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Research paper

Research on optimization operation technology of QT oil pipeline based on the Heuristic algorithm

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ABSTRACT

Global environmental problems have become increasingly prominent, and China, as one of the world's major powers, should take action. China promises to achieve a "carbon peak" by 2030, and carbon dioxide emissions will no longer increase, and will gradually decrease after reaching the peak. To achieve "carbon neutrality" by 2060, all the carbon dioxide emissions will be offset by tree planting, energy saving and emission reduction. The optimization of pipeline energy consumption is also associated with it. In recent years, the transportation mode of the QT oil pipeline has changed from normal temperature transportation to heating transportation. The energy consumption of this transportation method mainly comes from heating furnaces and pumps. In order to reduce energy consumption and find a suitable pipeline operation plan, this article optimizes and analyzes the transformed QT oil pipeline under the premise of ensuring safe production. Based on programming software, this article establishes a corresponding mathematical model of energy consumption of the QT oil pipeline, and uses artificial bee colony algorithm, invasive weed algorithm and optimization algorithm based on biogeography to solve the model. The article innovatively introduces the speed of the variable frequency pump as a variable to study the energy consumption optimization problem of the oil pipeline, analyze the practical application of the oil pipeline of the QT oil pipeline, and obtains the best plan for the optimized operation of the oil pipeline of the QT oil pipeline It provided research basis and played a role in promoting the country's dual-carbon goals.

1. Introduction

In recent years, China is seeking a more sustainable, inclusive and resilient economic growth mode. The carbon peak and carbon neutral goal vision requires China to establish a sound economic system for green and low-carbon circular development, and establish a clean, low-carbon, efficient, and A safe and modern energy production and consumption system (Weitzman, 1974; Miyata et al., 2018; Allan et al., 2014). To achieve the dual-carbon goal, all industries must take actions. For the petroleum industry, long-distance transmission pipelines account for a large proportion of crude oil transportation (Liu et al., 2019a). Therefore, it is essential to ensure the smooth operation of the pipeline. Among them, the smooth operation of the pipeline includes the optimization of pipeline energy consumption. When the pipeline energy consumption optimization research is carried out, the research content mainly includes: the optimal production operation plan, the main energy consumption of the equipment, the establishment of a mathematical model and the determination of the most suitable solution Method to achieve the purpose of optimizing pipeline energy consumption (Jefeerson and Yong, 1961; Wang et al., 2019). Optimizing pipeline energy consumption not only ensures the smooth operation of pipelines, but also greatly helps my country's economic development.

Taking my country's QT oil pipeline as a column, with the development of time, the output of DQ Oilfield has gradually decreased. The QT oil pipeline has changed from transporting Russian crude oil to QJ oil, and the hydraulic and thermal characteristics of the pipeline have also changed. QT oil pipeline transportation Crude oil is highly viscous and condensable crude oil. In the process of heating and transporting, pumps and heating furnaces are the main energy-consuming equipment. These transmission equipments mainly consumes electricity and fuel, especially pipelines with long transmission distances and low transmission volume. The self-consumption fuels consumption of heating alone accounts for 1% to 3% of the transmission volume, or even higher (Cheng et al., 2017). This paper establishes an optimization model for QT oil pipeline and uses intelligent algorithms to solve it.

There are many studies on reducing the energy consumption of oil pipelines. In recent years, many pipeline systems

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have introduced new materials or improved equipment to reduce pipeline energy consumption. If there is the use of drag reducers to increase the oil output and improve the efficiency (Guan et al., 2008), if there is the use of variable frequency speed regulation, in 2015, Hoevenaars et al. used harmonics to adjust the variable speed drive to make the generator more operability and transformational., Achieved the purpose of saving energy and fuel (Hoevenaars et al., 2015). In 2018, Liu et al. used variable frequency speed regulation technology to reduce the load of the centrifugal pump by 20%–50% through speed regulation, effectively match the output power of the motor and the pipeline flow, and reduce energy consumption (Liu et al., 2018). There are also temperature adjustments. In 2010, Wang et al. used a circulating water mixing process simulation tested machine to cool the circulating water and save energy, providing new technologies and reliable methods for pipeline energy saving (Wang et al., 2010). In 2016, Jia et al. used the vacuum furnace dilution effected and uniform temperature disturbance to increase the water flow velocity in the heat exchange tube, which effectively extended the fouling time and maintenance cycled of the boiler pipe (Chao et al., 2016). In 2017, He et al. propose to replace traditional heaters with high-temperature heat pumps, and replace traditional heating furnaces with high-temperature hot water to heat crude oil, reducing energy consumption (He et al., 2017).

Like the above-mentioned program conclusions, scholars have achieved the effect of pipeline energy saving by improving the performance of the equipment to extend or improve the operation capacity of the equipment. With the rapid development of computer science, many scholars apply intelligent algorithms to solve the problem of the pipeline. Optimal operation plans. The optimal operation plan generally aims at the lowest energy consumption or the least cost. With the in-depth research and the expansion of the pipeline system, more and more problems appear in the pipeline optimization. These problems promote the improvement of the algorithm. Using traditional optimization algorithms may not be conducive to finding the global optimal solution (Ríos-Mercado and Borraz-Sánchez, 2015). Therefore, some scholars have begun to use intelligent optimization algorithms to optimize pipelines, which can achieve better results in calculations. Among them, genetic algorithm, simulated annealing algorithm, and particle swarm algorithm are used more in pipeline optimization (see Table 1).

