the individual differences of

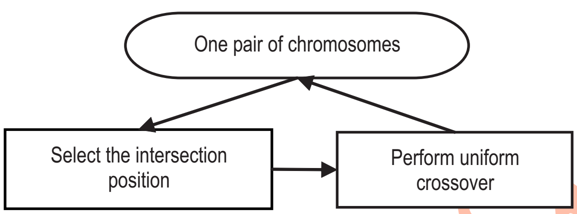

Fig. 3 : Hybrid crossover operator process

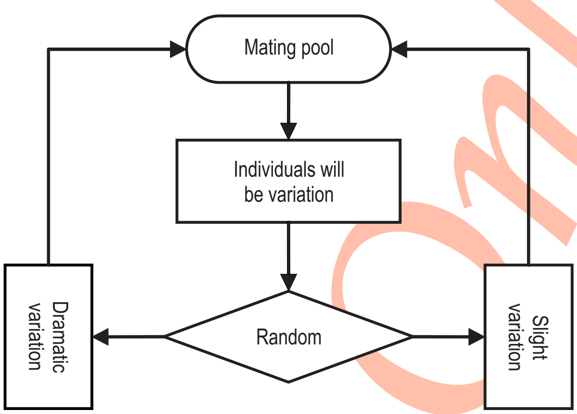

Fig. 4 : Mixed variation operation process

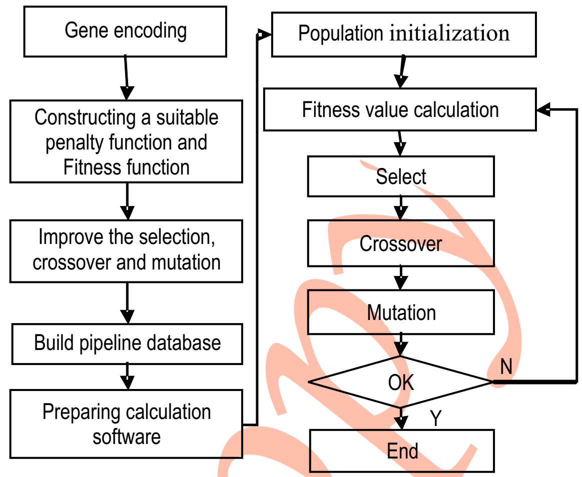

Fig. 5 : Steps to solve optimization model of crude oil pipeline

groups were small. So it needed mutation to maintain group diversity to avoid precocity. Because individual was close to minimum, it required mutation to improve the local search ability of genetic algorithm. Severe mutation method was selected from individual performing initialization to produce a new individual. Through these new individuals, the species would be enriched, thus maintaining the group diversity. In order to improve the local search ability of genetic algorithm, a slight variation way in algorithm was required. The process of mixing two variation ways and forming mixed mutation operator was based on mutation rates, choosing individuals in mating pool. Dramatic or light variation operation for selected individuals was performed randomly. The schematic diagram is shown in Fig. 4.

Crude oil pipeline optimization model: Improved genetic algorithm was used to solve crude oil pipeline optimization model, and the solving steps is shown in Fig. 5.

Results and Discussion

The length of pipeline was 324.3 km, and design capacity was 500×10^{4} Tyr^{-1}. In addition, design pressure was 8.0 MPa, and diameter was DN450. The elevation and mileage of S-L pipeline is shown in Fig.6.

Six stations in S-L pipeline, including four heat pump stations, one hot site is listed in Table 1. Oil parameters and viscosity-temperature relationship is given in Table 2 and Table 3. In addition, there were three types of pumps in S-L pipeline, including HD1, HD2 and HD3, and these operating point parameters of pumps are listed in Table 4. Finally, some constraint conditions was established in Table 5.

The pressure, flow, temperature parameters were taken in February 2012 were taken, for instance to perform optimization calculation (Table 6). The flow in February was 29.4710^{4}t, the lowest pitted pressure was 0.3MPa and lowest pitted temperature was 26ºC. The best operation scheme was determined by optimization calculation (Table 7). The first station opened 3 pumps, one of HD1 type and two of HD2 type. 2nd, 3rd and 4th station opened one main pump respectively. 1st, 3rd and 5th station opened furnace. Besides, energy consumption situation, using energy conversion, was obtained (Table 8). The production unit consumption of the scheme was 360.5 kgce.$(10^4 t{\cdot}km)^{-1}$, which was -6.69% lower than the actual operation scheme of energy consumption value. From the simulate results it was observed that the main energy consumption of S-L oil pipeline came from heat consumption.

