

Management of Oil Transportation Via Main Pipelines using SCADA System Data

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ABSTRACT

This paper is devoted to developed oil transportation software and focuses on integration of the software with a SCADA (Supervisory Control and Data Acquisition) system of pipeline transport companies. Functionality and performance capabilities of the software are described. Integration of the software with a SCADA was presented through the example of JSC “KazTransOil”. This paper shows how pipelines sensor data can be used to improve software’s mathematical model of heat-hydraulic calculations. The results of the digital technology development to control oil transportation along the main oil pipelines of the Republic of Kazakhstan using the software are presented. The calculations result of pumping modes prove the economic efficiency of digital technology implementation.

Keywords: oil transportation, pipeline, SCADA, heat-hydraulic calculations, software

1. Introduction

The management of oil transportation via the main oil pipelines is carried out using the SmartTran software in conjunction with a SCADA system, which provides monitoring, management and optimization of technological modes of oil pumping [1,2]. This technology monitors the operation of pumping units, heating furnaces, oil pumping modes in real time and allows process automation during pipeline transportation. As a result, operational reliability and efficiency of the main oil pipelines is increased. In this paper, we present the results of the digital technology development for oil transportation through the main oil pipeline sections by integrating the SmartTran software and the SCADA system of JSC “KazTransOil” (hereinafter KTO).

SCADA System of the KTO

The main oil pipelines (MP) of the KTO are characterized by the following features:

- the main technological objects of MP have a high single capacity;
- MP objects are classified as dangerous;

- MP objects are spaced at long distances;
- climatic and other external conditions are severe, unfavorable.

The principle of operation of Supervisory Control and Data Acquisition (SCADA system) is in providing industrial and information security; effectiveness; standardization and information compatibility.

The SCADA system of the KTO is one of the largest in the world with technological equipment including 80 main pumping units, 40 booster pumps, 62 heating furnaces, 86 tanks, 626 auxiliary system, 1731 pipe gate valves, 2468 temperature sensors, 1649 pressure sensors, 995 level sensors, 239 consumption sensors, 323 vibration sensors, 213 gas content sensors, 721 current and voltage sensors.

The main function of the SCADA system:

- visualization and information input;
- data control;
- management of process equipment;
- registration and storage of events and accidents;
- storing the history of technological parameter values;
- reports formation;
- communication with technological networks (via OPC technology);
- inter-level transmission of technological information.

The SCADA system receives data via the fiber-optic system from sensors that measure pressure and temperature of the oil flow, the soil temperature at the points of measurement in the linear section of the pipeline and equipment (pump units, gate valves, etc.). The values from pressure, temperature and flow sensors helps to monitor the flow of oil in the pipeline and the operation of process equipment.

2. Oil Transportation Simulation Software

The oil transportation simulation software (named SmartTran) is a joint development of the authors, and it is designed for forecasting, modeling and optimization of energy-saving modes of oil mixtures transport at sections of the main oil pipelines. Also it gives an opportunity to design new pipelines with the identification of sections, pumping equipment and heating furnaces. Modeling and optimizing the energy saving mode of “hot” oil transportation distinguishes the SmartTran software from other products.

The functionality of the SmartTran software consists of the following tasks:

- determination of energy-saving operation modes of pumping units with detachable rotors and variable frequency drive;

