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RESEARCH ON PREDICTIVE MANAGEMENT SYSTEMS AND ANTICIPATORY MAINTENANCE TECHNOLOGIES OF PIPELINE TRANSPORT INFRASTRUCTURES

BY

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Abstract. The paper aims to evaluate the state of predictive management technologies for reducing crude oil losses reducing costs and operating problems, improving the reliability and flexibility of technological installations, and minimizing the negative impact on the environment. In this research, we evaluated the qualified technological documentation of a crude oil transportation company, the factors that affect the efficiency of maintenance management, and the technological risk, analyzing the risks through the MADS technique. The decision to evaluate the integrity of the pipelines is essential to efficient maintenance scheduling, minimizing technical accidents and the risk of spills into the environment. By managing risk, a maintenance process optimization system can operate efficiently and reduce downtime, increasing process reliability and performance through effective management and implementing appropriate strategies to enhance safety, reduce costs, and improve operational efficiency.

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1. Introduction

The maintenance of main or secondary pipelines intended for the transport of petroleum fluids, be they liquid, biphasic or gaseous, crude or finished, is part of the daily activity of those who work in this field.

Also checking, replacing and repairing pumping and monitoring equipment related to piping systems are routine maintenance activities.

If at the beginning of the pumping of petroleum fluids through pipelines, maintenance was carried out, following the observation in the field of the behavior of the transportation systems of petroleum fluids (crude oil, gasoline, ethane), by remedying any breakdowns and damages of the analyzed system, with the passage of time the basics of predictive maintenance and especially maintenance based on the interpretation of the results of non-invasive (non-destructive) inspection of installations.

Starting from the definitions of the standard "ISO 31000:2018, Risk management - Guidelines on the principles and implementation of risk management" (ISO 31000:2018), in a first stage of the risk assessment process, we identified and detected the sources, eventuality and circumstances the occurrence of unwanted events and their potential consequences.

We mentioned that in the specialized literature there are standards that are useful in the maintenance of petroleum fluid transport pipeline systems, but little applied in the Romanian industry, namely (ASME 2010):

B31.4, "Transport systems for liquid hydrocarbons and other liquids" (2016 edition) (www.asme.org);

B31.8, "Gas transport and distribution pipeline systems" (2016 edition) (Specific-technical-norms-are-the-maintenance-of-adjustment-measuring-stations-control-valves-and-nodes- technological);

B31.8S, "Managing the integrity of the gas piping system", supplement to B31.8 (2014 Edition) (Specific-technical-norms-are-the-maintenance-of-regulating-measuring-stations-control-valves- and technological-nodes);

B31G, "Manual for the Determination of Residual Strength of Corroded Pipelines" (2012 edition) (www.asme.org);

B31Q, "Qualification of Pipeline Operating Personnel" (2016 edition) (www.asme.org).

The API standard 5L:2005 – "Specifications for pipelines", integrated by the standard ISO 3183:2007 (Amended) "Oil and natural gas industries - Steel pipes for pipeline transportation systems" (ISO 3183:2007), provides for systems for transporting petroleum products, techniques for determining defects of nature: electromagnetic (magnetic flux and high-frequency currents);

ultrasonic (in the table or at welds); magnetic particles; radiography; penetrating liquids (B31.8).

Following the determination of defects, it is possible to create a maintenance plan whose objective is to reduce the operating pressure according to the ASME B31G standard "Manual for the determination of the remaining resistance of corroded pipes" (2012 edition) (www.asme.org) and pipe repair.

2. Considerations on the general framework in which anticipatory maintenance is applied

Considering the environmental and economic penalties applied in the event of an accident, it is absolutely necessary to design interventions and maintenance (at minimum costs) of the pipeline system to eliminate any accident.

Obviously, oil spills are an important environmental issue for the oil industry. Preventing leakages in operations and other types of leakages (for example, caused by sabotage or natural hazards) and managing and remediating leakages resulting from an incident is practically the preservation of an important part of the profit, present and future, because such events impact significantly all interested parties, with major concerns related to the negative potential associated with hydrocarbon losses/leaks, such as: environmental authorities - non-compliance with environmental legislation; employees and businessmen - safety and health issues resulting from such incidents; NGOs – preventing damage to the environment and the human community; companies and shareholders – profit reduction due to intervention and repair/greening costs and the damage to the company's reputation in the business environment and on the stock market.

Measures to prevent and control leakages generated by technical breakdowns or sabotage consist of identifying the sources of danger and assessing the associated risks; applying preventive maintenance to avoid pollution; creating action plans for emergencies, including the supply of materials and equipment necessary for rapid intervention in case of oil pollution; the implementation of procedures for the greening and restoration of the affected areas to their original state.

