MITIGATION MEASURES OF OIL PIPELINES IN CASE OF POWER FAILURE

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ABSTRACT
This work is to investigate the operations at various upset conditions due to power failure of the 1506-km Heglig-Portsudan pipeline. A simulator, developed at the Department of Oil/Gas Storage & Transportation, China University of Petroleum-Beijing, can simulate the existing long-distance waxy crude pipeline, exactly as it is configured in the field. For non-Newtonian flow, the fluid rheological consistency, *K* (Pa.sn) and the flow behaviour index *n* are evaluated experimentally. Those two parameters were required to be introduced into the software to assess their effects on surge scenarios.
Some surge cases of loss of communication were reviewed. Consequently, it is of great important that the operator should review some practical mitigation measures as well as the capacity of SCADA (Supervisory Control and Data Acquisition) system to ensure that the system has resources to accommodate normal and abnormal operations.

Key Words: *simulator, non-Newtonian, rheological properties, surge, SCADA.*

1. INTRODUCTION

There is a general concern regarding the pipeline transportation of the waxy crude oils at temperatures below the pour point and at various scenarios of operations. More importantly, this study is of practical significance in safe design and operation of pipelining the waxy crudes, it helps not only minimizing many risks which might encounter in the long-distance oil pipelining systems but also handling the expected problems arises when pumping the waxy crudes.

A pressure surge may produce even greater consequences. Excessive surge may move a pipe off its supports or rupture a pipeline, leading to significant repair or replacement costs. In the worst scenario, a major pipeline failure may cause injures to people and require a massive cleanup. Specifically, unexpected power failure or shut down scenarios may lead to great changes of transportation materials, operating parameters or equipments of pump stations; which in turns will induce surge in oil transfer pipeline. To conduct a dynamic surge analysis, a simulator has been developed. In addition, a set of input data is used to describe the specific pipeline system and its operation.

In China, the most complicated long-distance-crude-oil-pipeline technically and operationally is the China West Crude Oil Pipeline. The shear and thermal history of three PPD- beneficiated waxy crude oils transported through this pipeline were simulated by using a stirred vessel and with the energy dissipation of viscous flow as the shear simulation parameter. The comparisons of flow properties of the crude oils obtained from field tests with experimental simulation show that the gel points and viscosities from simulation are in agreement with the field data.[1]

Based on the characteristic method, Jing Gong and Wang [2] established a numerical calculation and simulated the pressure variation process, when a valve at the terminal station was accidentally closed in a product pipeline. Further research combining the boundary condition of relief system was carried out.

Bruce and Gerald [3] have found that integrating data analysis, safety devices and controller training were the best tools to control surge.

Anindya, *et al.* [4] conducted a numerical simulation to analyze transients in gas flow and pressure in a horizontal straight pipe. The numerical results showed that depending upon the pipe dimensions and operating variables such as pressure and gas flow rate, transient effects in the pipeline may last for a long time and/or over significant length of pipe. The simulations predicted an initial surge in gas flow rate greater than the final steady-state value if the pressure drop across the pipe is increased.

An orientation visit [5] to Heglig Central Processing Unit was done by the author, it was well stated that two Pour Point Depressants (PPD) Products which were suggested by Chinese partner had provided acceptable values of pour point and viscosity with a slight difference. But, field test was strongly suggested to verify laboratory results as well as to determine the true effects of different blends in the real pipeline. On the other hand, Dafan & Zheming [6] investigated the variation of the rheological properties of Da Qing waxy crude with their thermal history and their

time effect. They found, experimentally, that such properties were very sensitive to heat treatment. Also, it was denoted that, the structural strength of Da Qing crude varied with heat treatment.
More experimental works had been done at the Laboratory of Oil Rheology, China University of Petroleum, Beijing. It has been quite clear that Da Qing waxy crude is similar to Sudan waxy crude. However, the best heat treatment temperature for Da Qing crude oil was 60ºC and reheating the crude was found to be of great importance. Whereas, heating the Nile Blend up to 90ºC was quite acceptable. Nevertheless, still heating to 80ºC may be considered for operating cost reduction regardless of other shortcomings.

