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Development of Implementation Chart for Non-Stationary Risks Minimization Management Technology based on Information-Management Safety System

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Abstract: A great number of oil and gas industry enterprises are faced with problems of industrial safety management and risk prognostication at hazardous production facilities these days. The goal of this research is to develop industrial safety for hazardous production facilities by means of non-stationary risk minimization. To meet the challenge of solving the tasks assigned by the research, the following methods were involved: analysis of industrial safety control management methodology for hazardous production facilities in oil and gas complex, assessment, identification and categorization of risks, construction of "event trees" and "fault trees". The study covers analysis of management methodology implementation for industrial safety of hazardous production facilities in oil and gas complex from the practical point of view and it also gives grounds for justification of requirements for application of non-stationary system risks control methodology for solution of tasks connected with industrial safety of hazardous production facilities including transportation of explosive and flammable materials. On completion of research analysis on non-stationary conditions for incident initiation and development of emergency situations a risk minimization management technology has been suggested in order to minimize risks for hazardous production facilities of oil and gas complex, based on a system analysis of the input information and a more reliable prognostication of emergency situations at an early stage of development.

Key words: Industrial safety, industrial hazardous facility (HPF), oil and gas complex, prognostication of risks, minimization of risks, situations

INTRODUCTION

A great number of oil and gas industry enterprises are faced with problems of industrial safety management and risk prognostication at Hazardous Production Facilities (HPF) these days.

The studies carried out by the majority of Russian and Foreign scientists are basically referred to development of methodology for risk analysis and industrial safety assessment of hazardous production facilities where HPFs are viewed as stationary systems with invariable operational parameters concerning the time factor.

However, all known studies reflect practices of application of risk analysis methods in general as a declarative issue and are mostly restricted only by risk assessment in industrial safety declaration for hazardous production facilities not taking into consideration minimization of risks management in the process of long-run operation of technological facilities as non-stationary dynamic systems (Lisanov, 2002; Marshall, 1987).

Lately there have been elaborated new assessment criteria of "integral" and "integrated" risk (Abdrakhmanov *et al*., 2015a, b; Shavaleev and Abdrakhmanov, 2012; Solodovnikov and Shavaleev, 2011) which reflect only final expected damage (evaluated in monetary terms) and are problematic from the point of view of early identification and prevention of emergency and pre-emergency situations, there is also a lack of experimental data for non-stationarity of technological processes.

Moreover, one more vital negative factor in the solution of safety problems now a days can be defined as insufficient attention of researchers and designers of safety systems to preventive management, technical and information security measures in the process of accident-prevention systems design for HPF.

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Only Russian designers have recently started conceptualizing acceptable risk methods based on application of preventive actions of technical and managerial character (Abdrakhmanov, 2014; Savko, 2012; Abdrakhmanov and Shavaleev, 2013) and they are actively elaborating theoretical guidelines of industrial safety adaptive management for HPF.

Oversees, predominantly in the USA, Japan and Great Britain (Anonymous, 1995; Vinnem, 2007), a concept of safety supply is based, in the first place, on the concept of acceptable "absolute" risk, in addition to that a great number of different leading companies in various technological systems of oil and gas complex implement automated operational systems with feedback and regular maintenance of industrial safety control at acceptable level with minimum operating personnel involved.

In general, the results of the carried out research give all the grounds to come to a conclusion that the basic reasons for low efficiency in the sphere of industrial safety control and invalid data acquisition during numerical analysis of risks are defined as follows:

- Insufficient comprehensiveness of statistics as to the risk analysis
- High methodic inaccuracy in the process of input data extrapolation, leading to poor accuracy of emergency situation assessment
- High methodic inaccuracy due to low quality of construction of "event trees" and "fault trees" where expert assessment of hazardous situations is applied
- Insufficient input data collection
- Consideration of HPF safety where HPF is regarded as a static system
- Lack of concern to numerous factors of dynamic changes of information parameters and environment in terms of time representation
- Lack of due control of subjective expert risk assessment which in many cases causes poor informational reliability and does not correspond to reality
- Lack of concern to non-stationarity of technological processes in time
- Lack of consideration for interconnection of dependent and independent random processes during operation of equipment and transportation of explosion and fire hazardous substances
- Inability to assess the impact of non-stationary factors during operation of HPF using experimental methods