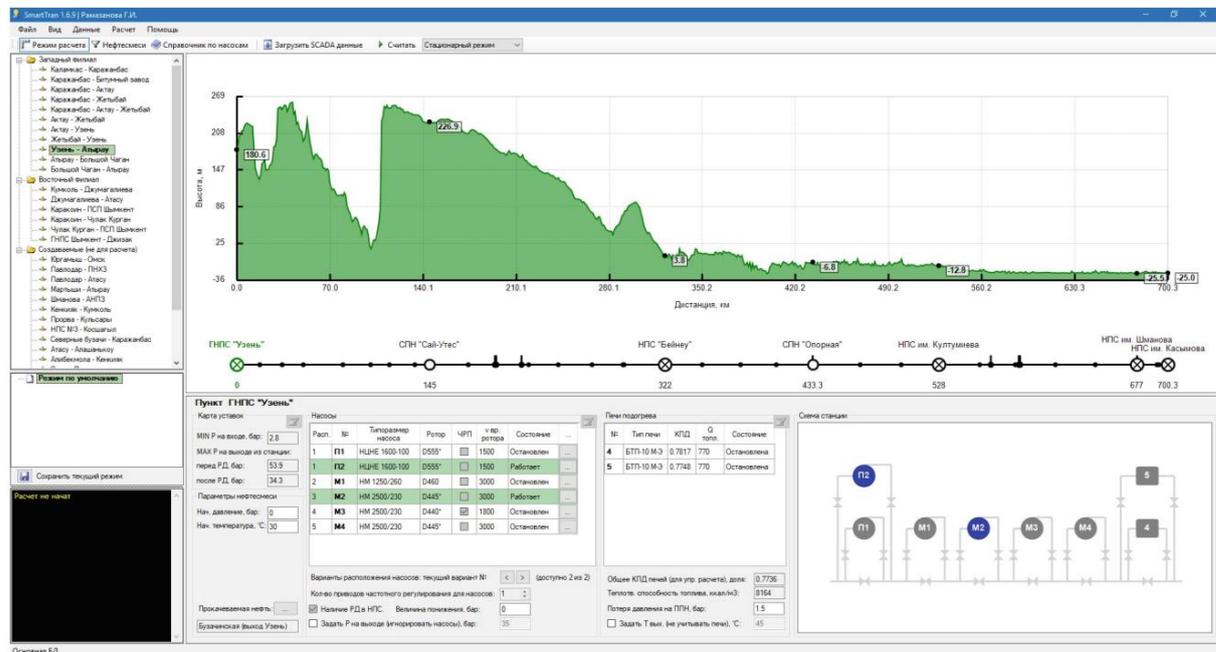
- determination of the optimum oil mixtures temperature at pipeline sections under energy-saving operating conditions for heating furnaces;
- determination of energy saving modes of “hot” oil transportation in main oil pipelines;
- determination of energy saving modes of oil transportation using chemical additives (depressor and anti-turbulent additives);
- determination of the economic efficiency of technological modes of oil transportation taking into account the difference in tariffs for fuel and electricity.

SmartTran performance capabilities:

- heat-hydraulic calculations of stationary modes of high viscous and high pour point oil transportation for the safe operation of the main pipelines (taking into account associated pumping and pumping out, loops, pipe defects, pressure regulator and input of additives);
- heat-hydraulic calculations of non-stationary pumping modes after short term stops for the safe operation of main oil pipelines;
- heat-hydraulic calculations of serial transfer of different varieties of high viscous and high pour point oils mixtures along main oil pipelines;
- heat-hydraulic calculations of energy saving modes of main pumping units with detachable rotors and variable frequency drive for stationary operation;
- determination of the optimum temperature of heating oil mixtures and energy-saving modes of heating units for stationary operation;
- selection of pumping equipment of pumping stations (PS) with detachable rotors and variable frequency drive for forecasting the maximum capacity of the pipeline with permissible operating modes of pumping equipment;
- adaptation of real characteristics of pumping equipment of the PS according to the SCADA system data;
- Designing of new sites, the addition of pumping equipment at PS and input of rheological properties of oil mixtures.

Figure 1 shows the SmartTran software window during calculation of the main pumping station (MPS) Uzen - PS named after T. Kasymov section.