2. MATERIALS AND METHODS

The major purpose of the current work was to further investigate the problems encountered pipeline transportation of the Nile blend in case of unexpected power failure. This research was, mainly, adopting methods to utilize a software simulator and carry out laboratory techniques that are capable of providing essential data and analyses necessary for assessing the important mitigation measures for safe operations of Heglig-Portsudan pipeline.
The crude sample to be studied was brought by the Pipeline Science Research Institute of China National Petroleum Corporation (CNPC), Lang Fang. The sample was too waxy, refer to table 1 & 2. Due to high solidification temperature, high viscosity at low temperature and high yield strength, novel oil transporting technology methods have to be studied and developed.

Table 1 The main physical properties of the crude sample

The wax content (approximately)	23% by weight
The Wax Appearance Temperature	57ºC
Average inlet temperature	60 °C
Heat capacity	2100 J/kg.°C
Fluid density	843 kg/m3
The viscosity at 28°C and 10 s-1	101 mPa.s
The kinematic viscosity at 28°C and 10 s-1	0.12 m2/s

Table 2 The base value for control set points of Heglig-Portsudan pipeline

Minimum suction pressure station #1	490kPa
Minimum suction pressure at all other stations	280kPa
Max. Allowable operating pressure (MAOP) under normal condition	9724kPa
Max. Allowable operating pressure under upset condition	9724+10%(9724) = 10696kPa
Discharge pressure controller	9724-1%(9724) = 9627kPa
Discharge pressure shutdown high (DPSH)	9724+5%(9724)= 10210kPa with 30 sec delay
Discharge pressure shutdown high high (DPSHH)	9724+7.5%(9724)= 10453kPa with no delay

In the experimental setup carried out at the laboratory of rheology, China University of Petroleum-Beijing, the viscometer VT500 with a Phoenix P2 circulator has been selected as the main device. The viscometer VT500 is a combination of viscometer (VT) with a power supply VS500 with DOS-based application. A Phoenix P2 circulator was used as temperature controller .The measurements have been carried out at different heat treatment and shear conditions. Depending on those measurements, the values of the fluid rheological consistency, K (Pa.sn) and the flow behaviour index n were introduced into the software.

3. RESULTS AND DISCUSSION

The prediction of pressure surges is of economic importance in pipeline transportation where the pressure must be maintained within narrow limits to prevent damage of pipe and/or devices.
In the current work, the main cause of the pressure surges was the unexpected power failure. When the pump shuts down or power failure at an intermediate location, e.g. at station#3, the rotational inertia of the motor-pump system continues to transfer energy to the liquid until the pump head has decreased to zero. The pump impeller rotates as the flow continues through the pump. The rotational inertia of the motor-pump system and the efficiency of energy transfer from the impeller to the fluid both contribute to determine the rate of run-down (the rate the motor and pump slow down when the electrical energy is disconnected).
The outcome of this case study, fig.1 & Fig.2 indicated that to what extent the mitigation measures should be taken to keep the MAOP within the limit. However, the maximum value displayed at station#1, 10.6MPa, is safe when compared to the MAOP (Maximum Allowable Operating Pressure) under abnormal condition, i.e. 10.696MPa.