It goes without saying that spill prevention and control measures have a significant counterpart in the costs associated with the activity of hydrocarbon transport. On the other hand, much higher costs involve ignoring the technical condition of the pipelines, translated, as effects, into the production of accidents resulting in leakage of petroleum products.

This is where the most visible role of preventive management is manifested, i.e. carrying out minimal but sufficient expenses to eliminate major accidents and reduce minor accidents and spills to the minimum possible (Chiș, 1996).

The oil industry and especially the industry of transportation of oil products through pipelines is an industrial activity where eliminating unacceptable risk is not possible, but the interval in which it can occur can be increased. Determining the level of unacceptable risk for the company is based on an assessment that takes into account the specific circumstances of each case, as well as the seriousness of the impact that the risk may have on the health and safety of people and the environment. This includes the analysis of possible negative effects, their durability and reversibility, as well as the delayed effects of the respective incidents.

In the oil industry, prediction is used as a risk reduction technique, which through the rigorous investigation of accidents occurring both in the studied facility and especially in facilities of the same design and manufacture and the proposal of maintenance and control techniques for the facilities, leads to ultimately reducing risk (Pavel, 1981) (Fig. 1).

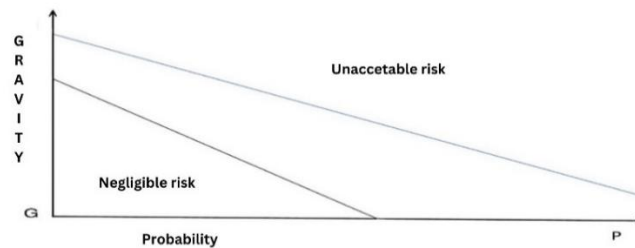


Fig. 1 – Fields characteristic of technical risk.

2.1. Factors influencing technological risk

To carry out a technological risk analysis in a functional oil installation, all risk factors must be identified: intrinsic (specific to the system, mainly manufacturing defects); specific to the exploitation stage, being associated with the location conditions of the pipelines; the human factor, permanent as a manifestation.

Usually, the human factor has an effect on oil installations at all stages of the technological process, starting from the design phase (in which the increase in reliability and maintainability is achieved), continuing with the technological exploitation phase and ending with the maintenance phase.

As a consequence, the technical accident can be seen as a convergence of several dysfunctions, understood as anomalies, deviations from the proper functioning of the technical-technological system and which are likely to lead to its failure or damage.

The prevention of technical/technological accidents through risk analysis (hazard analysis) involves the use of quantitative and qualitative methods of analysis of technological systems (from the design stage to the decommissioning stage).

For example, we studied risk analysis methods, the most used being: "Method for Analysis of System Dysfunctions" - MADS-MOSAR (Popescu and Pavel, 1998), the analysis method on the basis for building the event tree, the method of evaluating previous accidents, the method of parametric evaluation of the consequences of not taking protective measures in the operation of technological installations (Law no. 59/2016).

The MADS reference model of the evolution of the state of danger presents the risk factors that appear and manifest within the field of the state of danger (Bouloiz *et al.*, 2011).

The field of hazardous conditions can damage the physical integrity of oil installations.

The following are also affected: the health and physical integrity of the employed staff, the health and physical integrity of the population, the quality of the environment.

Although the activities in the oil installations are continuous, accidents cannot be anticipated.

The analysis of statistical databases of chemical accidents leads to the formation of an overall picture of the possibilities of accidents and the high degree of danger.

At the same time, by studying technological accidents (Pavel, 1988) at oil facilities I managed to determine the following aspects of their production, starting from the fact that most major technological accidents occur in oil treatment facilities and then in the transport and distribution industry (72% vs. 28%).

In operation, there are: accidents in current operation - operating errors (27%), accidents occurring during maintenance activities, repairs (29%), also a significant number of accidents were found during the start-up and shutdown operations of the facilities oil companies (56%).

It should be remembered that not only serious, major accidents have a great impact on the environment and health, but also accidents considered less serious (Moraru and Băbuț, 2010).

They have a high probability of occurring and result in the accumulation of toxic substances in water or soil.

In conclusion, we can state the following: risk is present in real life and in the oil industry; even if all measures were taken to eliminate it, there is a residual risk; after the accident at Seveso (10.07.1976), its evaluation was imposed by the directives of the European Union. (Directive 2012/18/EU - SEVESO III)

2.2 The MOSAR-MADS method

Introductory information

The MOSAR-MADS method is part of the risk analysis techniques in the oil industry (Perilhon, 2000).