Figure 1. A SmartTran software window during calculation of the selected section



2.1 SCADA system of the KTO

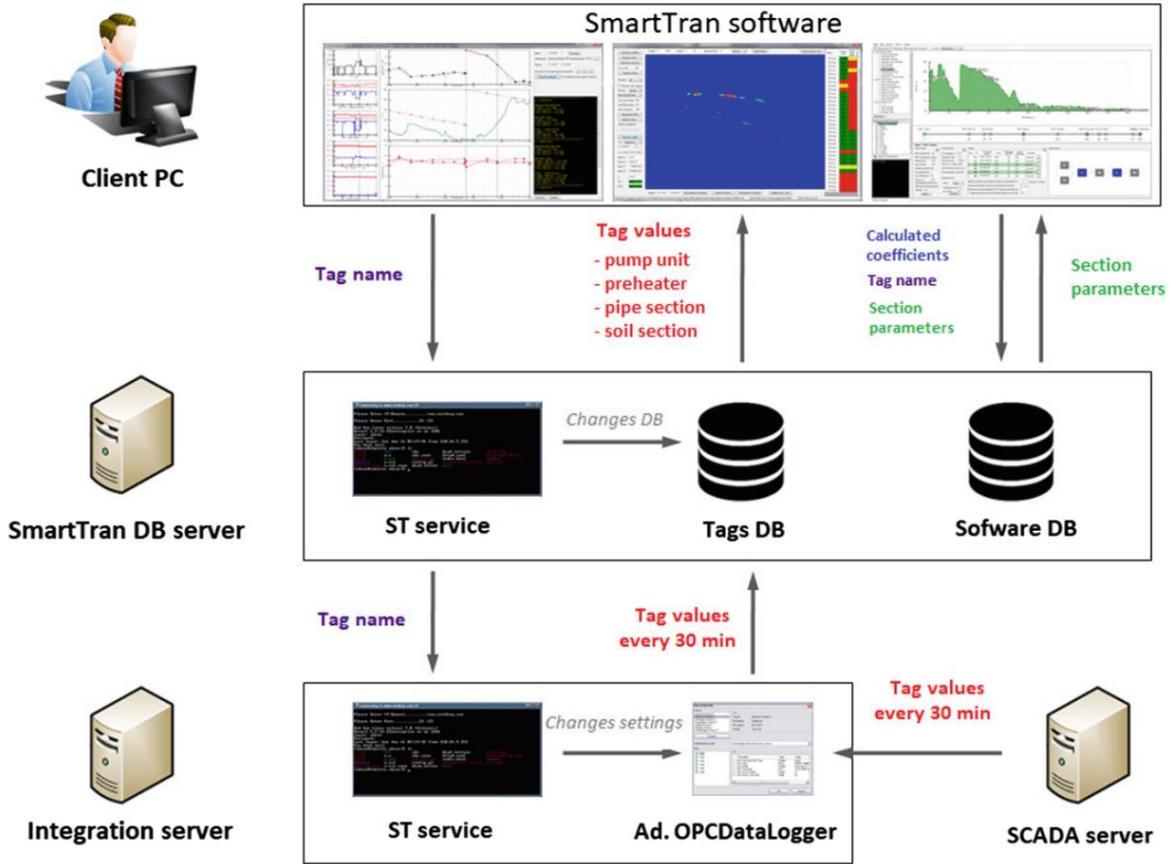
Figure 2 shows structurally how the SmartTran integrates with the SCADA system.

As a result of integration the following initial data were obtained:

- pressure-volumetric characteristics of pumps, depending on the service life for determining the power consumption and efficiency;
- pressure and temperature values at the inlet/outlet of pumping units and oil pumping stations;
- oil parameters in the linear sections of the main oil pipeline (flow rate and pressure, oil temperature);
- hydraulic and thermal characteristics of pipes within sections (waxing of inner part, stagnant zones, soil parameters);
- parameters of the heating furnaces (oil and gas consumption, oil temperature at the inlet and outlet of the furnaces).

The SmartTran software uses data obtained from the SCADA system to determine the energy saving modes of oil mixture transportation at sections of the main oil pipelines

Figure 2. Integration diagram of the SCADA system with SmartTran



2.2 Determination of Pumping Units Power Consumption

Figure 3 shows the head-capacity characteristic of the pumping units, taking into account its operational life, obtained by the SmartTran adaptation module. Actual data of volumetric flow and pressure drop (Q , $P_{out} - P_{in}$) obtained by the SCADA system are used to determine the power consumption and the coefficient of performance of the pumping unit. The points indicate an actual data of the pumps working. The transition from blue to red color displays an increase in the points concentration. The adaptation module constructs a regression curve (black line on the plot).

The coefficient of performance of the pumping units is described by [3]:

$$\eta_{PE} = \eta_P \eta_{MT} \eta_{EM} = \frac{(P_{out} - P_{in})Q}{N_{act}} \quad (1)$$