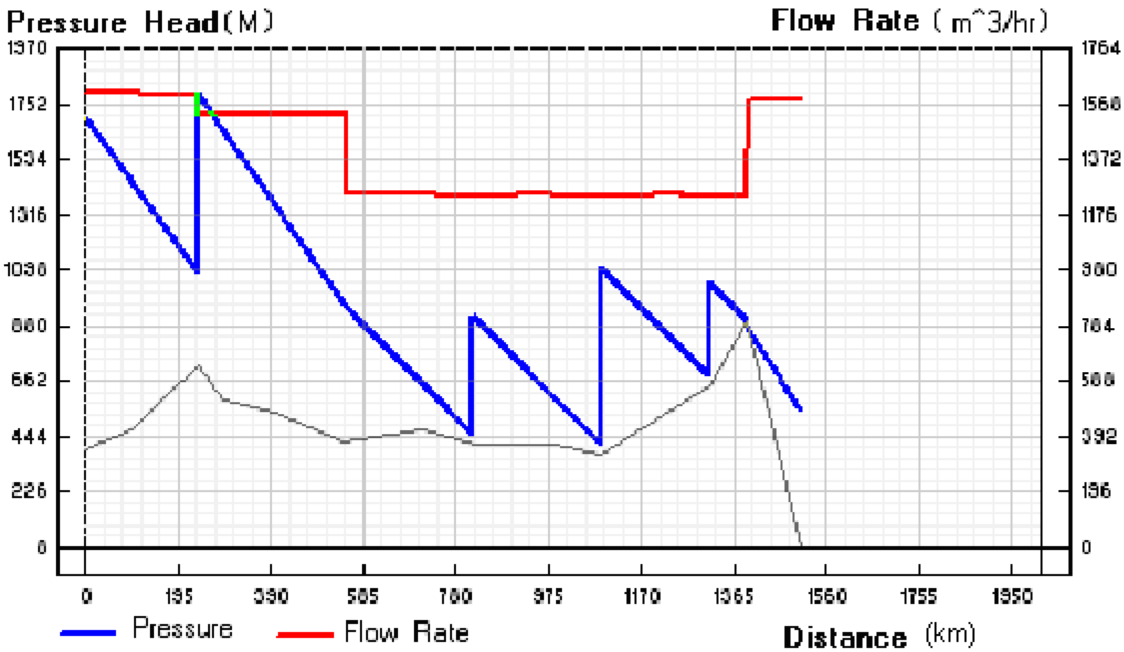

Fig. 1 The transient.

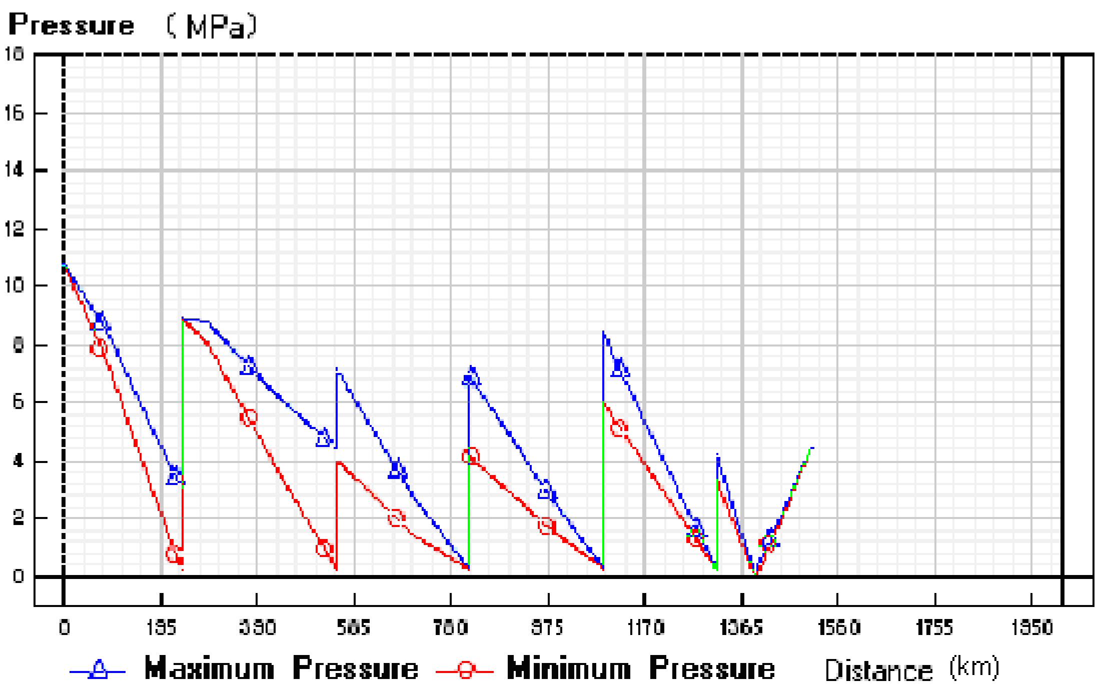

Fig. 2 Maximum & Minimum Pressure Curves.

The power failure at station#3 can cause large pressure surges. A low pressure surge travels downstream as the pump head decreases. The flow rate and velocity downstream decrease as the new pressure gradient is established. Pump shutdowns also affect the flow upstream of the third station; i.e. a high pressure travels upstream as the flow velocity decreases, fig.3-a and fig.3-b.