According to the above description, there are many researches on the energy consumption of oil pipelines, which are mainly reflected in two aspects: first, using new equipment and materials to replace old equipment and old materials to reduce the energy consumption of pipelines, Second, to find the optimal pipeline operation optimization schemes to reduce pipeline energy consumption. However, most scholars only study the operation scheme of the oil pipeline unilaterally or propose the alternative new equipment, and seldom combine the two aspects. On this basis, this paper takes the minimum production energy consumption as the objective function. Aiming at the characteristics of variable frequency pump in QT oil pipeline, the key operating parameter of variable frequency pump, the output temperature and the combination mode of pump, etc. be set as optimization variables at the same time. Taking the inlet and outlet pressures of the pumping station, the inlet and outlet temperature of the heating station, the hydraulic and thermal conditions of the whole pipeline, the heat load of the heating furnace equipped by the heating station, and the relevant parameters of the pump equipped by the pumping station as the constraint conditions of the optimization model, the mathematic model for the operation optimization of the crude oil pipeline in QT oil pipeline was established. According to the characteristics of the established model, choose the artificial colony algorithm and invasive weeds algorithm and biogeography of the three different heuristic search algorithm to the programming model, through comparing the advantages and disadvantages of three kinds of algorithm, it is recommended to using invasive weeds algorithm, to the study of pipeline energy consumption optimization has a certain guiding role.

The structure of this paper is arranged as follows: In the second part, the paper establishes the corresponding pipeline model with the minimum energy consumption as the objective function, including thermodynamic calculation, hydraulic calculation, energy consumption calculation and other detailed calculations. In the third part, the artificial bee colony algorithm, invasive weed algorithm and biogeography algorithm are used to analyze the optimization of temperature, pressure and energy consumption of QT oil pipeline respectively, and the relevant conclusions are given in the end.

2. Model and methods

In this part, the establishment of pipeline optimization model, and the limitation conditions and calculation of relevant parameters are introduced in detail. These calculations are based on the premise that the piping system has been reduced to usable abstract mathematical expressions in this paper.

2.1. Establishment of optimization model

2.1.1. The objective function

In order to prevent the crude oil from solidifying and blocking the pipeline, a heating furnace is needed to heat the crude oil during the transportation process. Therefore, the energy consumption of the crude oil pipeline is mainly concentrated in power and thermal energy consumption. This paper takes the minimum energy consumption of crude oil pipeline as the objective function, as shown in Eq. (1).

$$\min E = \min(\sum_{i=1}^{p} N_p(P_i, t_i, \omega_1) + \sum_{i=1}^{h} N_h(B_i, t_i, \omega_2)) \tag{1}$$

Where, E – total energy consumption of pipeline operation, kgce,
N_p – Pipeline operation consumes electricity, kgce;
p – Pump station number;
P_i – The total power of the pump station at station I, KW;
ω_1 – Standard Coal Coefficient of electrical conversion, 0.1229 kgce/(kW h);
N_h – Fuel consumption of pipeline operation, kgce,
B_i – Fuel consumption for the first heating station, kg/s;
h – Number of heating stations;
t_i – Operation Time of the first station yard, s;
ω_2 – Standard Coal Coefficient of oil conversion, 1428.6 kgce/t.

2.1.2. Optimization variable

The energy consumption of the pipe is mainly the energy consumption of the pump and the furnace, so the operation state of the pump and the furnace directly determines the total energy consumption, therefore, the number of start-up pump, pump speed and heating station as the optimal temperature variables, as shown in formula

$$X = (C_{pi}, rs_i, T_{outi}) \tag{2}$$

where, C_{pi} – Number of pump stations I switched on;
rs_i – Speed of pumping station I, l/min;
T_{outi} – Exit temperature of the first heating station, °C.

Table 1
Research on using intelligent algorithms in recent years.

	Algorithm name	Result and conclusions	Reference
Energy consumption optimization related to GA algorithm	GA	The proposed optimal scheme can reduce the energy consumption of the simulated pipeline by 5%–9%.	Liu et al. (2015)
	GA, PSO and SA	The method reduces the production energy consumption of related pipelines by 33.77%.	Liu et al. (2019b)
	GA-BPNN	The GA-BPNN model is applicable to the apparent viscosity prediction of various crude oils.	Zhang et al. (2019)
	GA and MILP	This work is helpful to develop a tool for the effective utilization of pipeline network.	Ribas et al. (2013)
	GA and ACO	The buffer and sensing percentages in GA are higher than those in ACO.	Elnaggar et al. (2015)
	GA and SA	Optimization models for phased development of old oilfields are proposed.	Liu et al. (2019c)
	GA and support vector machine	GA-SVM hybrid model has the best effect in improving the predictive accuracy.	Xu et al. (2021)
Energy consumption optimization related to PSO algorithm	IPSO-RBFNN	This method has higher recognition accuracy for pipelines.	Zhang and Yu (2018)
	PSO and differential evolution algorithm	The data error of pipeline operation and energy cost are reduced.	Zhou et al. (2015)
	MC-GPSO, MC-LPSO, MC-FIPSO and MC-SLPSO	It shows that MC-SLPSO is more suitable for solving subsea pipeline optimization problems.	Zhang et al. (2017)
Energy consumption optimization related to ACO algorithm	ACO	It shows that the ACO is an interesting way for the gas pipeline operation optimization.	Chebouba et al. (2009)
	ACO	A self-learning algorithm is proposed for detailed optimal scheduling for product oil pipeline.	Zhang et al. (2018)
The energy consumption optimization derived from the intelligent algorithm is not generally used	TSA	The proposed optimization scheme greatly reduces the energy consumption of subsea pipelines.	Peng et al. (2019)
	A heuristic algorithm	The method greatly reduces the optimization time and the calculation is accurate.	Liu et al. (2019d)
	Improved Machine Learning Algorithms	The algorithm is very suitable for the optimization of natural gas supply system.	Qiao et al. (2021)
	BPNN, RBFNN and GRNN	Reduction of related simulated pipeline energy consumption by 10.75%	Zhang et al. (2020)
	FPA	IFPA-BP can accurately identify the pipelines defects and facilitate intelligent diagnosis of natural gas pipelines defects.	Liang et al. (2020)
	NFOA	The results show that the optimization speed and prediction accuracy of NFOA-SVR in LCY-Others set and LW-total set are significantly better than the other two algorithms.	Gang et al. (2021)