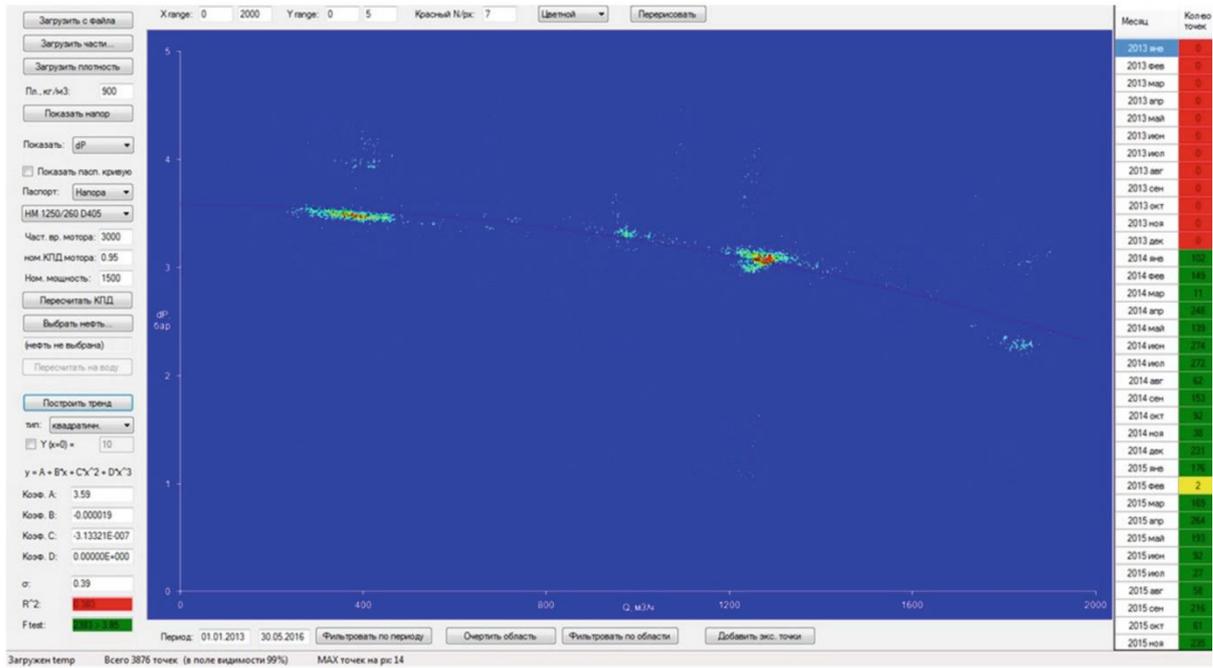
where N_{act} is active motor capacity, η_P is the coefficient of performance of the pumping unit, η_{MT} is the coefficient of performance of the power transmission from the motor to the pump, η_{EM} is the electric motor coefficient of performance, Q is the volume flow.

For the mechanical collar of the pump $\eta_{MT} = 0.99$, and η_{EM} can be calculated by [1]:

$$\eta_{EM} = \frac{1}{1 + \frac{1 - \eta_{nom}}{2\eta_{nom}k_{load}}(1 + k_{load}^2)}, \quad k_{load} = \frac{N_{act}}{N_{nom}} \quad (2)$$

where η_{nom} is the electric motor coefficient of performance at nominal load, N_{nom} is the standard horsepower of the electric motor, rating.

Figure 3. Pressure drop vs volumetric flow rate relationship $dP(Q)$



Based on the SCADA system's data the coefficient of performance of the pump is calculated as:

$$\eta_P = \frac{(P_{out} - P_{in})Q}{N_{act}\eta_{MT}} \left(1 + \frac{1 - \eta_{nom}}{2\eta_{nom}k_{load}} (1 + k_{load}^2) \right) \quad (3)$$

and energy consumed by pumping units:

$$N_P = \frac{\rho g H Q}{\eta_P \eta_{MT} \eta_{EM}} \quad (4)$$

Power consumption data are used to optimize energy saving modes of pumping units.

2.3 Determination of the energy consumed by the heating furnace

Calculation of the fuel consumption of any type is carried out in units of reference fuel. As a reference fuel is used 1 kg of fuel with a lowest calorific value $Q_{pr.f.} = 7000 \text{ kcal/kg}$ (29.3 MJ/kg). Specific consumption of gaseous fuel for heating 1 ton of oil by 1°C in the i -th heater is found from expression [4]:

$$b_f^i = \frac{7000}{Q_P^H} \cdot b_{r.f.}^i, \quad b_{r.f.}^i = \frac{142.86 \cdot 10^{-3}}{\eta_i^\theta} \cdot c_p \quad (5)$$

where Q_P^H is the calorie power of gas fuel, $b_{r.f.}^i$ is the specific consumption of reference fuel, c_p is the heating capacity of oil, η_i^θ is the coefficient of performance of the i -th heater.