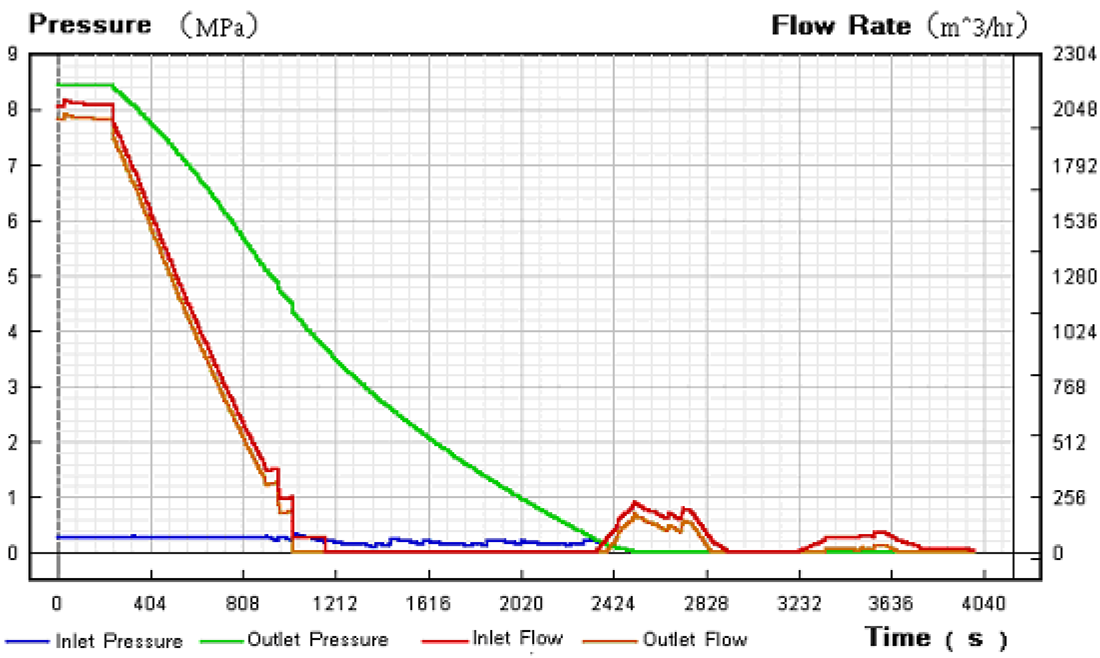

Fig.3-a Transient Curves at the 2nd Station.

