A New Software for Management, Scheduling, and Optimization for the Light Hydrocarbon Pipeline Network System of Daqing Oilfield

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Abstract

This paper presents the new software which specifically developed based on Visual Studio 2010 for Daqing Oilfield China includes the most complex light hydrocarbon pipeline network system in Asia, has become a powerful auxiliary tool to manage field data, makes scheduling plans for batching operation, and optimizes pumping plans. Firstly, DMM for recording and managing field data is summarized. Then, the batch scheduling simulation module called SSM for the difficult batch-scheduling issues of the multiple-source pipeline network system is introduced. Finally, SOM, that is Scheduling Optimization Module, is indicated for solving the problem of the pumps being started up/shut-down frequently.

Keywords: Daqing Oilfield, scheduling plan, batching operation, scheduling optimization

1. Introduction

Daqing Oilfield is the biggest oil and gas preliminary processing base in China. The annual output of Daqing Oilfield amounts about 800 thousand tons of light hydrocarbon, 67 thousand tons of which are transported by the light hydrocarbon pipeline network system. After years of continuous development, the system has resulted in a number of the pipelines having various specifications, all kinds of hydrocarbon-generating stations, many types of gas processing and crude stabilization units, adopting the most advanced technology around the world, and the largest light hydrocarbon storage depot in Asia-Guangming depot. The network system produces mainly three kinds of hydrocarbons, including deep cooling hydrocarbon, crude stabilization hydrocarbon, and shallow freezing hydrocarbon. Its purpose is to transport light hydrocarbons to downstream markets in order to guarantee the rapid expansion of Daqing Oilfield's economy. However, in doing so, resulting problems in daily operation include low automation level of data management and scheduling, and a high frequency of pump startup/shutdown operation, which had become more and more critical with the rising hydrocarbon transportation task [1].

China University of Petroleum-Beijing has now developed a software that integrates three modules including a Data Management Module (DMM), a Scheduling Simulation Module (SSM), and a Scheduling Optimization Module (SOM), which has solved these issues mentioned above effectively.

2. DMM

Today (2012), the light hydrocarbon pipeline network system is still in the development stage; in the future, the structure of the system will inevitably become more complex since the number of light hydrocarbon processing devices, oil and gas

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processing equipment, tanks and pumps of all stations will also rise rapidly. More importantly, constituents, saturated vapor pressures, and the carbon dioxide contents of light hydrocarbons produced from each unit are fluctuating throughout system operation. So, it is critical that field staffs must record the accurate operational data for each section of the system at the appropriate time enabling them to adjust the processing according to the changed physical properties and productions of light hydrocarbons. Nevertheless, until the development of this new software, there had not been any data management software controlling the system. Previously, a great amount of essential historical data, which could cover many volumes would be, recorded manually and archived to track the system data. This working mode not only resulted in a waste of manpower, material and financial resources, but also reduced the working efficiency of the enterprise.

The field data must be mastered by staffs during system running mainly includes:

(1) Information on 38 pipelines(total length is about 410.9km), such as geographical position, started and end point, design pressure, diameter, wall thickness and length of every pipeline;

(2) Information on light hydrocarbon in the 16 oil and gas processing stations, including production, density, viscosity, type, constituent, bubble point pressure of every light hydrocarbon and the amount of mixed-hydrocarbon volume;

(3) Information on the 40 pumps, such as pump type and data on the characteristic curve;

(4) Information on the 95 tanks, such as design pressure, volume, operation pressure and liquid level of each tank.

DMM, therefore, can be seen as the data management module developed to record and manage field data, as mentioned above, for the system. The main interface of DMM displays the topological structure of the whole network system in details (shown in Fig. 1). Each hydrocarbon-generating station of the network system has its own independent station interface. Clicking any rectangle with color on DMM, the station interface dialog box of the corresponding station for data management will pop up in Fig. 2.