This method was designed by an interdisciplinary research group, within the National Institute of Nuclear Science and Technology, belonging to the European Community. At first the technique was used for the nuclear industry, then being successfully introduced for the analysis of chemical and petroleum systems (Popescu *et al.*, 1998).

The MOSAR method (Organized and Systemic Risk Analysis Method) can be described as a complex risk analysis method, showing a high degree of generality.

The method is based on the analysis of the destructive effect of a hazard provided by a source (Fig. 2).

The MOSAR method is useful in the oil industry, being applicable to the occurrence of a risk that can produce chain accidents or incidents (domino-type) (Băbuț *et al.*, 2009).

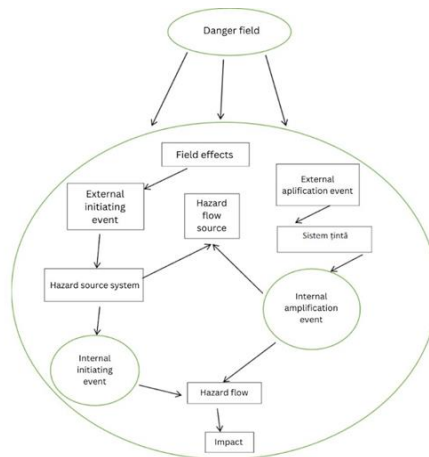


Fig. 2 – Impact of a hazard flow on a target (Pavel, 1981).

Structure of the MOSAR-MADS method

The MOSAR method results from the merging of two analysis modules, namely module A (Macroscopic risk analysis and identification of the behavior scenarios of the system affected by the risk) and module B (Detailed analysis of the scenarios identified within module A).

Macroscopic risk analysis

This module approaches the issue of risks from a macroscopic view of the investigated system. By highlighting the sources of malfunctions, respectively by removing them in stages using the causal relationships, a preliminary analysis of the main risks results (in the sense of identifying and neutralizing the scenarios of near miss accidents), but does not insist on the details regarding the operation or technological exploitation of the system.

Detailed analysis of risk scenarios

Module B carries out a probabilistic approach to what the possibility of risks means, in the circumstances of a detailed analysis of the studied system.

The risk analysis method considers the identification of all possible dysfunctions, which are grouped by characteristics.

After an examination of the information regarding the technological functioning (exploitation) of the system as well as the analysis of its maintenance techniques, the analysis of the influences of disruptive factors follows (Popescu and Pavel, 1998).

It is also analyzed: the interdependence of the essential variables of the technological process; the appearance of human errors in the operation process, as well as in the maintenance process; the possibilities of producing technical accidents, making it possible to optimize the placement of prevention barriers within the general failure trees.

Risk analysis using the MOSAR method

The risk analysis is carried out as follows:

a. the malfunctions of the investigated system are identified - this stage involves the identification of all the factors that can cause a risk in the operation of the technical systems;

b. the risks are evaluated - it consists in evaluating the consequences of technical accidents in the studied facility and their probabilities of occurrence.

In this case, the risks are ranked in the following categories: negligible, acceptable and unacceptable;

c. trying to reduce unacceptable risks - this stage involves establishing the methods, means and procedures intended to prevent the occurrence of major accidents and / or neutralize their effects;

d. the last stage consists in the control of residual risks. The establishment of crisis measures, plans and strategies is considered.

2.3. Stages of risk analysis*Analysis of risk factors*

The risk factors of a crude oil pipeline installation can be systematized as follows:

a) intrinsic factors. These factors are associated with the design and realization phases of the technological process. These factors often express the manufacturing defects of machines and technologies. The risk area is associated with the entry into operation of technologies (Fig. 3);

b) factors associated with operating conditions. They are factors that affect the technological system and can appear throughout its operation. There are factors that can also affect the territorial location of technological installations (Fig. 4);

c) the human factor involved in the exploitation phase. The human factor manifests itself in the process of producing accidents, throughout the existence of the analyzed system, so it must be taken into account in the risk assessment.

In the risk assessment process all these factors must be studied being in an interdependence throughout the existence of the technical installation (Cosham *et al.*, 2008).

Also, these factors are also in a mutual conditioning.