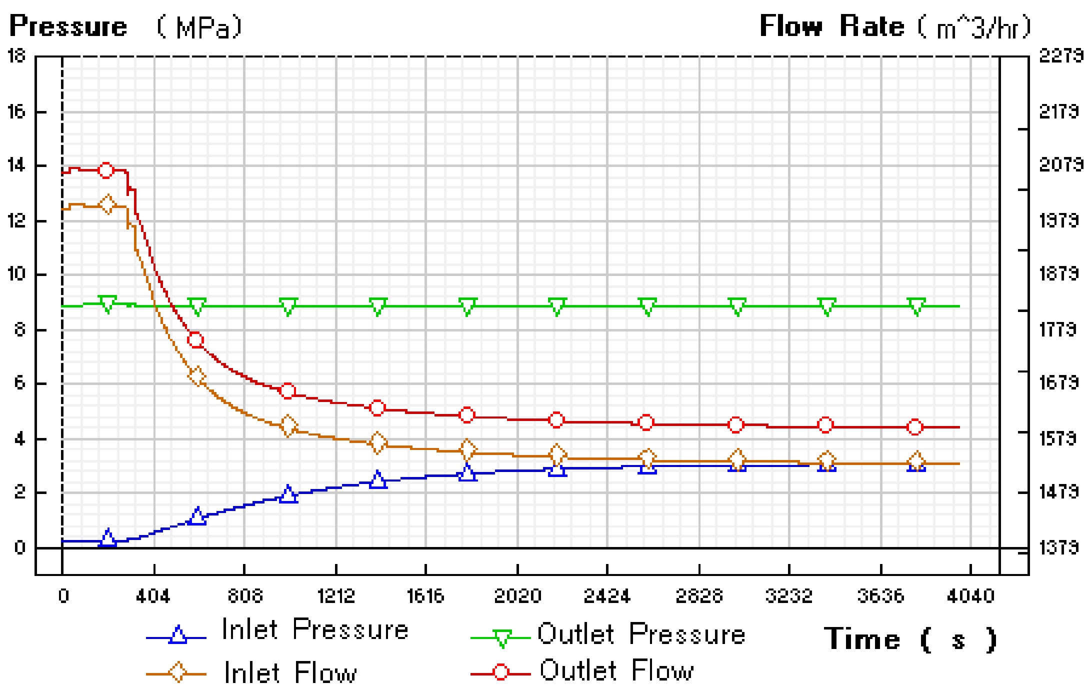

Fig.3-b Transient Curves at the 2nd Station (Modified).

Since the accident of surge here happens as a result of a power failure at station#3; therefore an effective mean of mitigation should be taken. This can be done by two levels of controls. Firstly, the oil can be released by means of PRV (Pressure Relief Valve). As the time goes the amount of oil released from the line is increased to keep the pressure within the allowable limits. Secondly, by considering a similar case in which the degree of opening of the adjusting valves should be set, separately, to a low value at the upstream of the station. In contrary, the adjusting valves at the downstream stations are to be kept to higher values.

The most successful mitigation measure considered is the bypass relief valves, which are better to be substituted by high integrity pressure sensors. In general, there were no surge pressure violations if relief bypass were used, and the pipeline was able to establish a steady-state flow rate. In addition to hardware control in these situations, the operator needs a comparatively low cost method for simulating surge pressures while working off-line.

4. WHAT WOULD HAPPEN TO HEGLIG PIPELINE IN THE ABSENCE OF SCADA

The worst condition of the sub-cases was when SCADA is out of service and the PRVs (Pressure Relieve Valves) were not in place while pumping the chemically untreated sample. The maximum pressure at stations #3, #4, and#6 were 12, 12, and 9.6MPa, respectively. A loss of communication with PRVs was taken place when Heglig-Portsudan Pipeline was simulated without SCADA, therefore acceptable means of minimizing the upset situations should be provided as suggested below. However, with PRVs and SCADA in service, a better quick response to mitigation is provided which results in reducing the maximum pressure recorded at stations #4 and #5 to their limit of 6 and 6.6MPa, respectively. Other modified set points can be shown in table 3.

On the other hand, without PRVs the role of SCADA was obvious in creating signals to other pump controls trying to maintain the pressures to their set points while surge accident was happening; significant reduction in the maximum limits of pressure were maintained at the terminal station, i.e. the surge accident start point. The maximum pressure recorded at stations #4, #6, and #7 were 11.4, 5.4 and 7.8MPa, respectively. Those values can be compared to 12, 9.6, 14.4MPa, respectively, when SCADA was out of service. Again, the purpose of getting optimal surge control measures was accomplished through adjusting the relief system on time as a major outcome of the simulator.

Nevertheless, surge generated by power cut off could be more destructive and the induced surge pressure would be much higher, so controlling surge of this kind is indispensable. Test looping for rheological investigations and/or computer programming for graphical simulations were few methods to assess the possible mitigation measures. However, in implementing this, several issues such as various failure scenarios and control measures should be looked into seriously as suggested above.

Table 3 The Modified Set points at Various Pump Stations

I. Parameter		St.#1	St.#2	St.#3	St.#4	St.#5	St.#6	St.#7
Pressure Adjusting	Inlet	-	0.28	0.28	0.28	0.28	0.28	**4.47**
	Outlet	9.60	**9.60**	6.90	6.90	6.9	6.90	-
Pressure Releasing	Inlet	-	2.4	2.4	2.4	2.4	2.4	**5.24**
	Outlet	**10.80**	**9.20**	9.7	9.70	9.70	9.70	-
Pressure Shutdown	Inlet	-	0.20	0.20	0.20	0.20	0.20	-
	Outlet	**11.20**	**9.40**	9.7	9.80	**10.20**	**9.80**	-
High Pressure Open/Close	Inlet	-	0.039	0.039	0.039	0.039	0.039	-
	Outlet	**11.40**	**10.9**	9.9	**10.00**	**10.40**	**10.1**	-
Flow Rate (+Inlet) (-Outlet)		+2066	-66	-330	-	-	-	-

Note: The Modified Set Points are indicated with Bold. Various failure conditions and control measures by virtue of a computer simulator in its full version have to be considered in more details.