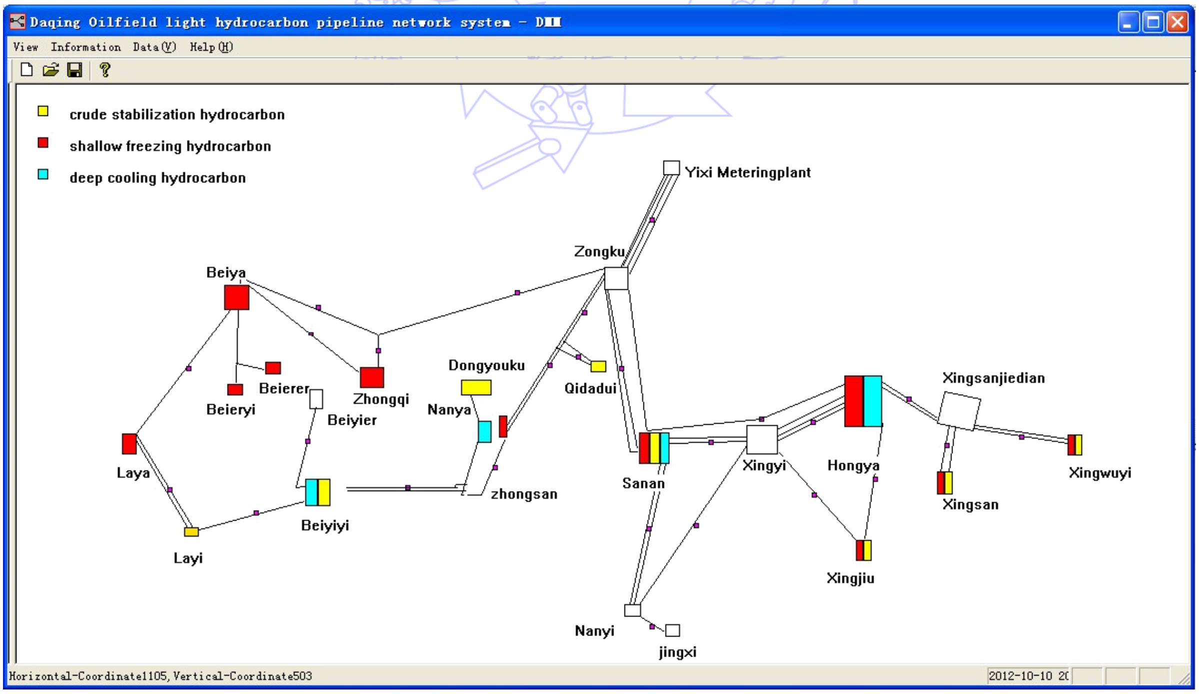

Fig. 1 The main interface of DMM

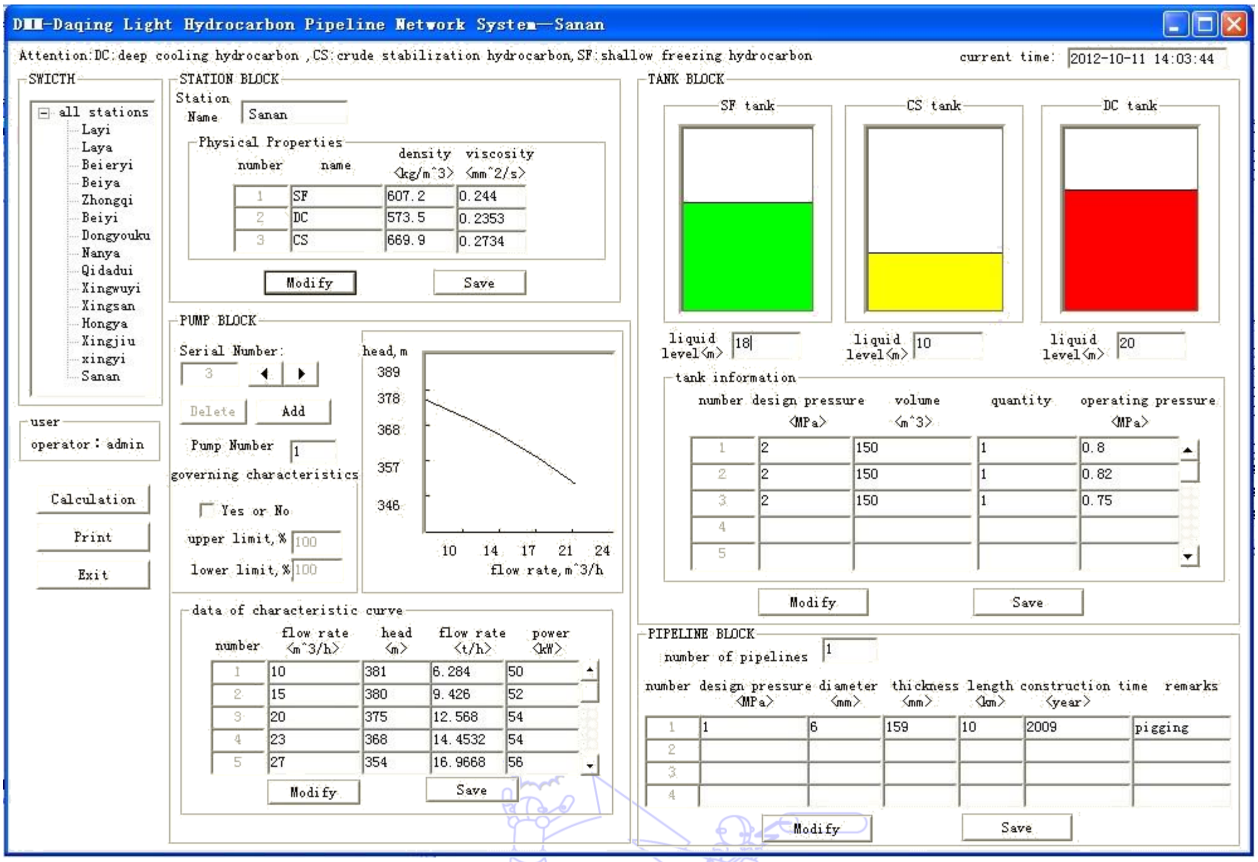

Fig. 2 The station interface dialog box

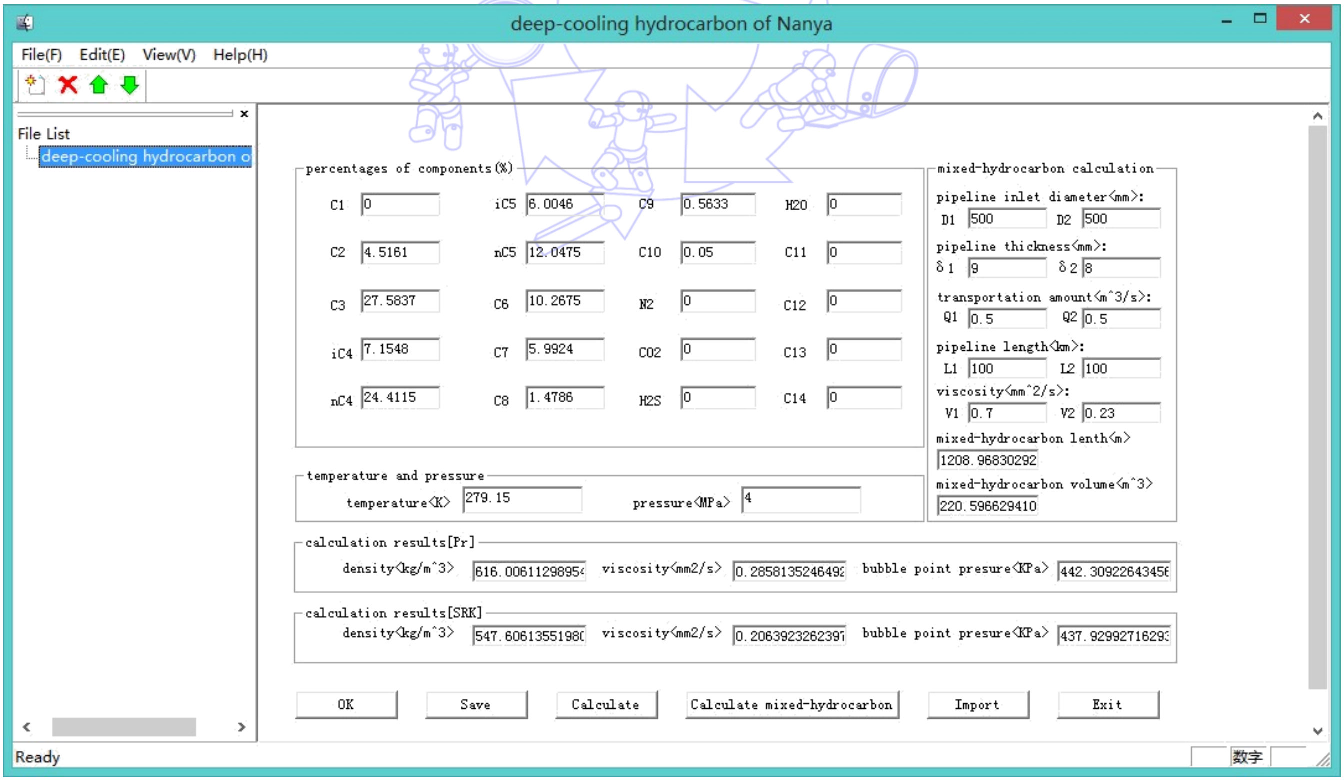

Fig. 3 Light hydrocarbon's density, viscosity, and bubble point pressure as related to pressure and temperature. DMM select SRK and PR state equation to make thermal calculation and Austin-Palfrey equation to calculate mixed-hydrocarbon volume.

The Sanan station located at the downstream of the XingQu Line One is the only station that produces three kinds of light hydrocarbons among the network system. Fig. 2 shows the station interface of Sanan and it is divided into four management blocks, comprising pipeline block, station block, pump block, and tank block. DMM designs all the field data with high frequency and importance as management data and displays them by various ways of frames, pictures or forms. In addition, it clearly describes the properties of all kinds of light hydrocarbons, the numbers and characteristic data of pumps, and the operation parameters of storage tanks. By clicking any station of the dendrogram (which is on the left side), it also will then switch to its station interface, whereupon all the information will be changed in a second; by clicking the "Calculation" button, the mixed-hydrocarbon calculation interface will then pop up in Fig. 3.