On the other hand, same method was used to optimize the operational conditions from January to July, 2012 and optimized results were obtained (Table 9). It was found that the

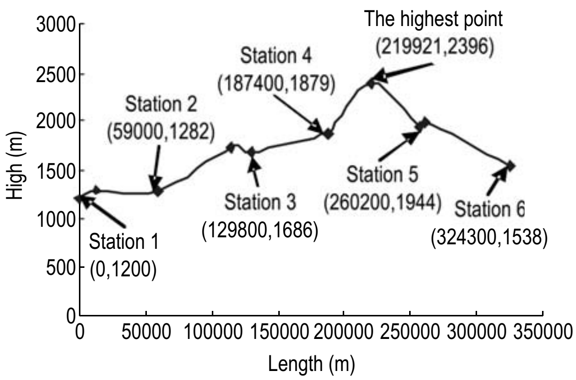

Fig. 6 : Elevation and mileage schematic of S-L pipeline

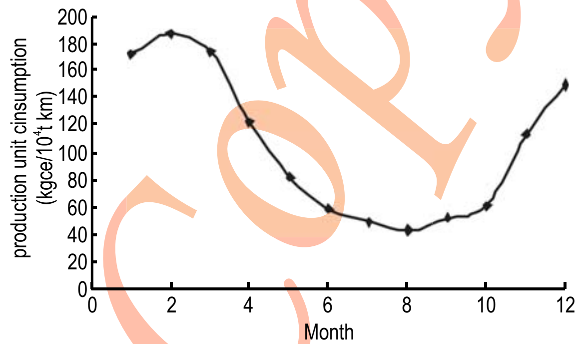

Fig. 7 : Production consumption trend with the seasons under the designed capacity

Table 1 : Employed at each station

Station name	Pump model	Number of pumps	Pump model	Number of pumps	Pump connections	Number of furnaces
Station 1	HD1	2	HD2	4	Series connection	4 x 5000kw
Station 2	HD2	2	HD3	2		3 x 4000kw
Station 3	HD2	4	-	-		3 x 4000kw
Station 4	HD2	2	HD3	2		3 x 5000kw
Station 5	-	-	-	-	-	2 x 5000kw
Station 6	-	-	-	-	-	-

Table 2 : Oil parameters

Relative density	Solidifying point (ºC)	Wax precipitation point (ºC)	Wax content (%)	Asphaltenes content (%)
0.8439	23	34.4	16.8	6.3

Table 3 : Viscosity-temperature parameters of crude oil

Temperature (ºC)	23	25	30	35	40	50	60	70	75
Dynamic viscosity (mPa·s)	107	50.4	17.7	10.4	8.56	6.89	5.77	4.49	4.12

Table 4 : Pump type and operating point parameters

Pump model	Ratings			Maximum flow ($m^3 hr^{-1}$)
	Rated flow Q ($m^3 hr^{-1}$)	Rated pressure head H (m)	Rated power N (kW)	
HD1	710	80	335	1089
HD2	710	200	453	1044
HD3	710	400	875	1000

flow of S-L pipeline was around 360~400 m tons yr^{-1} currently, which did not achieve the expected flow. Optimization operation scheme was used and it was found that produce unit dropped by 5%~9% as compared to actual measured value. It proved that pipeline had good savings potential.

Ground temperature at all seasons was different, and temperature drop along the pipeline was not same. To study the influence of seasons on pipeline operation energy consumption, energy consumption of crude oil pipeline at 500×10^{4}Tyr^{-1} was simulated and optimized . Optimal operation expenses of each

Table 5 : Constraint conditions

Station name	Maximum outbound pressure (MPa)	Minimum pitted pressure (MPa)	Maximum pitted pressure (MPa)	Minimum pitted temperature (ºC)	Maximum outbound temperature (ºC)
Station 1	8.0	0.3	7.8	26	65
Station 2	8.0	0.3	6	26	65
Station 3	8.0	0.3	6	26	65
Station 4	8.0	0.3	6	26	65
Station 5	8.0	0.3	8	26	65
Station 6	1.8	0.2	6	26	65

Table 6 : Input parameters

Time	2012-02	Transmission capacity	29.47x10^4
Pitted pressure at first station	0.3MPa	Pitted temperature at first station	24ºC
Minimum inlet temperature	26ºC	Maximum outbound temperature	65ºC