In practice though, implementation of the currently applied and unachievable concept of "absolute" hazard factors which does not take into consideration the non-stationarity of technological equipment operation and non-stationarity of technological processes operational working parameters leads to significant accumulation of equipment damage and promotes lack of readiness within emergency response service to take efficient actions for prevention and mitigation of accidents at oil and gas complex enterprises.

The results of the scientific research, presented in studies (Abdrakhmanov *et al*., 2015; Abdrakhmanov, 2014; Shavaleev *et al*., 2013), show that accidents and incidents at enterprises of oil and gas complex are not decreasing these days.

The crucial factor which determines non-stationarity of technological units operation appears to be daily consumption of raw materials and technological capacity utilization rate. Thus, for example, daily consumption of raw materials at certain technological units may differ by 30-35% which leads to significant non-stationarity of technological conditions in operation of equipment. Under these circumstances the non-stationarity of operational parameters which often occur (i.e., pressure, temperature and other parameters) will result in fundamental damage accumulation and as a consequence in accidents.

The other crucial factor which has influence on non-stationarity of the processes is the quality of raw materials processed when corrosion response of the equipment is being monitored (Lisanov, 2002; Abdrakhmanov, 2014; Shavaleev *et al*., 2013). Non-stationarity of operational loads and fatigue damage which occurs as a result are covered in papers (Lisanov, 2002; Abdrakhmanov, 2014).

It is important to pay more attention to particular major factors which cause non-stationarity of technological processes when analyzing the risks. The latter may be evoked by internal and external reasons connected with operation of technological equipment. As essential factors which may cause emergency situations for HPF we determine the following reasons: corrosion and fatigue wear, pressure non-stationarity, temperature non-stationarity, human error, termination of equipment non-failure lifespan (Abdrakhmanov *et al*., 2015; Abdrakhmanov, 2014).

The results of the risk analysis methodology monitoring which was carried out during operation of HPF allow us to emphasize the fact that the problem of considering non-stationarity of technological processes while solving the tasks of risk minimization in oil and gas complex has almost not been taken into account ever before. The technologies of risk management monitoring currently applied for HPF do not consider permanently changing in time non-stationary random character of production processes and their system interconnections (Abdrakhmanov *et al*., 2015).

The aim of this study is to develop industrial safety for hazardous production facilities by means of non-stationary risk minimization.

MATERIALS AND METHODS

For solution of tasks assigned by this research the following methods were used: analysis of methodology of industrial safety management for HPF of oil and gas complex, assessment, identification and categorizing of hazards, construction of "fault trees" and "event trees".

Based on the results of analysis made for research of non-stationary conditions for incident initiation and development aiming to minimize risks we suggest a risk minimization management technology for hazardous industrial facilities of oil and gas complex, based on a system analysis of the input information and a more reliable prognostication of emergency situations at an early stage of their development. Considering that the reasons of emergency situation are usually classified into the following groups which include:

- Deviation from technological regulations
- Equipment failures
- External reasons (natural disasters, catastrophes, subversive acts, etc.)
- Errors of production personnel

Based on the abovementioned classification, regulations of the Russian Federation legislation, Standards of OSHA 29 CFR 1910.119 and EPA RM Program Rule 40 CFR Part 68 and corporate standards of safety management, we suggest application of a well-known model of industrial safety and occupational health and safety management presented in Fig. 1. This model is recommended for development of HPF industrial safety and occupational health and safety system