The mixed hydrocarbon between different batches will affect the quality of light hydrocarbons and reduce the export price of light hydrocarbons. Therefore, accurately calculation of the length or volume of mixed hydrocarbon plays a very important significance in pipeline transportation. The calculation for mixed-hydrocarbon can decrease profit loss.

At present, most operators commonly use Austin-Palfrey formula to calculate mixed hydrocarbon volume in various domestic and foreign engineering companies. The formula is also recommended in the pipeline engineering design specifications in China. The empirical formula is made based on the large number of tests and production data of pipeline by Austen and Charles Bell Frye, calculated as follows,

(a) Kinematic viscosity

The kinematic viscosity of the mixed hydrocarbon is calculated by the empirical formula (1). This viscosity is one of the parameters to calculate Reynolds.

$$\lg\lg(\nu \times 10^6 + 0.89) = \frac{1}{2}\lg\lg(\nu_A \times 10^6 + 0.89) + \frac{1}{2}\lg\lg(\nu_B \times 10^6 + 0.89) \tag{1}$$

ν_A —— the kinematic viscosity of A hydrocarbon under transportation temperature, m^2/s;

ν_B —— the kinematic viscosity of B hydrocarbon under transportation temperature, m^2/s;

ν —— the kinematic viscosity of the mixed hydrocarbon between A and B, m^2/s.