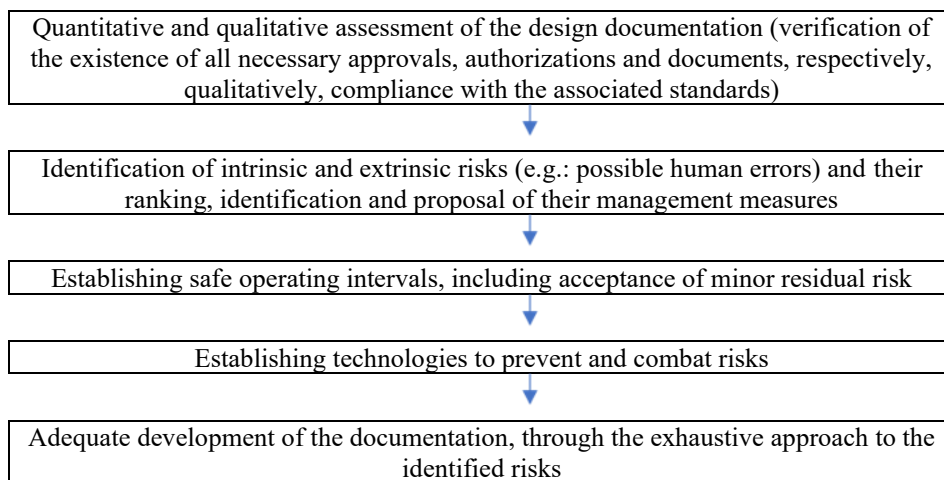


Fig. 3 – Risk analysis in the design stage.

Risk factors associated with human errors in the transportation of petroleum products can be grouped as follows:

- a) Technological exploitation: Organizational factors - inadequate organization and Physiological factors - fatigue, inattention, illness;
- b) Maintenance: Psychological factors - stress, communication errors; Social factors - labor relations; Economic factors - salary motivation.

The stages of solving risk analyses

The following steps are taken to assess the risk (Fig. 4):

1. The technological installation subject to risk analysis is established,
2. The working area of this installation is identified,
3. The interdependencies of the technological installation with the work environment (surrounding) associated with it are established,
4. Risks are identified,
5. The sources of risk production are identified,
6. The intrinsic, adjacent, external, conjunctural and human risk factors of the studied system are analyzed,

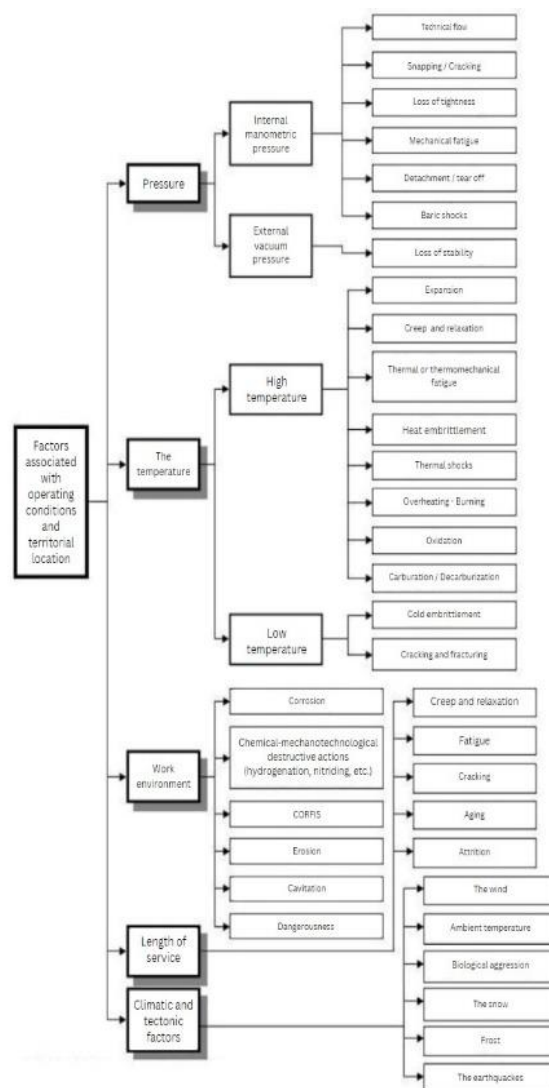


Fig. 4 – Factors associated with operating conditions (Popescu and Pavel, 1998).

7. Quantitatively and then qualitatively assess the possibility of accidents (quantitative and qualitative risk factors), using the MADS method;

8. Quantify the consequences of the analyzed risks that may manifest themselves,

9. The risks are ranked and the evaluation criteria are substantiated. Consequences are also ranked,

10. The residual risk acceptability limits are established,

11. Preventive actions necessary to limit and combat the effects of risks are proposed and developed.

Risks have the final effect of preventing major accidents and neutralizing the effects of risks.

After the implementation of risk reduction techniques and devices, their monitoring stage follows.

Also, the documentation resulting from the risk analysis is permanently completed.

The purpose of the qualitative and quantitative risk assessment is to analyze and prioritize the risks that appear and especially to limit the residual risk to a minimum (Popescu and Pavel, 1998).

Risk analysis using the MADS technique

Risk analysis by the MADS method involves the study of hazard states (field analysis of hazard states).