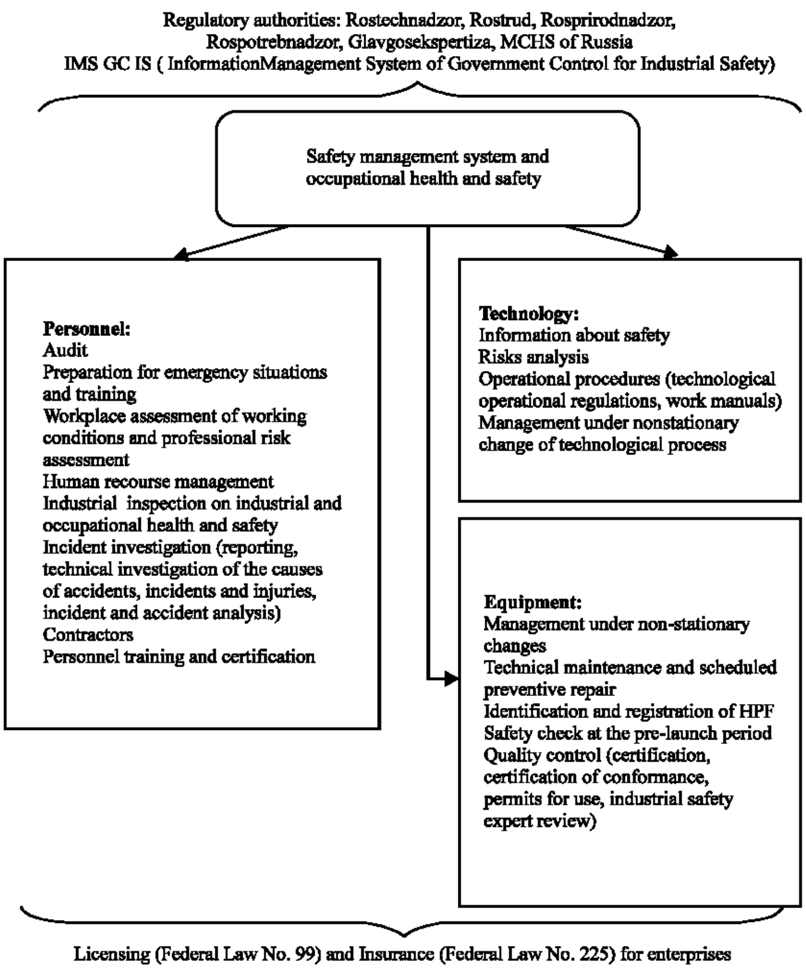

Fig. 1: Model for safety management system and occupational health and safety of oil and gas sector enterprises

(Shavaleev and Abdrakhmanov, 2012; Solodovnikov and Shavaleev, 2011). Let's examine the model in accordance with the current legislation requirements.

The "Technology" block from the point of view of safety issues is outlined in Federal Laws No. 116-FZ "On Industrial Safety of Hazardous Production Facilities" and No. 184-FZ "On Technical Regulation":

- Technological regulations (No. 116-FZ, No. 184-FZ, PB 09-563-03, FNP No. 96, dated 11.03.2012, FNP No. 101, dated 12.03.2013, etc.)
- Safety certificate for Potentially Hazardous Facility (PHF) (Order of Russia MCHS, dated 04.11.2001 No. 506)
- Declaration of Industrial Safety (No. 116-FZ, RD 03-357-00, RD 03-14-2005, RD 03-418-01, PB 03-314-99, etc.)
- Emergency Response Plan (No. 116-FZ, No. 69-FZ, FNP No. 101, dated 12.03.2013, etc.)
- Emergency situations response plan (No. 116-ФZ, FNP No. 96, dated 11.03.2012, etc.)
- Prevention and Mitigation Plan for Oil and Oil Product Spills (No. 68-FZ, No. 174-FZ 1996, No. 7-FZ, etc.)
- The 3 dimension model of PHF (MCHS directive, dated 03.02.2009 No. 7-3-3113)

The model elements of the block named "equipment" are used for execution of the documents such as:

- Permit for application of technical devices (FZ No. 116)
- Certification or declaration of conformance (FZ No. 116, FZ No. 184)
- Guidelines (manual books) for operation of a machine or equipment (technical regulations of CU "On Safety of Machinery and Equipment")
- Testing after start-up and commissioning (Construction Rules and Regulations 3.05.01-85, 3.05.05-84)
- Facilities identification (FZ No. 116, administrative regulations)
- Scheduled preventive repair (GOST (State Standard) 18322-78, GOST R ISO 17359-2009, etc.)
- Technical condition of equipment monitoring (GOST R 53564-2009);
- Industrial safety expert review (FZ No. 116)

The "personnel" block in the given model is central in the process of safety management system design. The statistics for HPF show that more than 60% of accidents are related to human factor (errors, rejects, violation of the labour discipline during design, construction and operation). Let's examine the "Personnel" block elements:

- Training and certification of managers and specialists (Rostechnadzor order No. 37, dated 29.01.2007)
- Cooperation with other organizations-contractors (as a rule are outlined in internal regulations of an industrial enterprise)
- The procedure of incident investigation (FZ No. 116, Administrative Regulations, approved by the order No. 191 of Ministry of Natural Recourses, dated 30.06.09)
- Occupational health and safety and industrial control organisation in the sphere of industrial safety (No. 116 FZ and GOST)
- Human recourses management (as to fulfilment of job duties and (or) competency-based personnel appraisal)
- Preventive measures for undesired events, etc.

RESULTS

The developed model of industrial and occupational health and safety management system for the enterprises of oil and gas complex allows us to formulate the principles of risk minimization management for operation of fire and explosion hazardous facilities at such enterprises.

The principles of system analysis of technological information and information model of emergency situations identification and forecast at the facilities of transportation of fire hazardous materials and operation of equipment for processing of hydrocarbon materials under pressure have been worked out and scientifically interpreted with the methods of "fault trees" and "event trees" construction.

The study developed new principles and requirements for design of information management system of emergency situations prevention and management of non-stationary risks minimization when HPFs are in operation.

The given model of management technology is put into practice as part of an information-management system of an exemplary typical enterprise which operates oil and gas equipment and inter-facility pipelines. The model that is developed (on the basis of the information-management system of a typical enterprise which operates oil and gas equipment and pipeline systems and applies the concept of risk minimization) consists of the following elements of technology, based on application of non-stationary correlation models and adaptive feedback with HPF:

- Technology of design for safe operation of HPF (CAD safety) in the "off-line" mode
- Technology of quantitative risk assessment, based on modelling of non-stationary technological processes
- Technology of geo informational modelling for affected zones and incident scenario development considering non-stationarity of technological processes
- Technology of HPF operation, based on correlation analysis of technological processes in the "on-line" mode
- Automated system of rapid monitoring and risk minimisation management, gathering all modules of technological units with emergency automation into one local network
- Automated system of risk minimisation, based on minimisation of financial and energy expenditures related to containment and mitigation of emergency situation consequences

The functional scheme of the technology elaborated for non-stationary risk minimisation management is presented in Fig. 2 (Abdrakhmanov, 2014). The technology is comprised of 7 technological subsystems:

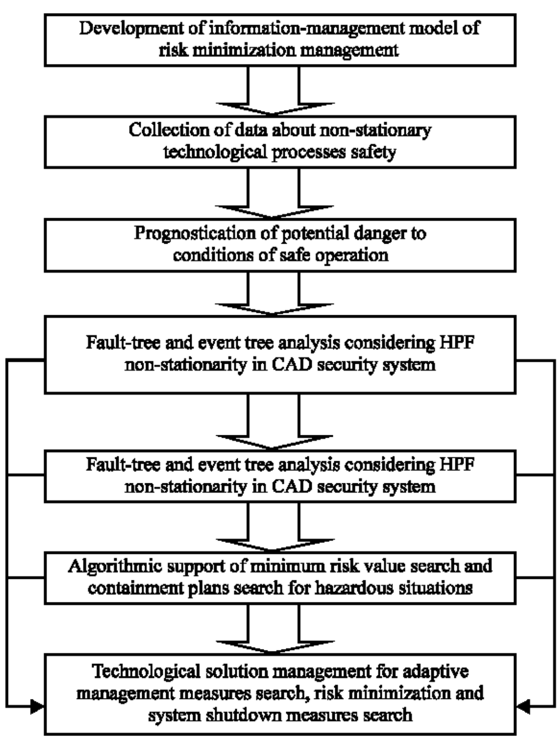

Fig. 2: Functional chart of implementation of risk minimization management technology on the basis of information-management system of safety