2.1.3. Constraint condition

In order to ensure the safety of the pipeline operation, we set the corresponding constraint conditions according to the actual operation of the crude oil pipeline to make the model more in line with the actual operation state.

a. Inbound pressure constraint

$$H_{ini} > H_{ini\_\min} \tag{3}$$

where, H_{ini} – Inlet head of pumping station I, m;
$H_{ini\_\min}$ – Minimum allowable inlet head of pumping station I, m.

b. Outbound pressure constraint

$$H_{d\max} > H_{outi} \tag{4}$$

where, H_{outi} – Outbound head of pumping station I, m;
$H_{d\max}$ – Maximum working head of pipe, m.

c. Full Line hydraulic restraint

$$H_i \geq h_i + h_{mi} + h_{rp} + \Delta Z_i \tag{5}$$

where, h_i – Frictional resistance between pumping stations, m;
h_{mi} – Local friction between pumping stations, m;
h_{rp} – Friction in the heating station when the pumping station passes through the heating station, m;

ΔZ_i – Difference in elevation between the starting and ending points, m.

d. Outbound temperature constraint

$$[T_{out\_\min}] \le T_{outi} \le [T_{out\_\max}] \tag{6}$$

where, $[T_{out\_\max}]$ – Maximum outbound temperature of the first heat station, °C;

$[T_{out\_\min}]$ – Minimum outbound temperature for the first heat station, °C.

e. Inbound temperature constraint

$$T_{ini} \ge [T_{in\_\min}] \tag{7}$$

where, T_{ini} – Inbound temperature of heating station no. I, °C;

$[T_{in\_\min}]$ – Minimum inbound temperature of the I heat station, °C.

f. Thermal load restraint of heating furnace

$$Q_{r\min} \le Q_{ri} \le Q_{r\max} \tag{8}$$

where, $Q_{r\min}$ – Minimum heat load of heating furnace, kJ/kg;

Q_{ri} – Heating furnace heat load of the first heat station, kJ/kg;

$Q_{r\max}$ – Rated heat load of heating furnace (maximum heat load), kJ/kg.

g. Pump power constraint

$$P_{\min} \le P_i \le P_{\max} \tag{9}$$

where, $P_{\min}$ – Minimum allowable pump power, kw;

P_i – The power of the first pumping station, kw;

$P_{\max}$ – Maximum allowable pump power, kw.

h. Pump speed constraint

$$rs_{\min} \le rs_i \le rs_{\max} \tag{10}$$

where, $rs_{\min}$ – Minimum allowable speed of pump, l/min;

rs_i – Speed of frequency conversion pump in the first pumping station, l/min;

$rs_{\max}$ – Maximum allowable speed of pump, l/min.

2.2. Thermal calculation and hydraulic calculation

2.2.1. Thermodynamic calculation

Because the crude oil pipeline system in this paper is long, that is, when the crude oil flows in the pipeline, it will have friction with the pipe wall, which will reduce the pressure along the pipeline, this part of the reduced pressure will eventually be converted into friction heat heating crude oil. So, this model takes into account Sukhov's formula for the heat of friction, which is calculated as follows:

$$T_L = (T_0 + b) + [T_R - (T_0 + b)]e^{-al} \tag{11}$$

$$a = \frac{K\pi D}{Gc} \qquad b = \frac{Ggi}{K\pi D}$$

where: T_L – L meters from the start of the pipe, °C;

T_0 – Environmental ground temperature of buried pipeline, °C;

T_R – The oil temperature at the beginning of the pipeline, °C;

G – Mass flow in pipe, kg/s;

c – Specific heat capacity of oil at average temperature, J/kg °C;

K – Total heat transfer Coefficient of pipeline;

i – Hydraulic gradient of pipeline;

g – gravitational acceleration.

2.2.2. Hydraulic calculation

In this paper, Bars formula is used to calculate the friction Coefficient, Reno number Re, relative roughness of pipe and pipe diameter d are taken into Bars formula to solve iteratively, and the friction coefficient is calculated.

$$\frac{1}{\sqrt{\lambda}} = -21g\left(\frac{\Delta}{3.7d} + \frac{5.1286}{Re^{0.89}}\right) \tag{12}$$

where: λ – Coefficient of friction,

g – gravitational acceleration;

Re – Reno number

Δ – Equivalent roughness of industrial piping, mm

When the friction coefficient is calculated, the following formula can be used to calculate the friction loss along the way.

$$h_f = \lambda \frac{L}{d}\frac{V^2}{2g} \tag{13}$$

where: h_f – Friction loss along the way, m;

L – Length of pipe, m;

d – Inside diameter of pipe, m;

V – The velocity of the fluid in the pipe, m/s;

g – gravitational acceleration;

λ – Coefficient of friction.