Using the specific fuel consumption, it is possible to determine the amount of gas G_i^{gas} (10^3 tons) for heating specific amount of oil G_i^{oil} (10^3 tons) on the i -th heater [4]:

$$G_i^{gas} = b_{r.f.}^i \cdot G_i^{oil} \cdot (T_i^{ex} - T_i^{en}) \quad (6)$$

where T_i^{ex} , T_i^{en} are oil temperature at inlet and outlet of the i -th heater.

In the case when several heating furnaces operate at a heating station the total amount of fuel is found from the following expression:

$$G^{gas} = \sum_i^n b_{r.f.}^i \cdot G_i^{oil} \cdot (T_i^{ex} - T_i^{en}) \quad (7)$$

The SCADA system data determine the temperature of oil at the i -th heating furnace inlet and outlet, at the heating station inlet and outlet; pressure at the heating station inlet and outlet, and the oil flow through the i -th furnace.

Based on SCADA system data SmartTran carry optimization of fuel consumption for heating oil at the heating station during “hot” transportation.

2.4 Determination of the hydraulic resistance of the pipeline

Hydraulic resistance is the most important characteristic of the pipeline, and the accuracy of its determination affects the economic efficiency of oil transportation.

Hydraulics of the oil pipeline depends on many factors (viscosity, roughness, flow velocity) when pumping high pour point (paraffinic) and high viscous oil and is based on the Darcy-Weisbach formula [1–3]. The oil temperature varies along the length of the pipeline due to heat transfer with the soil, and as a result the oil viscosity changes. The pipe roughness can vary for various reasons, including wax deposition on the walls, and requires constant adaptation of the hydraulic resistance.

The coefficient of hydraulic resistance is determined by solving the system of motion and continuity equations [5]:

$$\rho_0 \frac{\partial w}{\partial t} + \frac{\partial p}{\partial x} = -\lambda \frac{\rho_0 w^2}{2D} + \rho_0 g \sin \alpha(x) \quad (8)$$

$$\frac{\partial p}{\partial t} + \rho_0 c^2 \frac{\partial w}{\partial t} = 0 \quad (9)$$

where p , ρ_0 , w are pressure, density, velocity of oil, g is value of gravity acceleration, λ is hydraulic resistance coefficient, D is internal diameter of pipeline, α is angle of inclination of the pipeline axis to the horizontal, c is the speed of wave propagation in the pipeline ($c \approx 1000$ m/s).

The coefficient λ is expressed by the modified Altshul formula [1]:

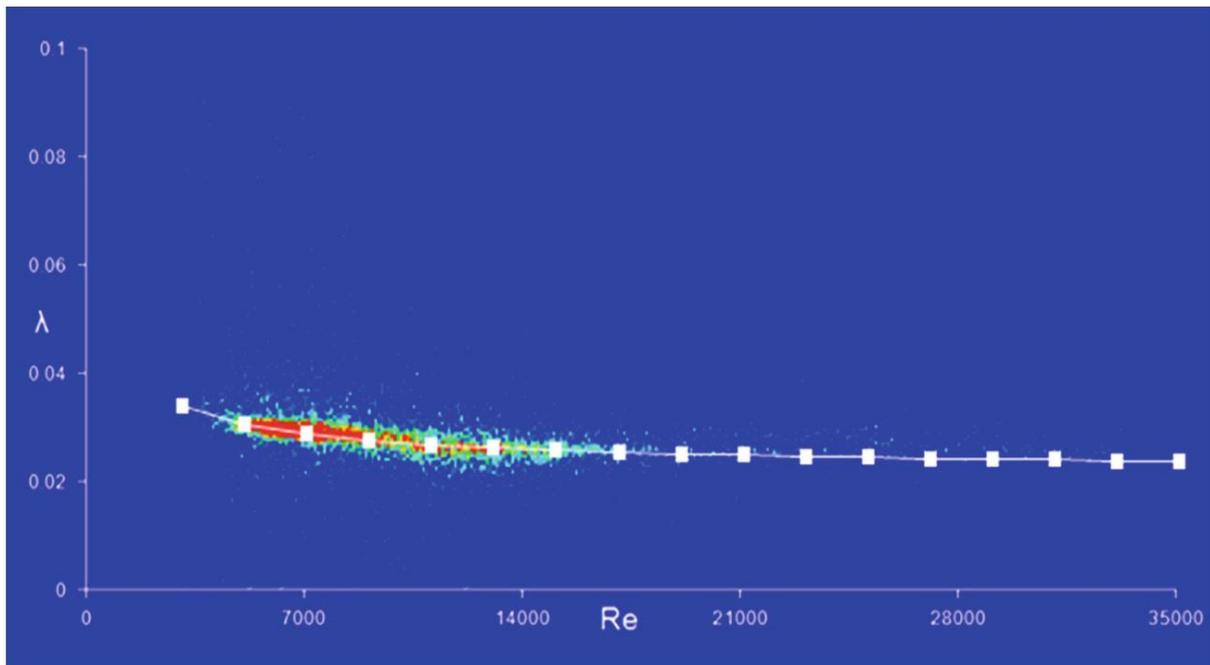
$$\lambda(Re) = a \left(\frac{68}{Re} + e \right)^b + d \quad (10)$$

