Study of An Environmentally Friendly Oil Pipeline Cleaning Technology Based on Self-Propelled Intelligent Robot

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Abstract. Polymers, coke, oil dirt, limescale, sediments and rust corrosives, which are adhered to pipe wall, will be generated during the oil pipeline transport, thus leading to degradation of production efficiency, increasing the energy consumption and seriously impacting oil transport quality, efficiency and safety. What’s worse, this will result in blockage and thus interrupt the flow and suspend the production. Based on modern artificial intelligence (AI) and new-type environmental protection technologies, a self-propelled robot of intelligent manipulation is proposed and enters oil pipeline to conduct environmentally friendly cleaning using high-pressure water jet, and the cleaning wastewater can be recycled. This environmentally friendly intelligent pipeline robot is applicable to detection and high-pressure water jet cleaning of circular variable-sectional-diameter pipelines in closed environment. Furthermore, it is capable of online pipe wall quality detection for horizontal, vertical and turning circular pipelines, and also cleaning effect evaluation. According to the operating principle, an environmentally friendly oil pipeline cleaning technology based on intelligent robot is proposed by combining the technical characteristics in the existing oil pipeline design and construction, in an effort to provide a reference for intelligent cleaning and automatic visual inspection and evaluation of oil pipelines.

1. Introduction
Pipeline transport has been widely applied to the petroleum field by virtue of large transport volume, conservation of land resources, small land occupation and mild pollution. With the continuous development of China’s oil exploitation industry, the total oil pipeline transport mileage is experiencing sustainable growth. Up to the end of 2018, the total pipeline length for oil transport reached 46,300 km. In comparison with developed countries, the oil pipeline transport volume accounts for less than 10% in China, and the total transport mileage also occupies a small proportion, which directly gives rise to insufficient oil transport capacity and relative tight supply of oil resources in some regions in China. The further expansion of China’s oil consumption market is restricted, to a certain extent, by the slackened pipe network construction. As put forward in Medium and Long-Term Oil and Gas Pipeline Network Planning, the nationwide oil and gas pipeline network will have reached 169,000 km by 2020, where the lengths of crude oil pipelines and refined oil pipelines will be 32,000 km and 33,000 km, respectively. As for the 2020 planning goal, the newly built crude oil pipelines and refined oil pipelines should reach 3,000 km and 5,000 km, respectively, by the end of 2020.
In recent years, the oil pipelines have been developed slowly. Up to the Two Sessions (the National People’s Congress and the Chinese Political Consultative Conference) in 2019, the National Development and Reform Commission put forward establishing a national official website company to integrate the oil pipeline business of three major oil companies and introduce social capitals, so as to facilitate business integration, exert innovation capability and motivate enterprise vitality. It is anticipated that China’s oil pipeline industry will welcome an era of accelerated construction in future years. At that time, the overall lagging construction and development problem of oil pipelines will be effectively solved, thus guaranteeing reasonable reserves of oil resources and oil energy, improving supply safety of oil energy and promoting the transformation of energy consumption structure, constructing a beautiful China and continuously satisfying people’s yearning for a better life.

2. Management problems in oil pipeline transport

2.1. Oil pipelines show signs of aging with potential safety hazards.
Oil and natural gas, which are under liquid state and gaseous state, respectively, are volatile and explosive combustible resources with easy leakage, where hydrocarbons are their main compositions. Pipeline transport can not only reduce volatilization loss but also mitigate air, water and soil contamination. Nearly all oil pipelines are buried underground, and the transport process is affected by the alternation of oil product and gaseous product, the geological change of soil, and the composition of water resources. As a result, pipe materials are prone to corrosion and chemical changes, and even worse, the original design service life may be shortened. The service life of over half of oil pipelines has exceeded twenty years in China, and that in some regions may already exceed thirty years. It is difficult to timely discover aging and damage of pipelines as they are buried underground. In addition, human factors such as improper ground construction or natural disasters like earthquake may have a strong impact on the service life and safety of oil pipelines.