2.2.3. Calculation of pump energy consumption

In the pipeline system of QT oil pipeline, the power consumption of station pump N_p can be expressed as:

$$N_p = \frac{GHgt_p}{1000\eta_p\eta_e} \times \omega_1 \tag{14}$$

where, G – Mass flow rate of crude oil transported in pipe, kg/s;

ω_1 – Standard Coal Coefficient of electrical conversion, 0.1229 kgce/(kW h);

H – Head provided by pumping station, m;

g – Gravitational acceleration, 9.8 m/s^2;

t_p – Operation Time of pumping station, h;

η_p, η_e – Mechanical efficiency and motor efficiency of pumping stations.

2.2.4. Calculation of energy consumption of heating furnace

In the pipeline system of QT oil pipeline, the fuel consumption is related to the heating furnace heat load, the fuel heat value and the heating furnace heat efficiency

$$N_h = \frac{Gc(T_{out} - T_{in})t_h}{q\eta_h} \times \omega_2 \tag{15}$$

where, G – Mass flow rate of crude oil transported in pipe, kg/s;

ω_2 – Standard Coal Coefficient of oil conversion, 1428.6 kgce/t;

c – Specific heat capacity of the medium being heated, kJ/(kg °C);

T_{in}, T_{out} – Inlet and outlet temperature of heating station, °C;

t_h – Time of operation of heating station, h;

η_h – Heating efficiency of heating station;

q – Low calorific value of fuel, kJ/kg.

2.3. Optimization algorithm

This paper is based on Matlab software programming, using artificial bee colony algorithm (ABC), Invasive Weed Algorithm (IWO), biogeography optimization Algorithm (BBO) to solve the model.

2.3.1. Artificial swarm algorithm

Artificial bee colony algorithm has a strong global search ability, but its convergence speed is slow and the accuracy is not high. This shortcoming is more obvious in dealing with variable-related problems (Gao et al., 2013; Karaboga, 2005; Wang et al., 2020). But based on the optimization model of the crude oil pipeline, according to the characteristics of the artificial bee colony algorithm, the optimization variables are coded to form the fitness function of the artificial bee colony algorithm. During the evolution process, the population size is 100 and the maximum number of iterations is 200. The calculation process is shown in Fig. 1.

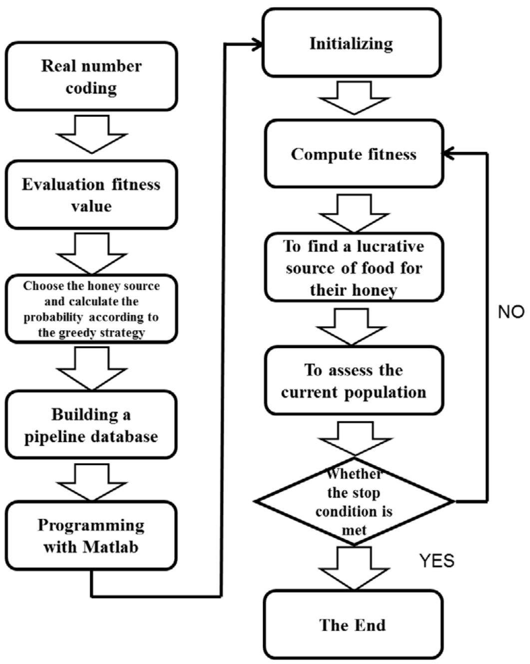

Fig. 1. ABC algorithm flow.

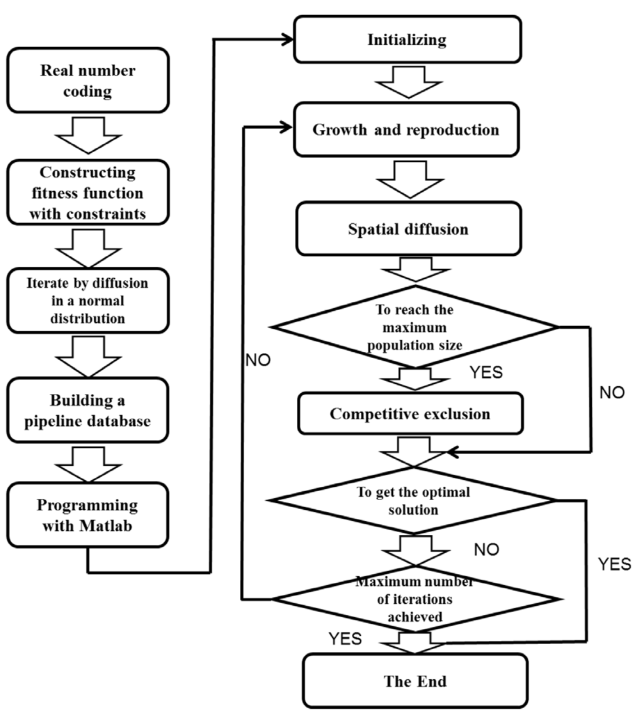

Fig. 2. IWO algorithm flowchart.