Table 7 : Optimal operation scheme

Station name	Pitted pressure (MPa)	Outbound pressure (MPa)	Pitted temperature (ºC)	Outbound temperature (ºC)	Configuration of the pumps
Station 1	0.3	4.56	24	55.53	HD1 type: 1 set HD2 type: 2 set
Station 2	2.97	6.64	-	-	HD3 type: 1 set
Station 3	2.32	4.16	26	50.09	HD2 type: 1 set
Station 4	1.69	5.37	-	-	HD3 type: 1 set
Station 5	3.76	3.76	26	42.87	-
Station 6	5.99	-	26	-	-

Table 8 : Energy consumption of optimal operation scheme

Turnover	9557.12 10^{4}t·km	Power consumption	301.24 10^{4}kW h
Fuel consumption	2152.78 t	Total energy consumption	3445.34 tce
Oil unit consumption	224.49 kgce.(10^{4}t·km)$^{-1}$	Power unit consumption	323.57 kW·h (10^{4}t·km)-1
Production unit consumption	360.5 kgce.(10^{4}t·km)$^{-1}$		

Table 9 : Energy consumption of S-L pipeline

Time	Unit consumption (kgce (10^{4}t·km)$^{-1}$)			Turnover (10^{4}t·km)	Power consumption (10^{4}kW·h)			Fuel consumption (t)		
	Optimal value	Measured value	Energy saving rate		Optimal value	Measured value	Deviation	Optimal value	Measured value	Deviation
2012-01	340.8	372.2	-8.44%	10255.1	311.21	351.87	-11.56%	2190.81	2369.46	-7.54%
2012-02	360.5	386.4	-6.69%	9510.7	301.24	312.84	-3.71%	2152.78	2303.11	-6.53%
2012-03	267.3	282.3	-5.32%	10113.3	320.00	305.50	4.75%	1623.74	1735.74	-6.45%
2012-04	258.6	276.8	-6.59%	9697.0	286.25	321.79	-11.04%	1511.07	1602.33	-5.70%
2012-05	196.5	207.5	-5.31%	10283.1	349.23	307.43	13.60%	1117.93	1228.83	-9.02%
2012-06	162.3	174	-6.74%	10792.8	366.05	341.48	7.20%	913.66	1020.87	-10.50%
2012-07	58.5	63.4	-7.70%	10490.5	351.47	308.34	13.99%	127.36	200.47	-36.47%

month is shown in Fig.7. Fig. 7 shows that, energy consumption in February was high in while August it was lowest. At the same time, it was found that consumption varied from spring to winter. With increasing ground temperature, the optimized fuel consumption dropped, and power consumption almost did not change. Meanwhile total energy consumption reduced significantly. The expression of power consumption showed that temperature change of soil had a great influence on the change of oil discharge temperature, and showed less influence on pump combination. Through optimization analysis of S-L crude oil pipeline and comparison to the actual working conditions, it found that the optimal operation scheme could reduce energy consumption by 5%~9%.

The method applied in the present study was is able to optimize combination of pumps, as well as combination of heaters, however, the method proposed by Gopal *et al*. (1980) was only suitable for optimization of pumps. Camacho *et al*. (1990), Jokic *et al*. (2001) and Xu *et al*. (2002) come up with a method aiming to lower the cost or power consumption , which was only available for evaluation of pipeline operation, while in the present study electricity and oil consumption of oil pipe were transformed to standard coal consumption and model was established based on its consumption of production. Consequently, this method was not only applicable for evaluation of pipeline operation, but also for comparison and analysis of different pipes, which were of great benefit for staffs to manage operation of pipeline, and find out the weakness of system. As for solution of model, the method applied by Meng *et al*. (2002), Xu *et al*. (2002), Song *et al*. (2007), Zuo *et al.* (2008) and Zhang *et al*. (2012) was only appropirate for pipeline with few pump stations and simple combination, while the method used in the present study was applicable for more pumps with complex combination, such as West Crude Oil pipe(1842 km, 13 pump stations). Meanwhile, the present study proposed a coding scheme of oil pipeline which can be applied for genetic algorithm successfully. It had intuitive, simple and adaptable characteristics. Therefore, it made encoding and decoding of algorithms more efficient and convenient. Besides, it made the results more intuitive and solution speed faster, which gave results within a minute.

According to the improved genetic algorithm, crude oil pipeline running optimization software was created. This software could converge fast and gave accurate results. So it could be used to guide the oil pipeline running programs analysis and optimization of energy saving.

Acknowledgments

This paper is a part project supported by the Special Fund of China's Central Government for Development of Local Colleges and Universities- the Project of National First-level Discipline in Oil and Gas Engineering, and the National Natural Science Foundation of China (No.51174172), and sub-project of National Science and Technology Major Project of China (No.2011ZX05054).

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