- Subsystem of information-management model development for risk minimisation management. The model is based on correlative modelling of non-stationary risks
- Subsystem of data collection and creation of a database about safe operation of technological units and about equipment failures
- Subsystem of prognostication of potentially dangerous conditions which put safe operation of technological equipment under threat, based on analysis of probability-statistical models of emergency situations detection
- Subsystem of "fault tree" and "event tree" analysis, based on consideration of non-stationary of processes and events using "CAD Security System"
- Subsystem of monitoring and immediate analysis of emergency situations probability at an early stage of their arising, called "SAW Security". It allows to provide early detection of pre-emergency situations in the on-line mode and emergency shutdown if needed
- Subsystem of algorithmic and software supported search for minimum risk value and plans of pre-emergency situation containment and response
- Subsystem of technological solution management for adaptive management measures search, risk minimization and system shutdown measures search

Stage 1 of the developed system database uses GIS-technology for the subsystems of the given technology as integrated databank of an enterprise with application of DBMS Oracle and GIS Arc/Info. The technology of access and build up of the integrated databank of an enterprise is based on Client Server Architecture where the "Client" corresponds to GIS Arc/View (Savko, 2012; Abdrakhmanov *et al*., 2008; Shaybakov *et al*., 2008).

Experimental testing of the technology, developed by the authors and the HPF information-management system, described in this paper, showed the degree of technical risk reduction three levels down (Koptev, 2000; Shavaleev and Abdrakhmanov, 2012; Shavaleev *et al*., 2013).

DISCUSSION

The given functional chart of risk minimization concept (Fig. 2) will provide acceptable level of security and is aimed to prevent emergency situations by application of projects for safe location of technological equipment modules with consideration for affecting factors, installation of programmed controllers, shutdown equipment, protection screens, appropriate venting systems, application of automated systems of valve control and other protection technologies which provide the required level of security both in the "Off-line" CAD Security System and in the "On-line" mode in "Automated Workstation Security" system of the information-management system we present. Note, that risk minimization value must correspond to probability of system elements failure considering non-stationary of technological processes (Abdrakhmanov, 2014).

Testing of the first stage of "IUS-Safety" and the new technology of management was carried out by the authors at pilot facilities in the period of 2000-2013 (Abdrakhmanov, 2014).

Column equipment and heaters of technological units as highly hazardous production facilities of oil and gas complex were used for the testing. The system of emergency shutdown was supplied with auxiliary equipment of broadband acoustic vibration sensors for bearings, temperature sensors and pressure sensors for pumping equipment. At the same time the startup and the shutdown of pumps were secured by installation of controlled valves on the lead lines and the pressure lines of the pipeline with the help of feedbacks provided by the risk minimization adaptive management system.

To avoid the chance of petroleum products and explosive vapor-gas mixture ignition vapor concentration sensors were installed and that allowed preventing ignition even in conditions far beyond permissible concentration limit.

As long as the modules described in this research are hazardous in terms of fire and explosion, the system of emergency shutdown "IUS-Safety" was equipped with computerized technologies of immediate monitoring, control and shutdown through automatic blockings which shutdown the pumps, supplying the heat carrier.

In the process of emergency situations scenarios design based on data, taken from "CAD-Safety", the units and the modules of columns were equipped with level transmitters which secured continuous supply of oil, steam, electric power, air and fuel and were constantly monitored. Apart from that there were installed supplementary sensors of gas contamination for the territory. The columns and the column units were also supplied with sensors of residue level, sensors of temperature in the upper part of the column and pressure sensors with corresponding gauging units connected to "automated workstation operator" of an information-management system.