The field of danger states manifested on the technological process is identified by analyzing the material systems of the process and the integrity of the employed personnel.

Also, the integrity of the population around the facility and the quality of the environment in the area of the objective are analyzed.

In the field of danger states, there is an interaction between the existing systems.

Also, there is an interaction between the main event (transmitting the hazard stream) and the final product of the technological process.

The hazard flow represents a transfer of matter, energy and information, which negatively affects the technological system. The transfer of hazard flow is done from the source to the target.

At the level of the interaction between the source and the target, protective barriers (preventing the evolution of the danger state) are foreseen.

These barriers are necessary: to neutralize the source of danger and to protect the target.

Also, the protective barriers must also ensure the neutralization of the danger flow, the effects of the field of danger states.

Risks are classified into acceptable (or residual) risks and unacceptable risks (where interventions must be made to reduce them, with a tendency - at least theoretically proposed, as desired - to eliminate them).

In specialized literature, the probability of an accident occurring is expressed by the number of events/accidents occurring in the unit of time (hour or year).

The production of technical accidents is qualitatively probabilistic: improbable; extremely rare; rare; likely; frequency.

Finally, we can say that risk analysis involves determining the probability-gravity grid (p – G) and establishing the acceptability limits (of the residual risk) of the hazard (DEPOMURES SA Security Report).

It is also necessary to rank the risk/operation scenarios, their classification and the ranking of the intervention to limit the risk (installation of risk reduction barriers).

The probability-gravity analysis grid is therefore a graphic representation of the correlation that is established between the probability of a technical accident and the severity of its consequences on potential targets.

The grid field allows the delimitation of residual (acceptable) risk from unacceptable risk.

Not at all paradoxical, the bigger (unacceptable) a risk is, the more effective the measures to remove it are, because not any insignificant event can cause this risk to materialize, but only major causes, major, flagrant, far-reaching errors, therefore, relatively easily identifiable and, as such, treatable preventively.

The elimination of unacceptable risks consists in preventing the production of unacceptable scenarios (Fig. 6).

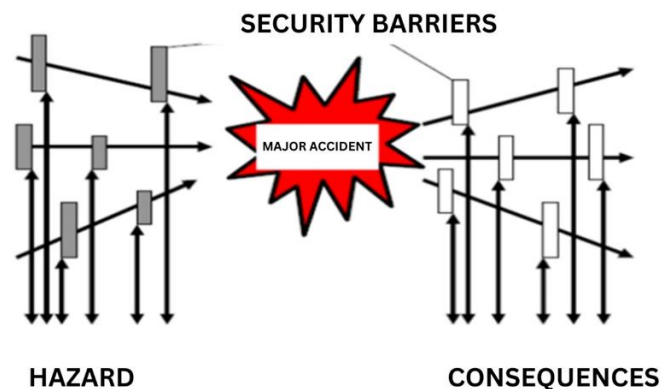


Fig. 6 – Security system logic of an oil process.

The applicability of the MOSAR methodology within the analyzed company allowed:

- identifying hazards that can cause incidents that could lead to a chain effect. For example, an oil spill could start a fire, and this fire could affect other facilities or equipment;
- implementing preventive measures such as physical protections, more rigorous control processes, or staff training;
- creating detailed plans to respond effectively in the event of an incident;

- analyzing some possible scenarios to evaluate the behavior of the systems under risk conditions and to understand how an incident in one part of the installation can affect the entire system;

- constant monitoring of risks and evaluation of the effectiveness of implemented measures, to continuously improve safety management.

In the oil industry, where the risks are high, for example, in the case of oil spills or explosions, the application of the MOSAR method helps to prevent serious events and protect not only employees but also the environment.

2.4. Assessment of the integrity of the pipelines according to the ASME B31 G standard

The general loss of metal in the case of pipelines, which are assimilated to components under pressure, is due to the processes of corrosion, erosion or combinations thereof.

Due to the effect of corrosion during exploitation, the wall thickness of the pipeline is reduced leading to the rupture of the pipeline, when exploited at the initial design pressure.

In these conditions, the pipe will be repaired, replaced or operated at a reduced pressure.