In the formula (10) the coefficients (a , b , e , d) are considered unknown and are found by comparing calculated and experimental data.

As indicated above, the SmartTran adaptation module determines the coefficient of hydraulic resistance by comparing the calculated and experimental data of the SCADA system. After that

dependence of the coefficient of hydraulic resistance on Reynolds number $\lambda(Re)$ at the section of the main oil pipeline is identified (Fig.4). In the Fig.4 square dots indicate the experimental data of the SCADA system, the white line is a regression curve.

Figure 4. Dependence of the coefficient of hydraulic resistance on Reynolds number $\lambda(Re)$



2.5 Determination of operating practices of oil transportation

The integration of the SmartTran and the SCADA system creates digital technology to control the technological modes of oil transportation while ensuring the safety of the main oil pipeline. As a proof, the results of the determination of oil transportation modes on some sections of main oil pipelines are given below. Figure5 shows the results of comparing the calculated data of the SmartTran with the real data of the SCADA system at the Karazhanbas-Aktau section.

As can be seen from Fig.5, the calculations results on the distribution of the hydro-slope, oil pressure and temperature are in agreement with the actual data received from the SCADA system. The results of monitoring the technological mode of “hot” pumping in the Atyrau-Bolshoy Chagan section are shown in Fig.6. It is necessary to note the agreement of the data calculated at the Smart Tran and the field data received from the SCADA system regarding power capacity of pumps at the PS named after T. Kasymov and Inder (Fig.6). Similar data were obtained at the Djumagaliev - Atasu (Fig.7) and Djumagaliev - Chulak Kurgan (Fig.8) sections.

Thus, the developed digital technology allows the simulation of oil pipeline operation and manages the technological modes of oil mixtures transportation through the integration of the SmartTran software and the SCADA system.

Figure 5. Comparison of data from the SmartTran software and the SCADA system for the Karazhanbas-Aktau section