2.2. The oil pipeline cleaning management technology lags behind relatively.
Transport pipelines are in a waxing development period in China, and a complete transport management system is needed to construct a transport pipeline network of comprehensive coverage. First, the cleaning management of transport pipelines is stuck in technical difficulty. The dirt adhered to pipe wall contains a large amount of organic matters and solid-state or ooze-state substances of impurities like sediments, which increase the fluid resistance, if attached to pipelines for a long time, also cause rising overall operation power cost and even impact the operation safety of transport pipelines. Second, the data collection and management, analysis and feedback as well as intelligent means, which are included into geographic information technology, are not used in design, construction and detection of oil pipelines. The above mentioned are problems needing consideration and solutions in China’s oil pipeline management and construction process in the foreseeable future.

2.3. The layout of oil pipeline network remains to be encrypted and perfected.
The practical researches of domestic (Chinese) and foreign transportation departments indicate that transport pipelines are featured by short construction period and low cost. Under the same transport volume, the construction period of transport pipelines is only 2/3 of railway. Especially with relatively poor geological, geomorphic and climatic conditions, the technical difficulty is great in railway construction, along with huge construction investment, longer construction period, and arduous railway maintenance. The construction investment will present fold increase for projects spanning Qinling Mountains and other mountains and rivers. Statistical information shows that the pipeline construction cost is lower than railway construction cost by about 60%. The layout of oil pipeline network obviously varies from region to region in China and the transport pipeline networks are mutually isolated. The crude oil pipeline networks are mainly distributed in northwest China and around Changqing Oilfield. However, the networks are sparsely distributed in eastern China, where regional networks are independent of each other and no connection is formed. Relative to the oil
transport pipelines in developed countries like America, the connection of oil transport pipelines and their supervision work remain to be further improved by the Chinese government. What’s more, it is essential to investigate legal and regulatory mechanisms regarding market operation access and security service of oil transport pipelines.

3. Current situation of oil transport pipeline cleaning

The main solid matters in crude oil are sulfates or carbonates of hydrocarbon, Ba, Sr, Mg and Ca, which will form many impurities if accumulated inside pipelines with long-term uninterrupted transport and flow of oil. Consequently, polymers, coking, oil dirt, limescale, sediments and rust corrosives will be generated at inner wall of pipelines, and then cause serious failure of equipment and pipelines, reduce the production efficiency and increase the energy consumption. Even worse, this will interrupt the flow and cause blockage, so as to suspend the production and bring about major economic losses. Therefore, it is necessary to conduct regular oil pipeline cleaning. In most cases, artificial cleaning flow is used at present, accompanied by a series of problems such as narrow pipeline space, harsh working environment, large amount of labor and high labor intensity; in recent years, some oil enterprises have applied go-devil cleaning technology to cleaning and maintenance of oil transport pipelines, thus considerably bringing down the enormous harm caused by hazardous substances to operators [1].

The paraffin, sediments and other impurities contained in crude oil will be extracted out through the transport pipelines in oil well during the exploitation process, so the oil pipelines are usually blocked and should be replaced for cleaning. As human body cannot directly enter oil pipeline, the pipeline can be cleaned only by using chemical cleaning method, which will lead to serious pipeline corrosion and impose severe contamination to the surrounding ecological environment. Hence, the cleaning problem of oil pipelines has always perplexed most enterprise users of pipelines, especially oil pipelines, in China.

Scholars and researchers from all over the world have studied various pipeline robots. At the end of the 20th century, Toshio Fukuda et al. in University of Tokyo developed a wheel driven robot applicable to 150 mm pipelines. Staying in the test phase, this robot (Figure 1) was not put into practical application in the end.

![Figure 1. Pipeline robot of University of Tokyo, Japan](image1)

![Figure 2. German MAKRO pipeline robot](image2)

In 2000, a German scholar developed a sort of multi-joint worm-like robot MAKRO (Figure 2) applicable to pipelines 300 mm-600 mm in diameter. A double-track pipeline robot adaptable to different pipe diameters was developed by Canadian INUKTUN Corporation. In 1997, Toshiba (Japan) developed a wheel driven pipeline robot applicable to 25 mm pipelines, where the miniature CCD camera installed at front end was used to detect foreign bodies in pipelines and further realize cleaning by manipulating the mechanical arms. Over 30 scientific research institutions and R & D enterprises, e.g. Tsinghua University, Zhejiang University, Shanghai Jiaotong University and Daqing Oil Administration Bureau, in China probed into pipeline robots in succession. No application-oriented
breakthroughs, however, have been achieved. The reasons through research and analysis are presented as follows: First, over 20 years ago, the mileage of oil pipelines was not long enough, the market was not big and enterprise demand was not urgent enough; second, labor cost was small while robot cost was high, so the application prospect and economic benefit of robots were not evident; third, the developed robots failed to realize accurate positioning in pipelines with poor walking stability, so their application could not be promoted.