5. CONCLUSIONS

In parallel with SCADA system implementation, a simulator working on off-line basis is of great interest in terms of safety, cost and productivity. However, the suggested mitigation measures were proved to be more practical tool control for sophisticated systems such as Heglig-Portsudan pipeline.

6. ACKNOWLEDGEMENT

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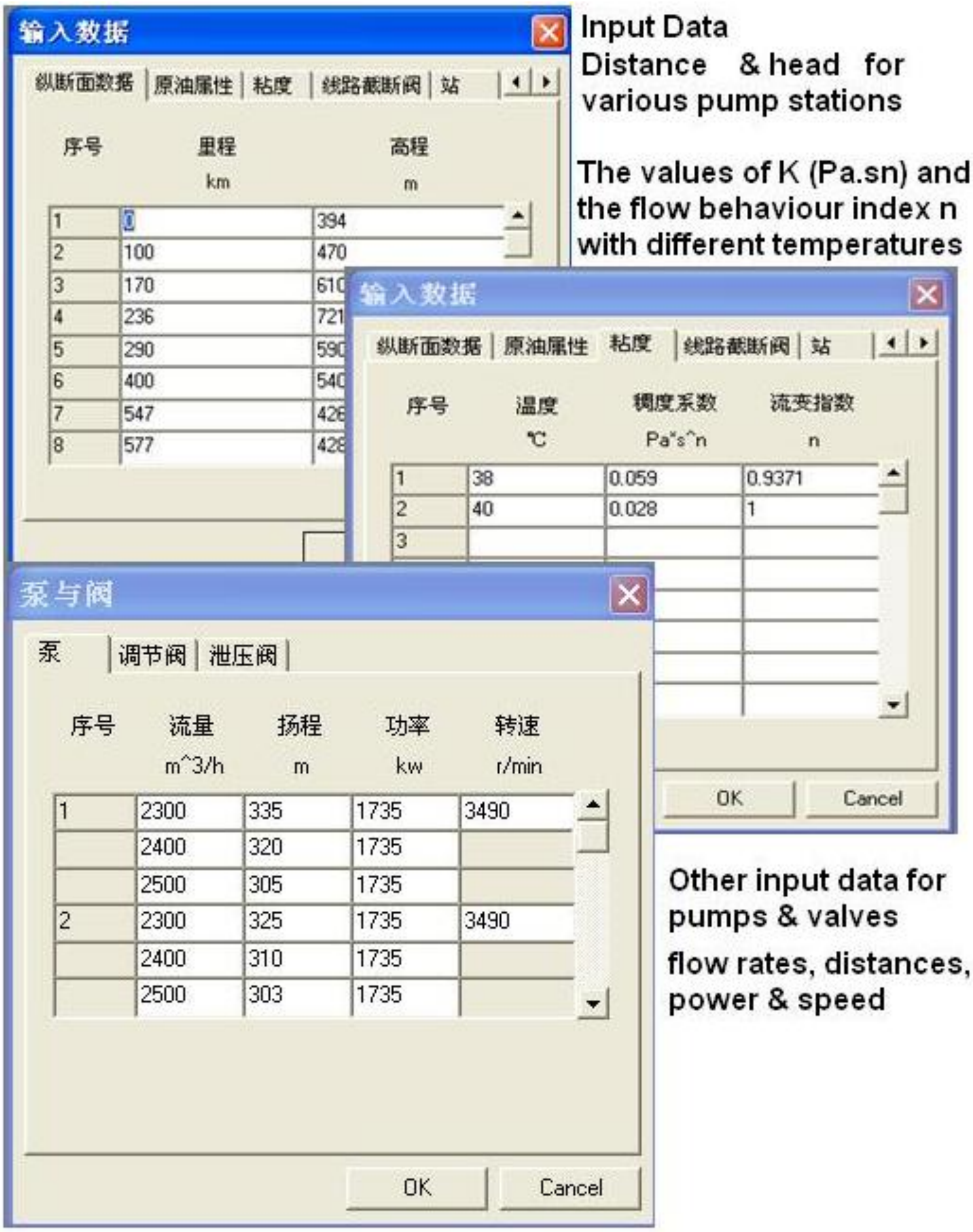
7. APPENDICES