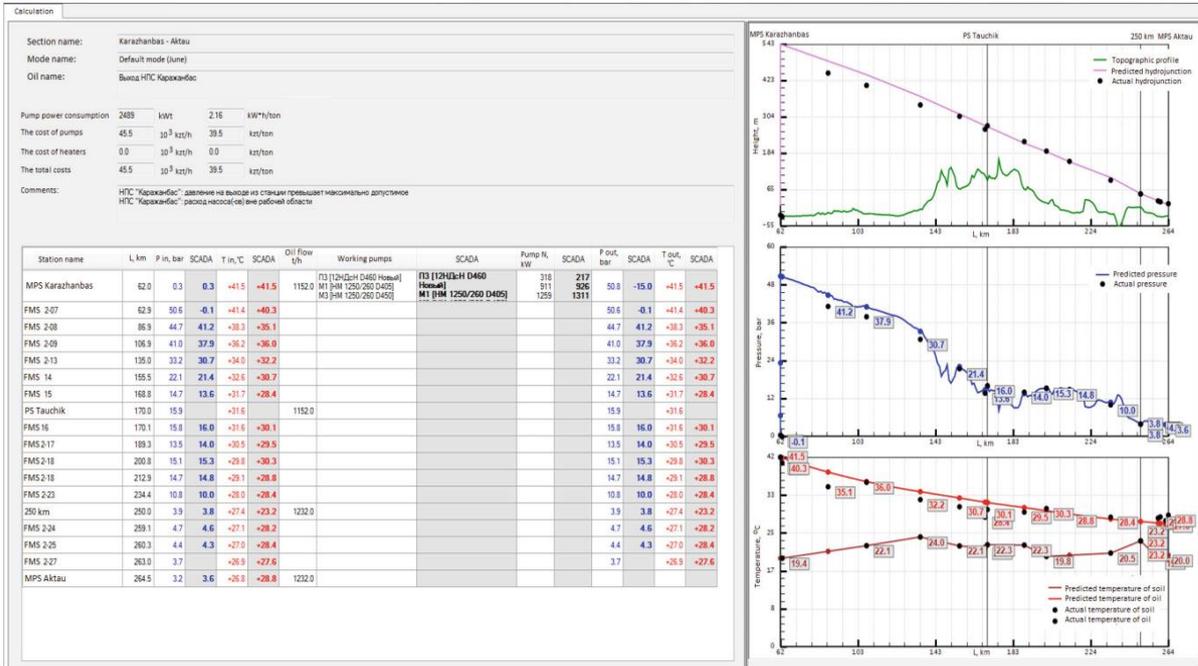


Figure 6. Comparison of data from the SmartTran software and the SCADA system for the Atyrau-Bolshoy Chagan section

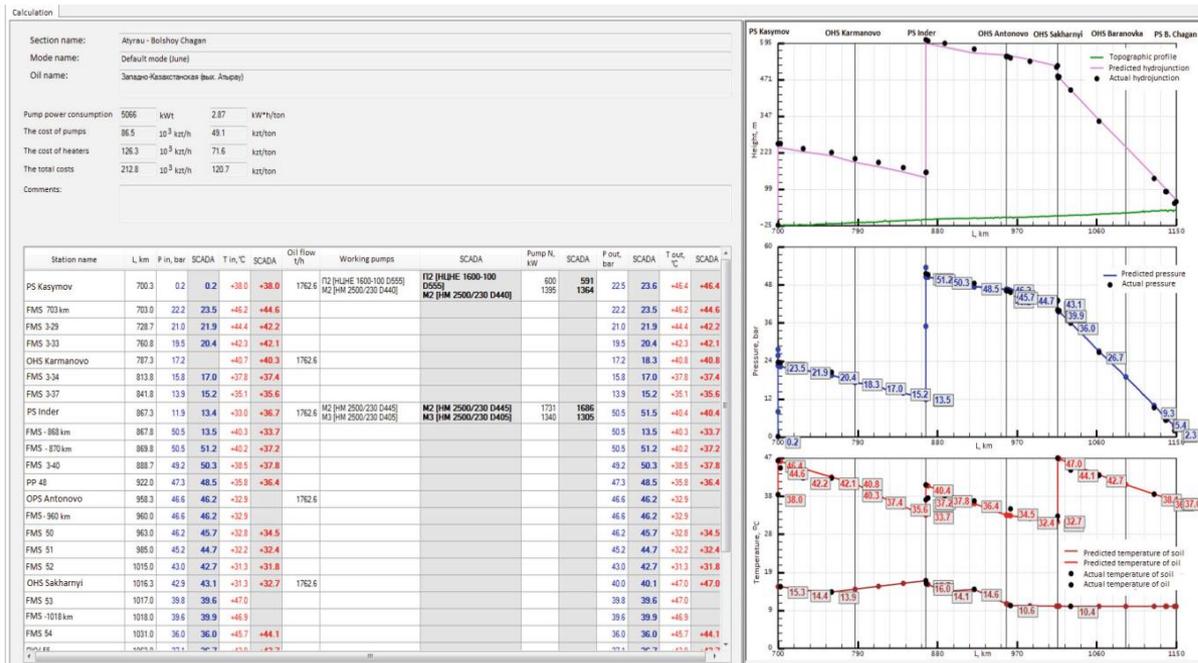


Figure 7. Comparison of Smart Tran and the SCADA system data at the Djumagaliev-Atasu section