(b) Reynolds

The critical Reynolds is calculated using the formula (2).

$$\mathrm{Re}_j = 10000\, e^{2.72 d^{0.5}} \tag{2}$$

e —— natural logarithm, equals to 2.87;

d —— pipeline inside diameter, m;

Re_j —— the critical Reynolds of mixed hydrocarbon.

(c) Mixed hydrocarbon

The length of mixed hydrocarbon is calculated using the formula (3).

$$C = 11.75 d^{0.5} L^{0.5}\, \mathrm{Re}^{-0.1} \tag{3}$$

C —— the length of mixed hydrocarbon, m;

d —— pipeline inside diameter, m;

L —— pipeline length, m.

In summary, DMM has been developed to:

(1) Change the way of data storage, processing, and application mode in the system, based on the strong sharing and low redundancy of DMM.

(2) Improve the way to extensively retrieve, amend, update and expand pipeline data, in order to guarantee the security, integrity, reliability, and management efficiency of field data.

(3) Capture and memorize all the real-time data, and tracks the main operating parameters and historical conditions of equipment, so as to standardize and package the relevant records desired by management. As a result, files are formed enabling users to accurately know the characteristics of the pipeline network.

Thereby, field staffs can get various specific data, according to their needs, which are necessary for batch scheduling and pipeline network running. DMM, therefore, not only meets the need for speedy information to management of all the basic data of the pipeline network system, but also achieves the high-speed, accuracy and integrity of data collection.

3. SSM

SSM is the batch scheduling simulation module developed for the complicated batch-scheduling issues of the multiple-source pipeline network system. Most research until now has been on short-term scheduling plans for multi-product or hydrocarbon pipeline operations, and deals with pipelines featuring a single input terminal [2-4]. The input operation of intermediate stations raises several new problematic issues. SSM establishes a network scheduling model and develops suitable algorithms to provide a secure and accurate basis for system operation.

Daqing light hydrocarbon pipeline network is a branched multiple-source system with all its processing stations being injection points. One injection point is one source. Restricted by its specific structure today, the system has to adopt blending transportation mode to transport the products to the Guangming depot. In addition, there is a high energy cost caused by this mode. The continuous fluctuation of hydrocarbon physical properties caused by the current blending transportation mode influences the stability and security of the system operation. Therefore, it was necessary and advisable that the Daqing Oilfield decided to use batching operation mode for products transportation. This transformation will reduce energy consumption of pumps and raise economic benefits.

Scheduling and management of multiple-source light hydrocarbon system involve light hydrocarbon production, tank capacity, and system coordination. The core of the task is to develop scheduling plans to meet the injection requirements, ensure pipeline safety and efficient operations[5, 6]. The pipeline which runs with batching operation is scheduled according to a schedule. Operators cannot witness the operation and location of different kinds of hydrocarbons. So, it needs to simulate pipeline operating conditions to ensure scheduling accuracy. SSM firstly, calculates the velocity by injection flow rate and pipe cross-sectional area, then divides the velocity by the distance between stations to work out arriving time. This will simulate the operation of light hydrocarbons with operational time [7].

All information about batch stripping under the ground is complicated and invisible during the multiple-source pipeline network system operation. Considering the diverse physical properties of light hydrocarbons, the important factors closely related to mixed-hydrocarbon lost is the batch integrity[8]. New batches injected will increase the mixed-hydrocarbon loss. Batch sequence along the pipeline is no longer the same as when they were injected at the initial station. A batch may not fall behind those batches that injected the pipeline previously (Fig. 4 and 5). The injection operation of the intermediate stations may either insert a new batch or increase the volume of some existing batches.

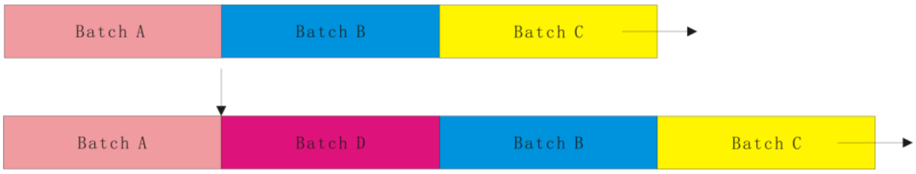

Fig. 4 The hydrocarbon type of Batch D is not the same as Batch A or Batch B, but a new batch.

Fig. 5 The hydrocarbon type of Batch D is the same as Batch A or Batch B, thus increasing the size of the batch whose type is the same as Batch D in the pipeline after the injection operation.

As it shown in Fig. 4 and Fig. 5, even though Batch A has been injected earlier at the source, it may be preceded by Batch D, which pumped from a downstream injection terminal. because the hydrocarbon type of Batch D, however, may or may not be the same as Batch A or Batch B, it is difficult to decide the exact time of injecting Batch D in order to make the mixed hydrocarbon as little as possible. The new batches injected at intermediate stations increase the difficulty of scheduling. The injecting operation station, batch order, flow rate, start/end time of a new batch will affect not only the volume of mixed hydrocarbon at the final terminal, but also the stability and the economy of pipeline network operation as a whole.