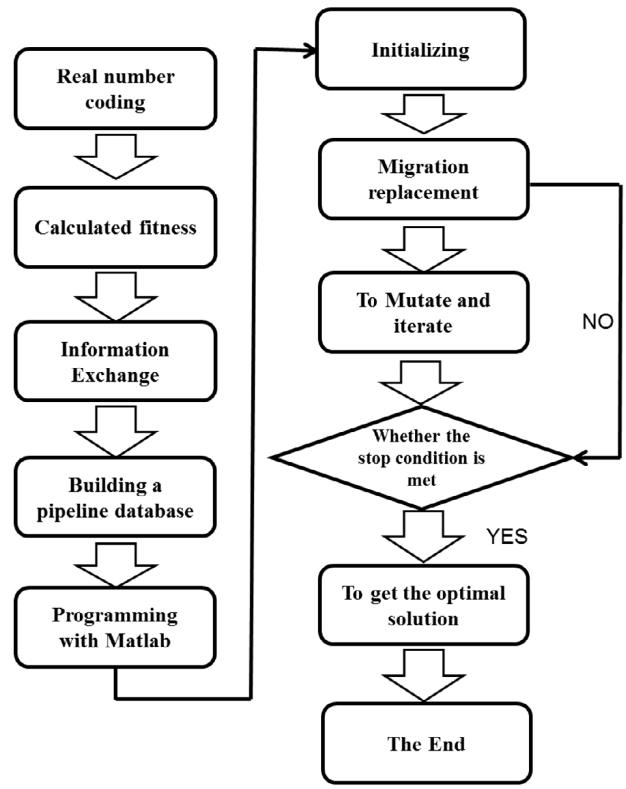

Fig. 3. Flow chart of biogeography based optimization algorithm.

2.3.2. Invasive weed algorithm

Invasive weed optimization algorithm is a random search algorithm that simulates the process of weed colonization in nature. It was proposed by ARMehrabian and C. Lucas in 2006. It has the characteristics of simple structure, few parameters, easy to understand and easy to program. It is a simple Effective swarm intelligence optimization algorithm (Mehrabian and Lucas, 2006; Giri et al., 2010). Compared with particle swarm algorithm, weed algorithm only needs smaller storage space when memorizing the trajectory of particles (Nguyen et al., 2020; Zhao et al., 2020; Mohammadi and Khodaygan, 2020), compared with genetic algorithm and other evolutionary algorithms, the algorithm programming is easy to implement, and it is easy to realize without genetic algorithm. In the case of operating operators, it can easily and effectively converge to the optimal solution of the problem. It is a very powerful intelligent optimization tool. Based on the optimization model of the crude oil pipeline, the optimization variables are coded according to the characteristics of the intrusive weed algorithm., Forming the fitness function of the invasive weed algorithm. During the evolution process, the initial population size is 10, the final population size is 25, and the maximum number of iterations is 200. The calculation process is shown in Fig. 2.

2.3.3. Optimal algorithm of biogeography

Biogeographic optimization is a novel natural heuristic optimization algorithm. It was first proposed by American scholar Dan Simon in 2008. It was originally applied to solve the problem of aero-engine optimization designs. Later, due to its unique search mechanism and better optimization performance, it has received extensive attention from domestic and foreign researchers (Tu et al., 2020; Albashish et al., 2020). The BBO algorithm is inspired by the population migration model in biogeography (Xiao et al., 2021). Based on the optimization model of the crude oil pipeline, according to the characteristics of the optimization algorithm of biogeography, the optimization variables are coded to form the fitness function of the optimization algorithm of biogeography. During the evolution process, the initial population size is 50 and the maximum number of iterations is 1000. The calculation process is shown in Fig. 3.

Table 2
Relevant parameters for each station of QT oil pipeline.

Yard number	Number of pumps for oil transportation	Rated load of heating furnace (kW)	Motor power (kW)	Number of variable frequency pumps
①	3	5000	2000	1
②	/	4650	/	/
③	3	5000	2300	1
④	3	4650	2300	0
⑤	3	4650	2300	1
⑥	3	4650	2300	1
⑦	3	4650	2000	1
⑧	0	4650	/	/
⑨	0	5000	/	/

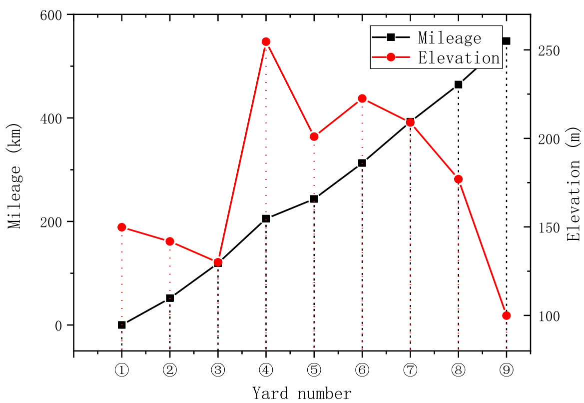

Fig. 4. Distribution map of stations on QT oil pipeline.

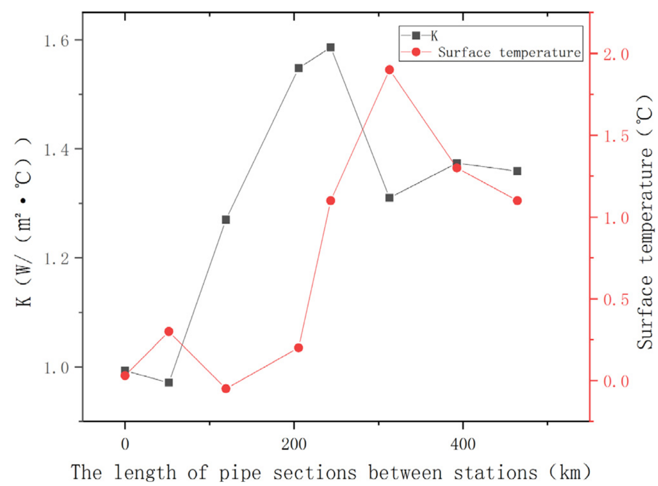

Fig. 5. Coefficient of heat transfers K and ground temperature between stations.