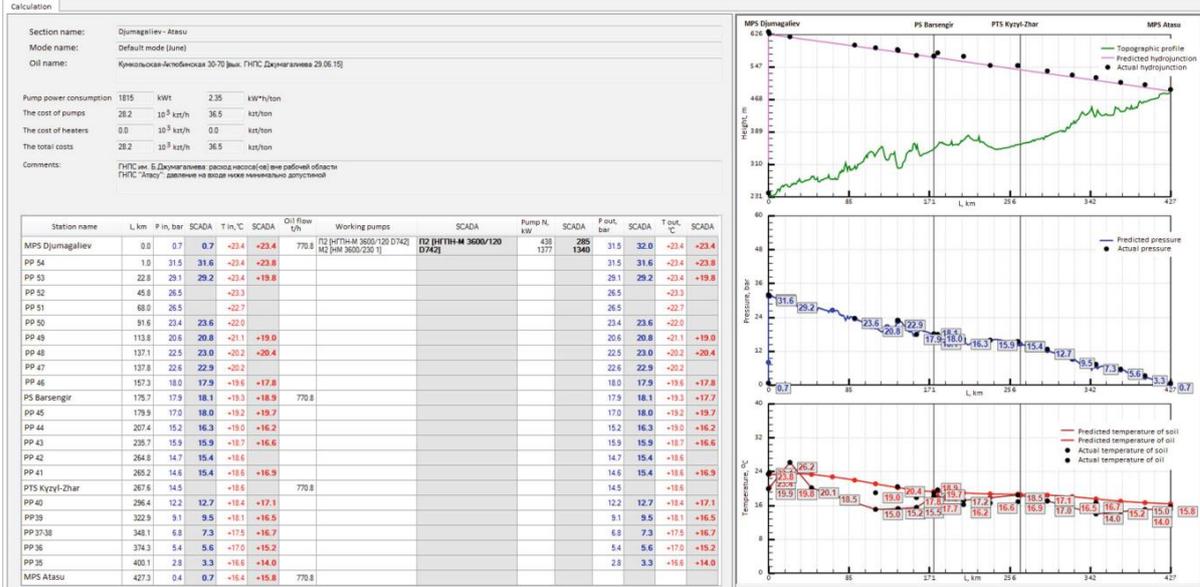
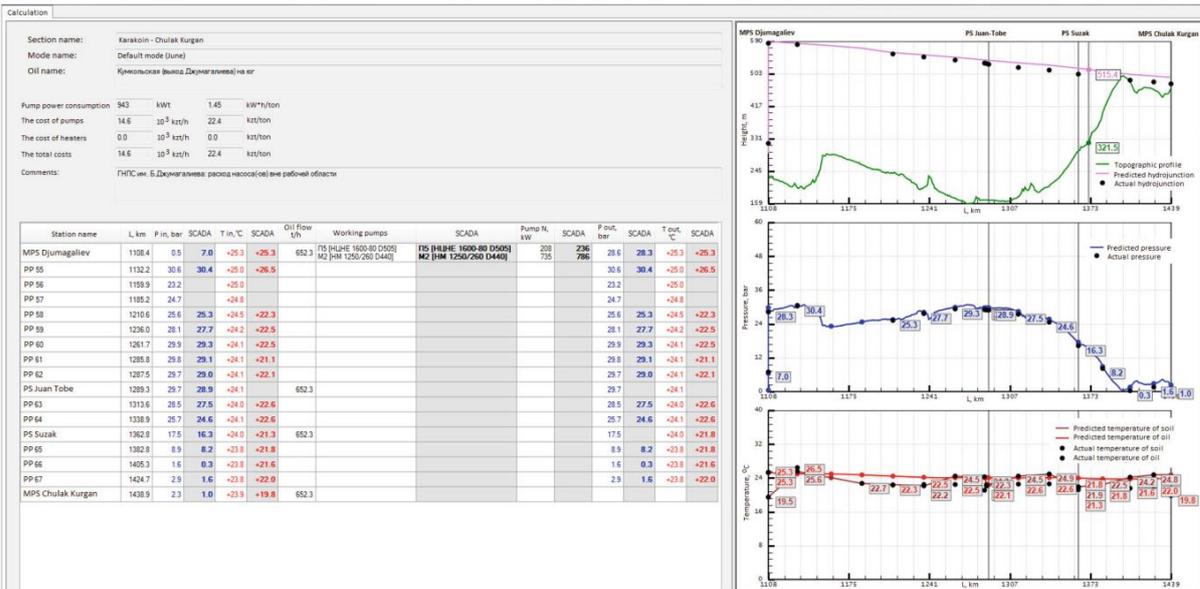


Figure 8. Comparison of Smart Tran and the SCADA system data at the Djumagaliev-Chulak Kurgan section



3. Conclusion

As a result of integration of the SCADA system and the SmartTran, the mathematical model of heat-hydraulic calculations was improved and simulations of various oil transportations modes became more accurate.

The results of simulations using the SmartTran software are in accordance with the field data of the SCADA system. Digital technology based on the SmartTran software and the SCADA system is an effective tool for efficient operation of the main oil pipelines of the Republic of Kazakhstan.

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