SSM solves the all-injection scheduling problems of mesh topology based on the current structure of the branched pipeline system. It can quickly make and simulate scheduling plans for batching operation, and also increases the amounts of batch volume as much as possible so as to reduce the number of batches [9]. In order to decrease the operational staffs input steps when they are working, SSM can read all static data about the pipeline network, such as hydrocarbon properties, pump data, and so on from the database managed by DMM.

An input schedule plan determines the input stations which batches are inserted, the order in which batches are injected, the entering hydrocarbons type, and the lengths, flow rates and start/end times of batches [10]. When making injection scheduling plans for all stations, the following constraints are taken into consideration:

(1) The inputting sequences and volume of different kinds of hydrocarbons at the initial station and at intermediate stations;
(2) Total tank capacity and current liquid level of all tanks at all stations along the pipeline;
(3) The longest pump running time of all pumps;
(4) The transportation capacity of the pipeline.

Fig. 6 describes a batch interface strip picture provided by SSM for the XingQu Line One which consists of five stations including Xingwuyi, Xingsan, Hongya, Xingyi, and Sanan. Guangming depot is the final terminal of this pipeline. As can be seen, the figure reflects a lot of information intuitively and clearly, which includes the injection plans for batching operation, the flow rates at different times and different locations, and the different kinds of hydrocarbons injected. Here, the horizontal axis represents time and the vertical axis represents the distance from the initial station. The short horizontal line illustrates the injecting process, the thickness of which is proportional to the flow rate. The data shown in the status bar from left to right are the distance between the location of the mouse pointer and the initial station, the begin and end points of injecting time-windows.

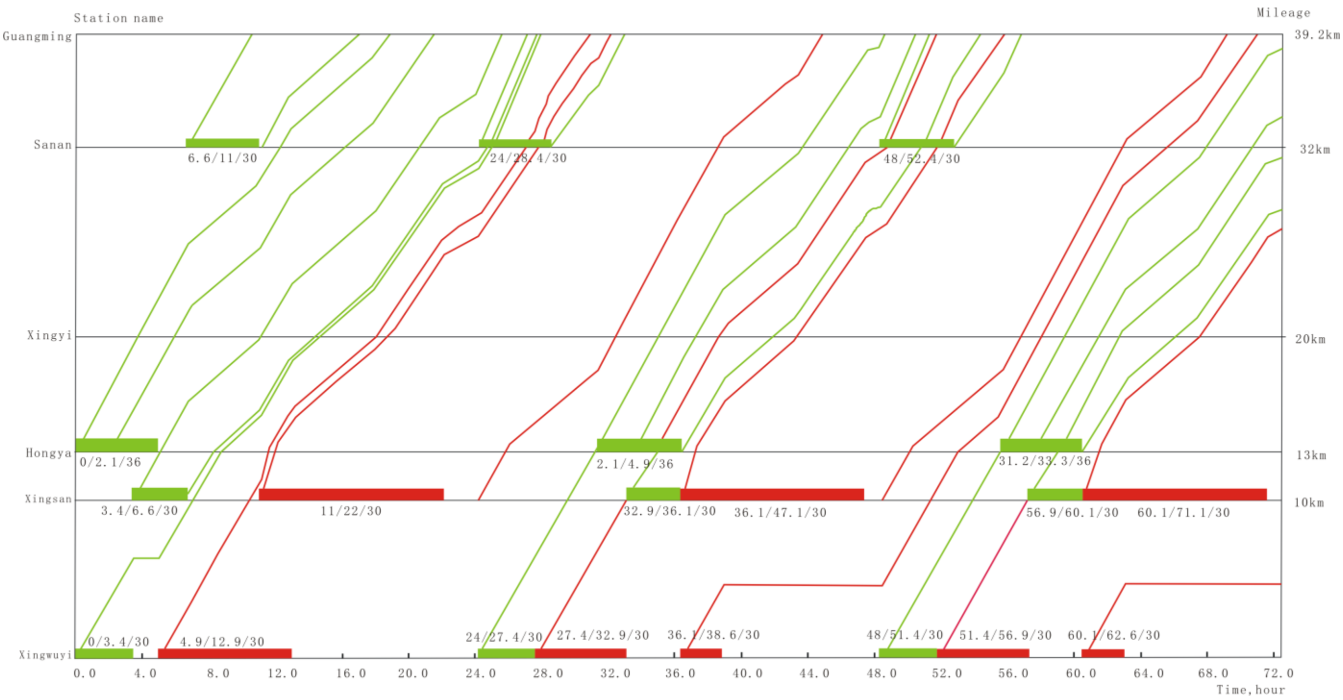

Fig. 6 The perspicuous batch interface strip picture of XingQu Line One

SSM not only can predict the batch strip process, but also calculates hydraulic simulation to work out the flow rates and pressures during the running time along XingQu Line One; moreover, SSM can simulate the pressure curve according to different parameters. Users can select discharge pressure at initial station whereupon the pressures along the pipeline during the whole running time can be found out. For example, set the discharge pressure at initial station 4Mpa (Area A), 3.5Mpa (Area B) and 3Mpa (Area C) respectively, taking 25 hours, 45 hours and 65 hours after the initial running time as simulation time points (Fig. 7) [11].