3. Results and discussion

3.1. Summary of crude oil pipeline in QT oil pipeline

3.1.1. Brief introduction of mileage distribution of QT oil pipeline

QT oil pipeline main line designs pressure 6.3 MPA, pipe diameter D711, the entire line length 548.5 km, the entire line adopts the heating airtight transportation technology, 1650104t/a from 1 to 3 stations, 2000104t/a from 3 to 6 stations, 1500104t/a from 6 to 9 stations. There are nine stations on the entire QT oil pipeline (Liu et al., 2020) (see Fig. 4).

3.1.2. Pump parameter

The pipeline of QT oil pipeline is closed transportation, the pumps of each pumping station are connected in series, and the pump parameters of each station are shown in Table 2.

The Way to realize frequency conversion in pump station of QT oil pipeline is to install frequency converter on the original centrifugal pump, so the characteristic equation of the constant speed pump can be expressed as the simplified characteristic equation of the variable speed pump with a certain speed. In order to make the calculation of the variable speed pump more convenient, the speed as a variable least squares curve fitting, get the variable speed pump pressures head curve equation.

$$H = AQ^2 + BQ + CQrs + Drs^2 + Ers + F \tag{16}$$

where: H – PUMP head, m;
Q – Pump flow, m3/h;
rs – Speed of oil pump, l/min;

The Coefficient of fitting equation of flow head relation, the corresponding data of each station are shown in Table 3.

Using the speed as a variable in the power curve equation, the least squares curve equation for the variable speed pump is:

$$P = aQ^2 + bQ + cQrs + drs^2 + ers + f \tag{17}$$

where: P – Pump power, kw;
Q – Pump flow, m^3/h;
rs – Speed of oil pump, l/min;
a, b, c, d, e, f – The Coefficient of fitting equation of flow-power relation, the corresponding data of each station are shown in Table 4.

3.1.3. Actual operating condition

The operating conditions of QT oil pipeline are given in this paper, as shown in Table 5.

The heat transfer Coefficient K and ground temperature between stations are shown in Fig. 5

3.2. Optimized result

3.2.1. Optimization results of artificial bee colony algorithm

The optimization schemes solved by artificial bee colony algorithm are shown in Table 6,

From the calculation and analysis, it can be seen that the speed of the station pump of different centrifugal pump stations is changed without changing the number of pumps on, and the results calculated by artificial bee colony algorithm are as follows: The temperature of the whole line is reduced after optimization, The pressure distribution of the whole line is optimized, and the final total energy consumption is reasonable.

3.2.2. Optimized results of invasive weed algorithm

The optimal solution of the invasive weed algorithm is shown in Table 7.

From the calculation and analysis, it can be seen that the pump speed of the station yard of different centrifugal pump

Table 3
Fitting coefficient of pressure head at each station.

Yard number	*A*	*B*	*C*	*D*	*E*	*F*
①+⑦	-5.961×10^{-5}	0.001575	7.935×10^{-6}	7.122×10^{-4}	−0.1892	213.9
③+⑤	-4.98×10^{-5}	0.006203	9.808×10^{-6}	7.578×10^{-4}	−0.2058	233.9
④+⑥	-2.152×10^{-5}	0.01381	6.503×10^{-5}	1.072×10^{-3}	−0.1978	229.3

Table 4
Pump power fitting coefficient of each station.

Yard number	*a*	*b*	*c*	*d*	*e*	*f*
①+⑦	-5.684×10^{-4}	−0.2646	0.0002787	0.0005761	−2.325	2536
③+⑤	-5.446×10^{-4}	−0.2959	0.0002922	0.000595	−2.4	2624
④+⑥	-2.152×10^{-4}	−0.1218	0.00006503	0.001072	−4.07	4140

Table 5
Actual operation plan of QT oil pipeline.

Yard number	Number of pump stations	Rotational speed (r/min)	Warming up (°C)	EXOTHER-MIC (°C)	Feed pressure (MPa)	Out Pressure (MPa)	Flow rate (kg/s)
①	3	/	43.78	46.52	0.46	5.63	478.73
②	/	/	39.87	45.78	4.13	3.91	574.73
③	2	2956	38.79	42 .01	1.23	5.17	478.51
④	2		36.64	41.42	1.56	4.25	640.60
⑤	2	2441	37.09	40.54	1.75	5.51	417.90
⑥	2	2375	36.40	43.41	1.29	5.15	501.46
⑦	2	2987	35.73	44.07	2.22	5.59	510.20
⑧	/	/	36.42	42.16	2.94	2.80	481.69
⑨	/	/	35.86	/	0.36	/	/

Total monthly energy consumption : 6124567.26 kgce, Electric Energy consumption : 2001131.13 kgce, Heat dissipation energy : 4123436.13 kgce.

Table 6
Schemes obtained by artificial bee colony algorithm.