The use of the pipeline at a reduced pressure is done when the length of the corroded area is greater than is allowed by the relations (1), (2) according to the studies and researches regarding the development of technologies to remedy the defects detected on the tubular material of the transport pipelines (Evaluation of pipeline defects, Studies and researches regarding the development of technologies for the remediation of defects detected on the tubular material of transport pipelines, CONPET S.A.).

$$L = 1,12 \times B \times \sqrt{D \times g_n} \quad (1)$$

in which:

L = maximum permissible longitudinal extension of the corroded zone

B = a value that does not exceed the value of 4.0 and that can be determined with the relationship:

$$B = \sqrt{\left(\frac{\frac{c}{g_n}}{\frac{1,1 \times C_n}{g_n} - 0,15} \right) - 1} \quad (2)$$

D = nominal outer diameter, inches

g_n = nominal wall thickness, inches

c = maximum depth of corroded area, inches

The reduced pressure at which it is safe to operate will be determined by relations (3), (4), ensuring that the corrosion is not longitudinal (where applicable), circumferential welds or in areas affected by heating: (Evaluation of pipeline defects, Studies and researches regarding the development of technologies for the remediation of defects detected on the tubular material of transport pipelines, CONPET S.A.).

$$G = \frac{0.893 \times L}{\sqrt{D \times g_n}} \quad \text{dimensionless parameter} \quad (3)$$

and for values of $G > 4$ the relationship will be used:

$$P_d = 1,1 \times \pi \left(1 - \frac{c}{g_n} \right) \quad (4)$$

except that P_d does not exceed P_i

P_d = reduced pressure SI (Pa)

P_i = initial design pressure SI (Pa)

The defect evaluation procedure is given in Fig. 7.

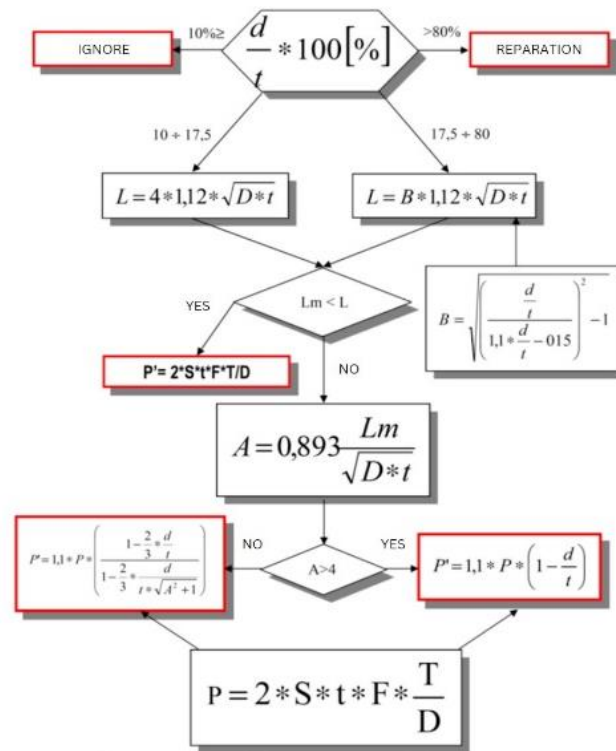


Fig. 7 – ASME B31 G defect evaluation mode.



Fig. 8 – Wall thickness assessment device-MFL.

By using the MFL (Fig. 8) extremely precise data can be collected regarding the internal defects of the pipeline (its state of integrity), and the graphic representations allow an eloquent and very useful visualization in the planning of preventive intervention (CONPET and U.P.G. Ploiesti, internal report).

Following the statistical analysis of damage to pressure equipment, it was found that:

- a. The major risk of failure occurs in the area of the actual welds and their thermal influence area,
- b. The risk of failure as a result of the lamellar fragmentation of the material or the layering of the sheet material and mechano-technological cracks, has the same order of magnitude as the risk due to damage that occurred based on fatigue in the exploitation of the material and especially its corrosion,
- c. More than 50% of pressure vessel failures are due to deviations from the operating conditions foreseen by the design,
- d. The period with the highest probability of the occurrence of defects is 2-3 years after being put into use, then under the conditions of normal exploitation (over a period of even 30 years), the risk of occurrence of a failure is constant in time and reduced.

The analysis of defects occurring in the machinery in operation in crude oil and gas treatment facilities, classifies the possibility of accidents as follows (Alexander, 1995):

- a. 38% for rotating machinery (pumps, compressors, etc.),
- b. 18% for steam boilers and furnaces,

- c. 22% for heat exchangers,
- d. 13% for fluid transport pipelines,
- e. 5% for measuring and control devices in oil installations,

The rest of the accidents (4%) occurred in electrical appliances and installations.

But the most detailed analysis of crude oil pipeline accidents assessed the defects as (Amirat *et al.*, 2006):

- a. Defects of measurement and control equipment -16% of cases,
- b. Pipe manufacturing defects - 4% of cases,
- c. Pipeline corrosion - 50% of cases,
- d. Defects appearing on welds - 5% of cases,
- e. Defects caused by external forces acting on the pipelines (criminal attacks) - 15% of cases,
- f. Breakdowns resulting from non-compliance with technological discipline (operating staff errors) - 5% of cases,
- g. Destructive actions of the environment (erosion of water banks, landslides) - 5% of cases.