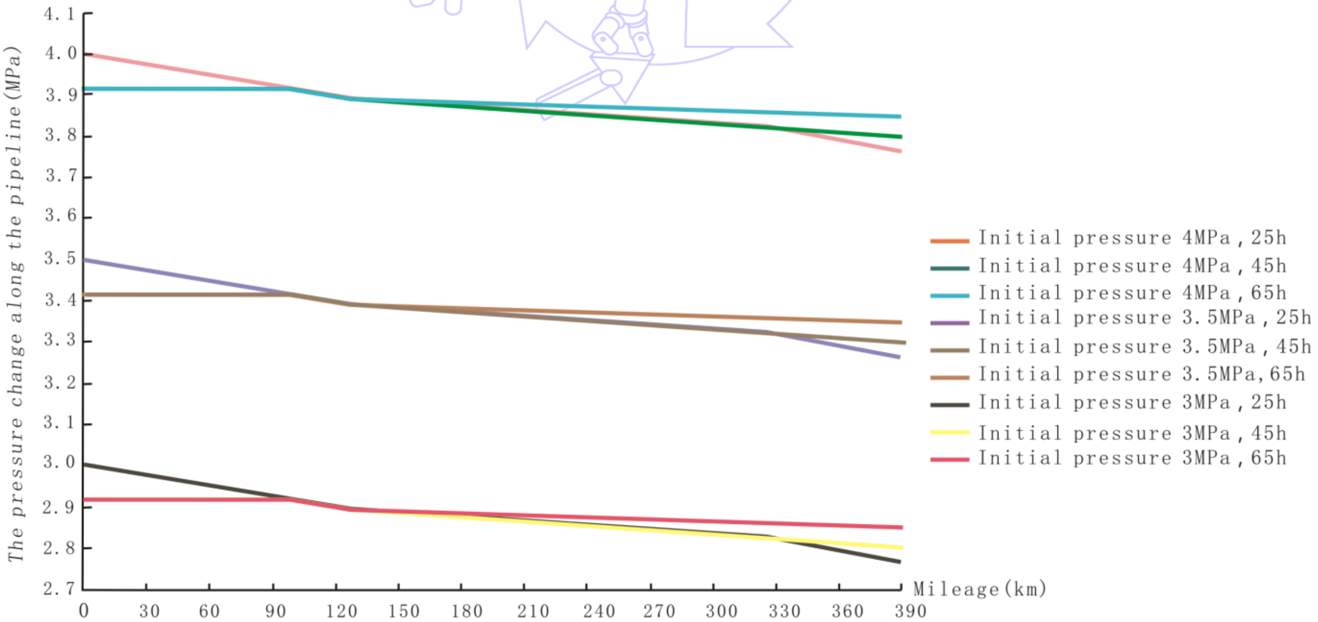

Fig. 7 The history curves of pressure after SSM simulation. SSM can calculate hydraulic simulation according to any given set of discharge pressures at the initial station. Considering pipeline's pressure bearing capacity and permitted minimum pressure, field staff can adjust the initial station's discharge pressure based on the pressure curve along the pipeline.

Fig. 8 shows how the inlet flow and discharge flow of each station vary with time.

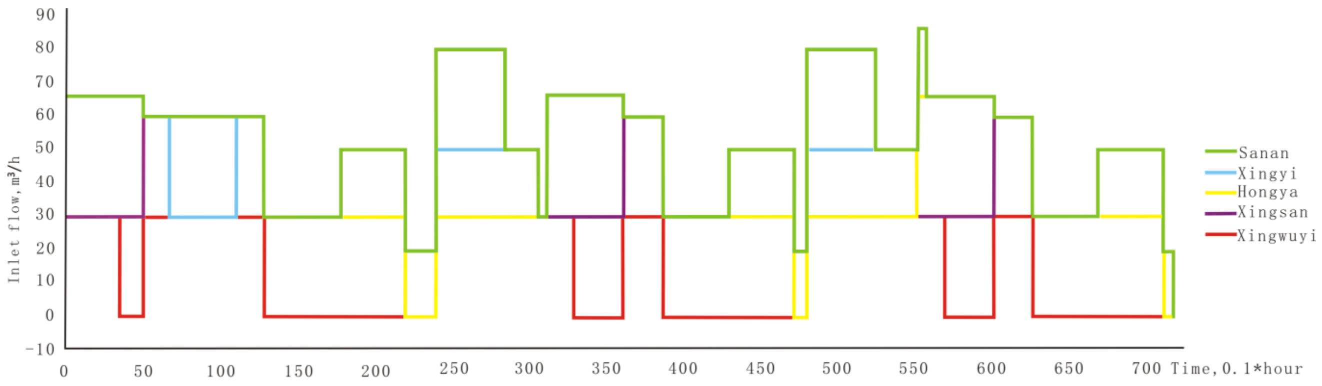

Fig. 8 The history curve of inlet flow of SSM. Different colors represent different stations. The horizontal axis is time and the vertical axis is the inlet flow. The injection of light hydrocarbon will increase the inlet flow. The inlet flow equals to zero means that there is no injection during this time period. It is important to master the variation of inlet flow and discharge flow when system running. Employee can ascertain the dangerous conditions from the history curves after SSM simulation.