Yard number	Number of pump stations	Rotational speed (r/min)	Warming up (°C)	EXOTHER-MIC (°C)	Feed pressure (MPa)	Out Pressure (MPa)	Flow rate (kg/s)
①	3	/	43.78	44.70	0.46	5.66	478.73
②	/	/	38.87	40.27	4.35	4.20	574.73
③	2	2207	36.02	40.51	2.01	5.19	478.51
④	2	/	35.73	41.72	1.53	4.35	640.60
⑤	2	2162	36.00	42.38	2.02	5.77	417.90
⑥	2	2947	36.13	42.75	1.07	5.02	501.46
⑦	2	2644	35.20	42.21	2.01	5.33	510.20
⑧	/	/	35.63	41.21	2.74	2.68	481.69
⑨	/	/	35.49	/	0.28	/	/

Total monthly energy consumption : 5680548.6 kgce, Electric Energy consumption : 1869256.59 kgce, Heat dissipation energy : 3811292.02 kgce

Table 7
The optimal solution of the invasive weed algorithm.

Yard number	Number of pump stations	Rotational speed (r/min)	Warming up (°C)	EXOTHER-MIC (°C)	Feed pressure (MPa)	Out Pressure (MPa)	Flow rate (kg/s)
①	3	/	43.78	44.91	0.45	5.66	478.73
②	/	/	38.87	44.26	4.53	4.50	574.73
③	2	2329	36.02	48.67	2.13	5.26	478.51
④	2	/	35.73	42.58	1.49	4.52	640.60
⑤	2	2411	36.00	49.32	2.15	5.68	417.90
⑥	2	2574	36.13	49.50	1.08	4.95	501.46
⑦	2	2348	35.20	42.72	1.93	5.05	510.20
⑧	/	/	35.63	41.21	2.91	2.81	481.69
⑨	/	/	35.49	/	0.33	/	/

Total monthly energy consumption : 5614802.80 kgce, Electric Energy consumption : 1820829.22 kgce, Heat dissipation energy : 3793973.30 kgce

Table 8
Biogeography based optimization algorithms.

Yard number	Number of pump stations	Rotational speed (r/min)	Warming up (°C)	EXOTHER-MIC (°C)	Feed pressure (MPa)	Out Pressure (MPa)	Flow rate (kg/s)
①	3	/	43.78	43.87	0.45	5.66	478.73
②	/	/	38.55	41.84	4.53	4.50	574.73
③	2	2147	37.01	41.09	2.08	5.26	478.51
④	2	/	36.46	42.00	2.16	5.75	640.60
⑤	2	2042	36.50	43.38	2.82	5.68	417.90
⑥	2	2747	36.62	42.61	1.14	5.40	501.46
⑦	2	2499	35.38	43.46	2.42	5.05	510.20
⑧	/	/	36.96	41.21	3.01	3.00	481.69
⑨	/	/	35.00	/	0.48	/	/

Total monthly energy consumption : 5744121.88 kgce, Electric Energy consumption : 1853247.53 kgce, Heat dissipation energy : 3890874.33 kgce.

stations is changed without changing the number of pumps on, and the results calculated by using the invasive weed algorithm are as follows: the temperature of the whole line is reduced after optimization, The pressure distribution of the whole line is optimized, and the final total energy consumption is reasonable.

3.2.3. Biogeographic optimization

The biogeography optimization algorithm solves the optimization problem as shown in Table 8

From the calculation and analysis, it can be seen that: by changing the station pump speed of different centrifugal pump stations without changing the opening quantity of the pump, The results obtained by using the biogeography algorithm are as follows: The temperature of the whole line is reduced after optimization, the pressure distribution of the whole line is optimized, and the final total energy consumption is reasonable.

Finally, the comparison and analysis of the results of the three algorithms used in the operation plan is shown in Fig. 6. Compared with the unoptimized before, the temperature of the entry and exit of the station has been reduced, resulting in a reduction in heat energy consumption, and the pressure distribution has become more reasonable, thereby optimizing power consumption.

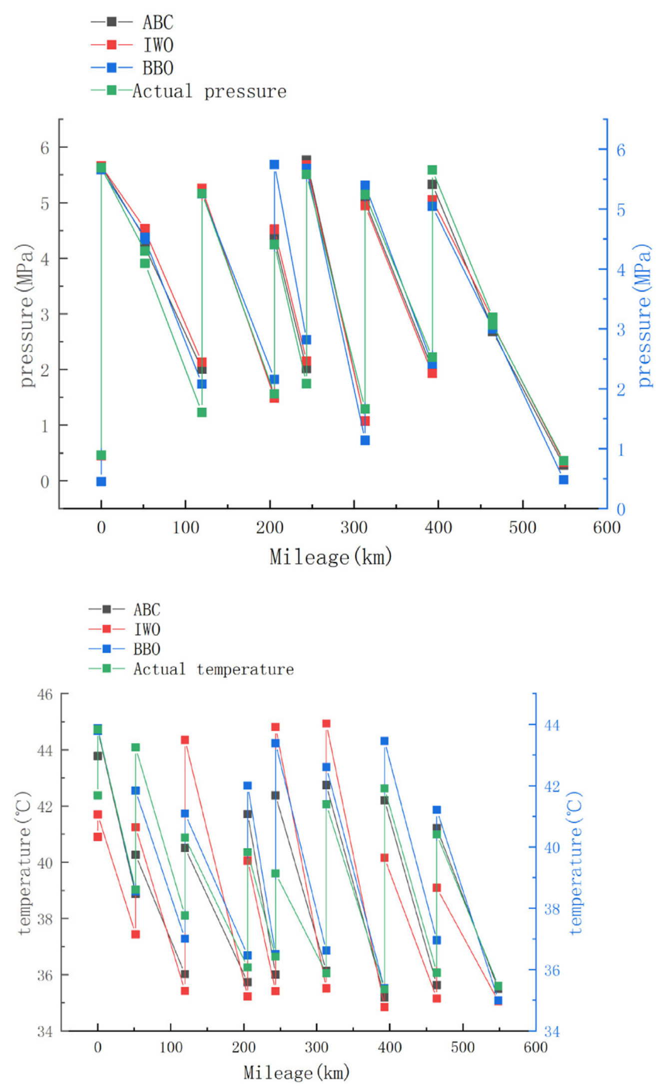

Fig. 6. Graph of pressure drop and temperature drop of practical scheme and ABC, IWO, BBO optimization algorithm.