7.1 THE GENERAL FEATURE OF THE SIMULATOR: The figure below shows the Main Menus of the Input Data of the simulator which designed and developed at the Department of Oil/Gas Storage & Transportation, China University of Petroleum-Beijing,



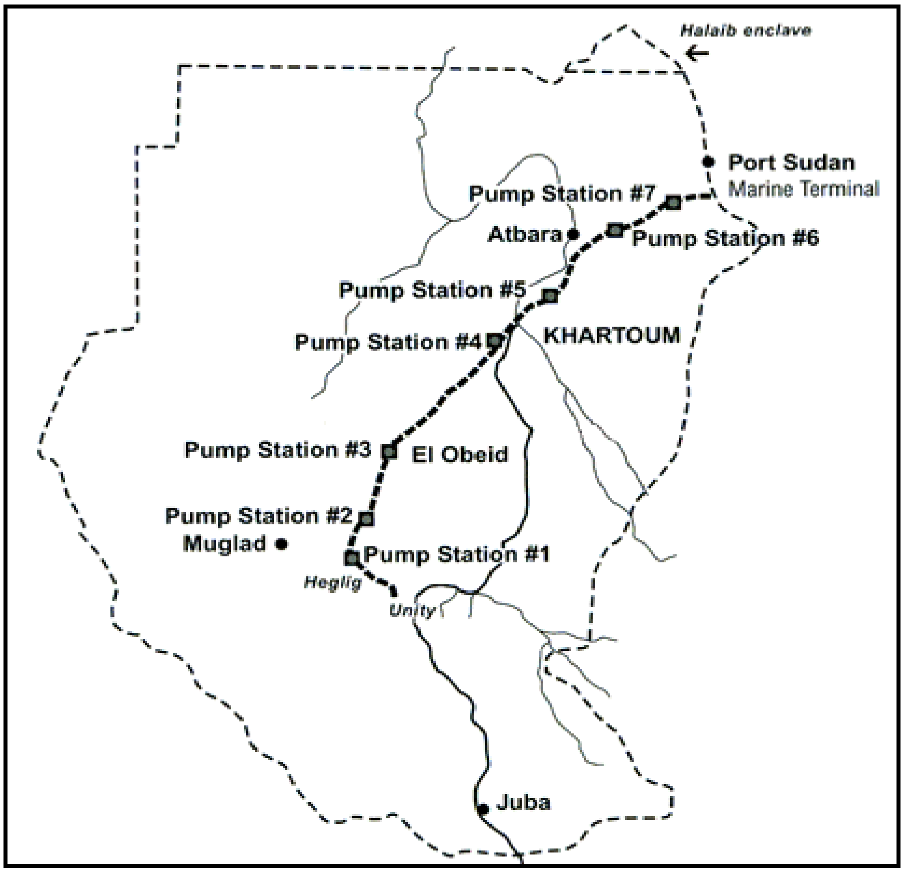
7.2 HEGLIG-PORTSUDAN CRUDE OIL PIPELINE.:

The construction of the 1540 kilometer export pipeline to Port Sudan is the most important achievement of GNPOC for the development of the whole Sudan famous basin and indeed the country as a whole. (*Note: The Greater Nile Petroleum Operating Company (GNPOC) consortium comprises China National Petroleum Corporation (CNPC),* *Malaysia's Petronas, Sudan's Sudapet, and India's Oil and National Gas Corporation (ONGC). ONGC acquired its interest from Canada's Talisman in March 2003.*)

Below, a map which shows the SEVEN pump stations, starting from the first station at Heglig and the terminal at Portsudan. Parts of the route through the northern desert and the Red Sea Hills were notoriously rocky and difficult to excavate. The pipe has been exposed to fluctuating extremes of heat and cold in the desert atmosphere. Better quality pipe was used in these sections to survive the thermal stresses of expansion and contraction.

The pressure inside the pipes is highest near the pump stations, and these sections also used the strongest pipes.

Also, the pipeline was exposed to ground movement, from flood erosion, for example, as well as organised attacks. Breaks could occur anywhere, and safety features were done successfully all along the route by the GNPOC under supervision of the Sudan Ministry of Energy & Mining.



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