In conclusion, incidents and risks of major accidents at oil and gas pipeline transport facilities can occur at any time in case of non-compliance with legislation, norms and technological discipline, as well as at the time of commissioning of facilities and equipment or in the first 3-5 years of operation after scheduled repairs and overhauls.

As factors of degradation of oil fluid transport pipelines, we have identified:

- a. Natural exploitation factors:
 - factors regarding the aggressiveness of the soil where the pipes are located, namely the corrosive action of the soil and water from precipitation, which can reach the pipes and cause corrosion piles in their wall area, and especially the installation of the pipes in areas with sharp rocks (which can cause pipe scratches),
 - the action of winds and precipitation on the pipes,
 - the action of soil movement, groundwater, etc.
- b. Factors from the production of the materials used in the installation and operation of the pipelines:
 - the quality of the steels / materials from which the piping elements are made,
 - the structural defects of the materials used,
 - non-observance of the prescribed mechanical characteristics of resistance and tenacity of steels or other materials, representing one of the main or secondary causes that determine the failure of pipes during operation.
- c. factors arising from the inadequate design of pipes and their related systems:

- factors regarding the constructive design of pipes and pipe manufacturing technologies,

- factors regarding assembly technology,
- factors regarding the choice of the constructive type of pipe and protective materials (both internal and external of oil pipelines).

d. factors coming from the installation of the pipes:

- defective end-to-end welding of pipes and auxiliary elements,
- inadequate pipe insulation,
- incorrect installation of equipment,
- inadequate installation of measurement and control installations,
- improper installation of cathodic protection installations.

e. factors resulting from non-compliance with the work regime when transporting products through pipelines:

- factors regarding the aggressiveness of the transported products, namely the sulfur content (which can create sulfuric acid or sulphurous acid through chemical reactions), water which can create corrosion piles, organic sediments (which can create fouling on the pipe walls and then the biochemical attack of them),

- non-compliance with the quality of transported products,
- often changing the operating pressure of the pipeline,
- the choice of fluid flow regimes through inappropriate pipes and in jumps,

- the use of fluids with inadequate working temperature (which can cause accidents or incidents such as the destruction of insulation, etc.),

- faulty monitoring and exceeding the prescribed operating limits.

All these factors can determine the inappropriate behavior of the pipes or create the conditions for their failure during operation.

The possible causes that can cause accidents of petroleum fluid transport pipelines are:

1) defects in the wall of the piping components (mechanical damage, cracks, lamination overlaps);

2) defects in surface welds (undercutting, incomplete welding, surface pores, surface cracks, etc.) and internal defects (slag inclusions, pores, incomplete penetration, lack of fusion and cracks);

3) welding defects (tensions and deformations during welding, there is no fusion in welding, excess of filler metal, welding processes by fusion unsuitable for the material);

4) defects specific to the welding carried out on site (non-compliant remedies, hardened areas, lack of molten core formation, overheating, inadequate penetration, cracks, distortions, expulsions, etc.).

To limit technical accidents and ensure safety in the operation of pipelines, there are several techniques for determining their integrity. These

techniques help identify and prevent potential defects or damage that could lead to leaks, explosions or other accidents, including:

1. Visual inspection is carried out by visually checking the pipeline for signs of corrosion, cracks, deformation or visible damage of pipelines that are easily accessible or during periodic inspections, but cannot detect hidden defects such as internal cracks or corrosion under the protective layer.

2. Ultrasonic testing uses sound waves to assess pipe thickness and integrity. Ultrasound can detect internal corrosion, cracks or other defects that are not visible on external inspection, and is used for non-destructive inspection of pipelines, both in the field and under laboratory conditions.

3. X-ray inspection uses X-rays or gamma rays to examine pipes, providing a detailed picture of their internal structure. This method can detect cracks, cavities or other internal defects in large pipelines and for evaluating weld areas, but the method requires special equipment and safety measures due to radiation.

4. Eddy Current Testing (ECT) uses inductive electric current to detect cracks or areas of corrosion in pipes. It is often used for metallic materials and can detect superficial defects, but cannot penetrate too deeply into the material and detect significant internal defects.

5. Magnetoscopy testing (MT) is based on the use of a magnetic field to detect surface defects (cracks, pores, corrosion) in ferromagnetic materials, but cannot detect deep defects in the material.

6. Continuous monitoring of operating conditions (Real-time Monitoring) includes tools to measure and record operating parameters such as pressure, temperature, and flow, and can detect changes that may signal problems in the pipeline (e.g., oil or fluid leaks). It is an effective method of prevention, allowing early identification of problems before they lead to major accidents.