To secure safety for heating modules operation on the lower level of "IUS-Safety" the researchers utilized the following computerized units of the emergency shutdown system, connected to the system "automated workstation operator" (Abdrakhmanov *et al*., 2014; Shaibakov *et al*., 2008):

- Measuring unit of hydrocarbon concentration in the vented gas
- measuring unit of hydrocarbon concentration in the environment
- Measuring unit of level in a condensate gathering tank
- Block of regulation for emergency bypass valve for product inflow into the coil
- Heating chamber flame monitor

In addition to that the system of immediate safety monitoring was supplied with a measuring unit which performed fuel pressure control within entire refinery local network.

The developed subsystem of lower level "IUS-Safety" system is aimed at securing the following modes of safety for HPF operation (Abdrakhmanov *et al*., 2015; Abdrakhmanov, 2014):

- Compliance of the raw material nominal values volume supplied with the requirements of the project design
- Compliance of the preheated raw material temperature with the optimal values
- Compliance of the bottom temperature with the temperature of the raw material supplied and the temperature of the cool reflux
- Feeding of optimal volume of fuel onto the burner of a directed module
- Checkup of pumps and pumping equipment working condition
- With the cool influx temperature increase performs automated air cooling
- A startup of a standby discharge pump with shutdown of the faulty one done both in automated and in manual modes through automated workstation operator in case of product pumping out reduction
- When the raw material consumption increases the system regulates it down to the optimal level with a bypass switch on and the primary valve shutoff in case of its failure
- Secures compliance of the injection pressure of the pump, feeding the product into the heating module with the pressure, measured at the module
- In case of pump malfunction it secures its shutdown and startup of a standby pump

All facts of operational modes irregularities are registered in the database by an operator and transmitted automatically via information computer network up to the higher levels of information management system for making management decisions. The results of the industrial automatic monitoring and shutdown emergency system testing on the lower level of "IUS-Safety" gave grounds for numerical assessment of risk level based on the technology of risk minimization. The application of the algorithm for calculation of emergency situation initiation and development probabilities allowed to decrease risks of emergency situations by three levels which comes to the value of 8.0×10^{-6} (Abdrakhmanov, 2014).

In some scientific studies by Shavaleev *et al*. (2013) and Abdrakhmanov *et al*. (2013, 2015) researchers developed, suggested and presented fundamentals for ecological and industrial safety for HPF with application of innovative technologies of management, based on minimization of fire and explosion hazardous factors and which is more significant, minimization of toxic hazards, therefore, opening chances for prevention of environment pollution caused by oil product emission and environment contamination in general. Application of the technological optimization methods will also allow us to minimize non-stationary technical risks during operation of HPF and secure detoxication and entrapping of volatile organic and sulfuric compounds together with techniques and technical measures taken for minimization of contamination in the process of oil equipment operation as well as in the process of oil treatment, transportation of oil, gas and petroleum products.

The analysis of harmful impact on environment caused by enterprises of oil and gas industry in the Russian Federation shows that now a days the tendency of increasing volume of contaminants being emitted in the process of oil equipment operation, oil, gas and petroleum products transportation is still growing which is well explained by rapid growth of industrial potential in oil and gas complex of the Russian Federation.

Most hazard production facilities and technological pipeline systems do still operate at the moment using obsolete technologies and worn down equipment and in many cases are located close to big residential areas, when even up-to-date industries are sources of hydrocarbon atmospheric pollution, contamination with sulfur dioxide, carbon oxide, nitrogen oxide and other toxic substances which being transported to groundwater aquifers and water bodies become dangerous. Taking into account all those factors, we must admit that the demand for development and implementation of HPF industrial and ecological control and monitoring system including monitoring of hydrocarbons and hazardous chemical compounds transportation pipeline systems performed in on-line mode becomes indisputable.