Previously, the scheduling of light hydrocarbon pipeline system is accomplished through artificial and manual calculation. Software calculating is faster than manual methods; furthermore, the software now offers the new transportation mode to replace original mixed mode to cancel later re-refining process. SSM has improved transport efficiency from process and work time. Overall, SSM has the following functions:

(1) Makes and simulates the plan of injection operation, and tracks the mixed hydrocarbon interface;
(2) Makes a dynamic simulation of the pressure along the pipeline;
(3) Calculates the pressure drop along the pipeline at the given moment;
(4) Calculates the pressure of some station during a certain period of time;
(5) Provides the history curves of inlet/discharge flow at all stations.

4. SOM

Hitherto, at a station, once per day each kind of hydrocarbon was pumped, which resulted in the pumps being started up/shut-down frequently, thus increasing the complexity of the staff's operation, the costs of equipment loss, the electric energy consume, and the inevitable significant effect on the pipeline network pressure fluctuation. This had a prodigious effect on the stable running of the pipeline network and increased the health and safety risks of daily operation. SOM, that is Scheduling Optimization Module, takes the batches sequences constraints, the time window constraints, and the depot capacity constraints at stations into consideration, establishes an optimal model, which has been developed to provide the optimal time window combination of injecting hydrocarbon rapidly and to solve the frequent pump operation problem [12].

SOM calculates the optimal hydrocarbon transportation time-windows according to the model and ascertains the most appropriate times when pumping operations cover the shortest time, yet the volumes of hydrocarbon transportation are the largest, through a critical path analysis of the system. At the same time, SOM can simulate optimal pumping required in the case of there being differences in the content of the tanks at each station.

4.1 Model assumptions

This pipeline network system scheduling optimization is restricted by many aspects of factors. On the other hand, taking into account the difficulty of solving the model, it needs to make some assumptions.

(a) hydrocarbon production assumption

The hydrocarbon production of all stations within the system is continuous and uninterrupted. So, the production remains stable for a long time and always in the vicinity of a certain value only sometimes may occur in a short float change. Therefore, during the study a constant production rate of hydrocarbon production of each station is assumed.

(b) pump flow assumption

Each station has various types of pumps for transported different hydrocarbons. Under normal circumstances, we can regulate the flow of light hydrocarbons as well as external pressure by adjusting the pump. So, all outside pumps are considered a specific flow during the study period.

(c) tank storage assumption

Each station hydrocarbon production operation is continuously during the study period, but external transmission is intermittent according to certain principles; each station is equipped with corresponding tanks for light hydrocarbon species. Specifically, storage pressure and tank capacity range of these tanks is certain. The actual reserves are constantly changing amount and real-time monitored. Therefore, the reserves of different hydrocarbon of the various stations at the starting point are assumed to be known.

(d) terminal reception assumption

It is assumed that the terminal has the ability to receive light hydrocarbons of all stations during the study time.

4.2 Model solutions

The model solution is divided into two stages: the optimal number of time windows and the largest hydrocarbon transmission. When the first feasible solution is appeared, it indicates that the number of time windows will meet the demand for hydrocarbon transmission. Because the time windows are enumeration from small to large, the number of time window is the optimal solution of time window. It needs to meet the maximum amount of hydrocarbon transmission at the same time, therefore, calculate the distribution of each time window for each number to solve the hydrocarbon transmission at next step. The maximum output is the optimal distribution of time window. In this paper, enumeration method and simplex method are used respectively at the two-phase solution process, which greatly simplifies the solving difficulty. In Fig. 9, “I” is the number of time-window and “N” is the total number of time window combinations.

Taking Sanan station for example, in this situation we select the midpoint of the light hydrocarbon tank capacity as the initial tank capacity and focus on the optimization results in a diverse given period of time. Study on scheduling optimization at Sanan station within 144 hours is shown below.

The results of calculating the pumping operation start/end time within 144 hours are shown in Table 1. Fig. 10 shows how the current liquid volume in the tanks of three kinds of light hydrocarbons changes with time during 144 hours.

Pump operating cost is a major part of pipeline operation cost and it was illustrated that whilst in the old mode the pumps were in use 18 times in the 144 hour period this figure was reduced to 7 operations after optimization. The times pumps were started have been decreased 61.1% compared with the old mode, representing a significant reduction. Therefore, by reducing the pump frequency, SOM has reduced pipeline running costs.