7. Inspection with "Smart Pig" technology (Inspection with smart pig devices). This specialized device, known as a "pig", is inserted inside the pipe and travels along its entire length, using sensors to detect anomalies such as corrosion, cracks or other defects. It is used for remote inspections of large pipelines, being able to capture detailed information along the entire length of the pipeline. "Smart Pig" requires a clean pipe and can be difficult to use in pipes with many bends or hard to reach areas.

8. Leakage detection using gas sensors. This type of monitoring uses specialized sensors to detect gas or liquid leaks. In this way, even the smallest leaks can be identified that could signal faults in the pipelines, and is mainly used to detect leaks of hazardous substances such as petroleum products.

9. Computer modeling and integrity simulations. Using simulation software and mathematical models, pipeline behaviors can be analyzed under various operating conditions. These simulations can identify weak points in a pipeline before an accident occurs. The method provides a proactive view of

pipeline integrity based on real data and predicted behavior, with the outcome dependent on the accuracy of the data and models used.

To ensure pipeline integrity and prevent technical accidents, a combination of these techniques is often necessary. Each method has advantages and limitations, and the selection of the technique depends on the type of pipeline, its accessibility and associated risks. It is important that inspections are carried out periodically and that corrective measures are implemented when defects are detected.

3. Conclusions

Risk has been defined in the specialized literature by the probability with which, in a process, an accident (P) occurs that induces a certain gravity of the consequences (G).

This incident lies on the acceptability curve of the system of which A is a part, according to the relationship (5): (Popescu and Pavel, 1998).

$$\text{Risk} = P * G * A \quad (5)$$

Finally, starting from the relationship above, I appreciate that we can define the technological risk as given by an event that can produce the possible danger (D) that induces a certain severity in the system (G), that event having a certain probability (P) and an acceptability (A), resulting in a relationship of the form:

$$\text{Risk} = D * G * p * A$$

The possibility of operational breakdowns is quite high in the field of oil pipeline transport. Thus, for the realistic preparation of investment programs and for the provision of safety and control equipment, it is necessary to carry out a pertinent analysis of the operational risk.

Research directions for the future:

a. Analyzing and highlighting the performance of the economic impact (costs, benefits, profitability) produced following the application of modern preventive maintenance management methods, with controlled planning;

b. The quantified presentation of the optimization of the company's own economic results, derived from the financial assistance of anticipatory maintenance programs;

c. Elaboration of an optimal maintenance model generated by evaluating, in a comparative temporal projection, the costs of reactive maintenance versus those associated with preventive maintenance that lead to a decrease in operating costs by extending the life span in appropriate technical conditions of the transport capacities.

The study of maintenance efficiency is of interest in the case of preventive maintenance.

The criteria for assessing the efficiency of maintenance are:

- the relative cost of assembly-disassembly work K_c for the execution of a corrective intervention;
- the economy of maintenance is given by the efficiency of resource consumption (manpower, materials) and maintenance costs.

We will apply mathematical models of maintainability analysis that take into account reliability, maintainability, availability (Availability as the ratio: actual uptime/desired uptime).

As part of the research, we will analyze the current situation, the factors that influence the effectiveness of maintenance management and calculate financial performance indicators (Internal Rate of Return (RRF/C), Net Presented Financial Value (VNAF), Cost Benefit Ratio, Recovery Period).

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CERCETĂRI PRIVIND SISTEMELE DE MANAGEMENT PREDICTIV ȘI TEHNOLOGII DE ÎNTREȚINERE ANTICIPATIVĂ A INFRASTRUCTURII DE TRANSPORT PRIN CONDUCTE

(Rezumat)

Lucrarea își propune să evalueze starea tehnologiilor de management predictiv pentru reducerea pierderilor de țiței, reducerea costurilor și problemelor de exploatare,

îmbunătățirea fiabilității și flexibilității instalațiilor tehnologice și minimizarea impactului negativ asupra mediului.

În această cercetare am evaluat documentația tehnologică calificată a unei companii de transport țiței, factorii care afectează eficiența managementului întreținerii și riscul tehnologic, analizând riscurile prin tehnica MADS. Decizia de a evalua integritatea conductelor este esențială pentru programarea eficientă a întreținerii, minimizarea accidentelor tehnice și a riscului de scurgeri în mediul înconjurător.

Prin gestionarea riscului, un sistem de optimizare a procesului de întreținere poate funcționa eficient și poate reduce timpul de nefuncționare, crescând fiabilitatea procesului și performanța printr-un management eficient și implementând strategii adecvate pentru a spori siguranța, reducerea costurilor și îmbunătățirea eficienței operaționale.