3.3. Energy consumption analysis

Each algorithm in the optimization of energy consumption and the actual situation of energy consumption is not optimized as shown in Fig. 7.

It is not difficult to see from the comparison chart that the results obtained after the optimization of the three algorithms are more or less lower than the actual scheme.

Compared with the actual scheme, the total energy consumption of the scheme obtained by the artificial bee colony algorithm optimization is reduced by 7.25%, the total energy consumption of the scheme obtained by the invasive weed algorithm optimization is reduced by 8.32%, optimization based on biogeography The total energy consumption of the solution obtained by the algorithm optimization is reduced by 6.21%. From the calculation results after optimization, the optimization effect of the scheme obtained by the invasive weed algorithm is better than the other two schemes.

In order to pursue the diversity of optimization, it is compared with three other classic intelligent algorithms (Liu et al., 2020). Compared with the actual solution, the total energy consumption of the solution obtained by the genetic algorithm optimization is reduced by 7.57%, the optimization obtained by the particle swarm optimization algorithm is reduced by 7.57%. The total energy consumption of the scheme was reduced by 7.84%, the total energy consumption of the scheme obtained by the simulated annealing algorithm optimization was reduced by 6.01%. From the optimization results, among the optimization schemes solved by the particle swarm algorithm, the production energy consumption is the lowest, which is the optimal scheme.

These algorithms as a whole have their own advantages. The two algorithms of the optimal scheme, namely IWO and particle swarm optimization, are compared. The IWO algorithm takes into account the diversity of the group and the strength of selection.

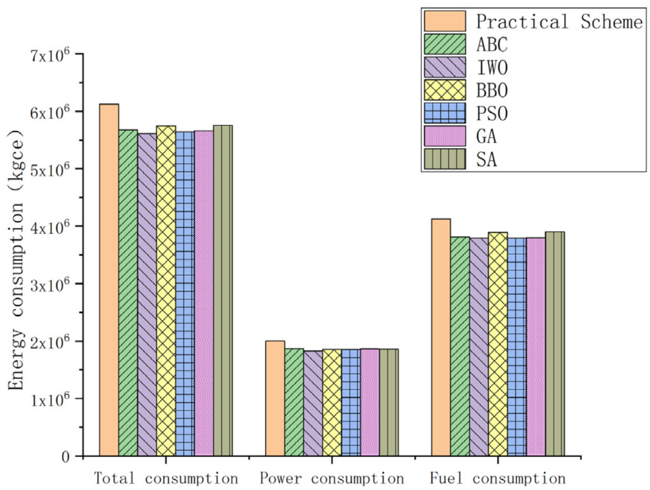

Fig. 7. Comparison chart of energy consumption calculated by each algorithm.

Compared with the ABC algorithm and the BBO algorithm, it has a larger search space and better performance. In addition, compared with the commonly used GA, the IWO algorithm is simple, easy to implement, does not require genetic operators, and can simply and effectively converge to the optimal solution of the problem. The particle swarm algorithm has fast search speed and simple structure, but it lacks dynamic adjustment of speed., It is easy to fall into the local optimum, resulting in low convergence accuracy and difficulty in convergence. When solving the optimal solution, we reasonably compare the requirements and flexibly use different algorithms to solve our own calculation results.

4. Conclusions

In this paper, based on the existing literature, a practical optimization model of crude oil pipeline is established, the model was solved using three different algorithms, namely artificial bee colony algorithm, invasive weed algorithm and biogeography based optimization algorithm, and was programmed using Matlab software as an auxiliary tool, finally, the practical schemes of two typical months are optimized, and the results of the three algorithms are compared and analyzed. The main conclusions are as follows:

(1) In this paper, the optimization model of hot oil pipeline is established, which considers the actual situation of oil pipeline. Variable frequency pump model, heating furnace model, pipeline thermal and hydraulic models are introduced in the optimization model to calculate the pump speed and the exit temperature of the oil pump pipeline system. It conforms to the actual situation of the project and has certain guiding significance to the field operation.

(2) The intelligent algorithm should be used to solve the pipeline model. The total energy consumption of the scheme optimized by the invasive weed algorithm is reduced by 8.32%, the oil consumption is reduced by 7.99%, and the electricity consumption is reduced by 9.01%, in order to obtain the optimal scheme of the pipeline and reduce the energy consumption, improve the efficiency of pipeline system. Among the three algorithms used in this paper, the invasive weed algorithm has advantages in solving speed and optimizing results, and can reduce energy consumption by 8.32%.

CRediT authorship contribution statement

Enbin Liu: Supervision, Methodology, Formal analysis, Investigation, Funding acquisition. **PinRong Lai:** Methodology, Investigation, Visualization, Writing – original draft, Writing – review & editing. **Yong Peng:** Investigation, Visualization. **Qikun Chen:** Investigation, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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