Successful development and application of new efficient technologies for reduction of hazardous substances emission into the atmosphere such as Volatile Organic Compounds (VOC), Carbon Oxide (CO), Nitrogen Oxide (NO_x), Sulfur dioxide (SO_2) and other may be advanced by fulfillment of requirements of the legislative and regulatory acts referred to minimization of technical risks. Nevertheless, the issue of primary importance will be given to development and implementation of new technologies of industrial safety control for HPF including facilities for transportation of fire and explosion hazardous substances.

Theoretical and practical bench experiments gave the authors grounds for formulation of the following requirements to the system of immediate industrial and ecological safety control for HPF, pipeline transportation systems which use technology of risk minimization with the aim to improve ecological safety of operation (Shaybakov *et al*., 2008; Abdrakhmanov, 2014; Abdrakhmanov and Shavaleev, 2013).

Fundamental requirements which were applied for operational monitoring of pipeline transportation systems and equipment are as follows:

- The management system must consist of a measurement and control module and a feedback module
- The management system must provide control of non-stationary processes in the "On-Line mode" in linear sections of a pipeline as well as in manifold including intersections, pumping units, valves, filters, check valves, etc
- The feedback module in the system of management must perform control over the throughput of pumping units and the consumption in the optimal modes which will ensure that the pumping parameters stay in compliance with the given operating mode parameters determined by the technological card
- The system must allow switching on a module of a shock wave absorber
- The system must be supplied with a switched-on module of emergency protection system for the pumping units, working under minimal and maximum pressure at the inlet and the outlet of the pumping stations with a maximum pressure drop on the gates of the pressure regulator
- The system must be supplied with a module of immediate control for pipeline walls and the wall mode of deformation

It is essential to mention that distinctive feature of the system of immediate monitoring and control presented in this study is the possibility of regulation of risk non-stationarity in the on-line mode when there is no need to perform complicated mathematical calculations for modeling of operational troubles and modes of hydrocarbons flow in the pipeline systems, furthermore, efficient operational monitoring and ability to timely regulate the modes of the pipeline systems in operation on the basis of minimization of the non-stationary risks for the first time enable us to solve the following tasks:

- Troubleshooting of side effects generated by multiphase flows of the products transported
- Decrease of the pressure pulsations of the liquid-gas mixture pumped through the pipeline
- Troubleshooting of complications connected with reduction of flow area or full blockage of pipeline system due to the gas and water blocks
- Elimination of corrosion wear of the pipeline caused by the presence of moisture in the product transported and building-up of hydrates under corresponding temperature and pressure
- Ensuring of operational reliability and power efficiency of pipeline transportation system operation

The systems of immediate monitoring for operation of the pipelines which are used now a days are predominantly, aimed at spotting of leaks of the hydrocarbons transported through the pipelines (LeakSpy NT systems designed by LLC “Energoavtomatika”, Sherlog Security Pipelines by “Technology”, the Czech Republic, Tyumen State Oil and Gas University system, etc.) and all of them are not capable of early detection of pre-emergency situations through the entire length of the pipeline system, let alone preventing operational complications along the pipeline route (Abdrakhmanov, 2014).

CONCLUSION

As a result of this research new requirements to the design of information management safety systems development for non-stationary HPF operation in oil and gas complex have been worked out. Principles of IT support for minimization of non-stationary risks management technologies have been suggested and developed.

Technology and the model of information management system for risk minimization have been suggested and developed.

Industrial testing results of the given technology application showed that it has proved to be a notable method to reduce synergetic risk for emergency situations occurrence by three levels.

The given research formulates principles of risk minimization management for operation of fire and explosion hazardous equipment at enterprises of oil and gas complex based on industrial and occupational health and safety management model for the abovementioned enterprises. The presented model of management is applied in the industry as part of information-management system for an exemplary typical enterprise which operates oil and gas equipment, we also have suggested a functional scheme of management for minimization of non-stationary risks.

General requirements, taken as crucial factors of immediate monitoring and control of non-stationary risks will allow to apply a new approach to creation of remote-monitoring for accident free operation of hazardous facilities in various operational conditions.

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