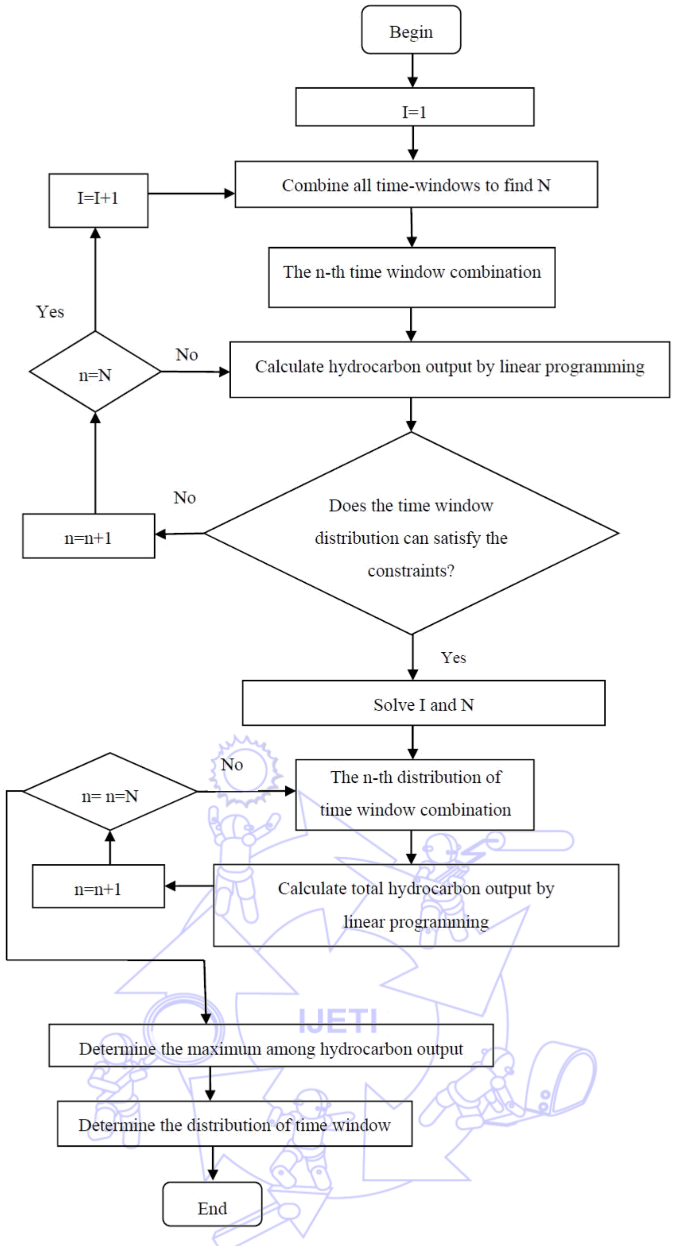

Fig. 9 Diagram of model solution

Table 1 Calculation results of pumping optimization within 144 hours

Time window, h-h	Pump Status
0—2.41	Off-line
2.41—16.75	Pumping deep cooling hydrocarbon
16.75—28.63	Off-line
28.63—46.88	Pumping crude stabilization hydrocarbon
46.88—51.08	Off-line
51.08—72.00	Pumping deep cooling hydrocarbon
72.00—81.4	Off-line
81.4—99.65	Pumping shallow freezing hydrocarbon
99.65—116.5	Pumping deep cooling hydrocarbon
116.5—133.5	Pumping crude stabilization hydrocarbon
133.5—144	Pumping deep cooling hydrocarbon

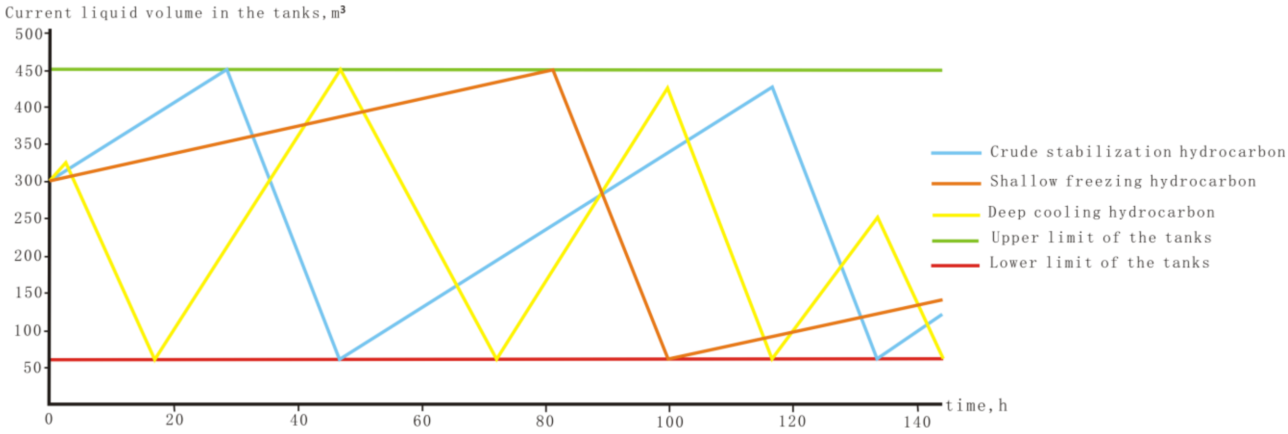

Fig. 10 The current liquid volume in the tanks of three kinds of light hydrocarbons within 144 hours

5. Conclusions

It can be seen, therefore, that this software dramatically improves the informative level of data management, and the ease of making a schedule and optimizing the pump operation electronically. This software has become one of the indispensable management tools in the daily operation of Daqing light hydrocarbon pipeline network.

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