4. Oil pipeline cleaning methods
Chemical cleaning and sand blasting cleaning are common pipeline cleaning technologies. In the wake of continuous development of science and technology, go-devil cleaning technology and high-pressure water jet technology, etc. have come into being, which are suitable for application scenarios of tens of and even several hundred kilometers of oil transport pipelines. The go-devil cleaning technology is selected in some cases, but chemical cleaning technology will be chosen under some special working conditions. When it comes to go-devil cleaning technology, pigging equipment parts scrape the transport pipeline wall and clear fouling products, which are adhered to the wall, out of the pipeline under hydraulic pressure or atmospheric pressure. The go-devil cleaning technology has the merits of wide range of transport pipe diameter it is applicable to, long transport distance, no use of chemical cleaning agents, no corrosion of transport pipelines and no land, soil and atmospheric contamination; moreover, it can realize online cleaning without production half, the operation is simple and convenient and cleaning cost is low. Nevertheless, it cannot perform real-time quantitative evaluation of cleaning quality, detect internal service conditions of transport pipelines or make comprehensive assessment of service conditions.

5. Environmentally friendly intelligent oil pipeline cleaning
The environmentally friendly cleaning technology based on self-propelled intelligent robot is applicable to long-period and long-distance pipeline cleaning, and it can complete detection, photographing, recording and data acquisition tasks only needing a small amount of detergent; it can carry visual system and thermal IR system for inspection, and moreover, it is adaptable to circular pipelines of different diameters.

5.1. Self-propelled cleaning robot system
The self-propelled mobile robot system consists of key technologies such as mobile robot system for variable-diameter circular pipeline, visual recognition technology under complex environment, modular tracked unit technology, high-pressure water jet clearing technology and remote-control system; the whole system satisfies the requirements for wide temperature range and high protection grade. The overall framework of the self-propelled mobile pipeline cleaning robot control system is shown in Figure 3.
The system structure is composed of track, radial extension and retraction device, visual lighting, guidance system, recording and sensing components. There is also a support vehicle, which includes power supply, cleaning agent matching box and sewage disposal and storage box. The self-propelled cleaning robot system consists of structural mechanism of integrated extension and retraction guidance and three-group track modules, the combination of which guides the drive mechanism. The three-group mechanisms are uniformly distributed along the cylindrical direction so that the robot can enter the pipeline at any posture. The robot can realize automatic positioning in the pipeline. The structure of integrated extension and retraction guidance endows the robot flexible adaptability to pipelines with different diameters, and ensures sufficient contact between track and pipe wall. There is a built-in power drive device in the integrated track module, so once the track rotates, the tracked robot can automatically move in the pipeline [6-8].

The self-propelled cleaning robot system is driven by a full servo motor. At 1 m from the equipment, the running noise is lower than 60 dB without abnormal vibration when the complete machine moves; the main body of this system is made of light aluminum alloy, and the contact part where displacement is mutually generated is made of copper alloy or aluminum alloy to buffer the impact between equipment and reduce the electrostatic accumulation; the size of the whole mechanism can be controlled with a φ300mm circle after the robot retraction as shown in Figure 4.
5.2. High-pressure water jet cleaning system

The high-pressure water jet cleaning technology is composed of four parts: cleaning vehicle, jet system, piping system and sewage storage system. According to Design Code for Oil Transportation Pipeline Engineering (GB50253-2006), the spacing between two linking wells of a petroleum pipeline is generally tens of meters, reaching as long as 300 m at most. In the cleaning process, a sewage pump should be placed in each of the linking walls so that the sewage flows towards the pump entrance via the designed longitudinal slope of the transport pipeline. In other words, the sewage is brought out of the pipeline through the sewage pump, and the sewage storage device will take charge of sewage disposal. The general working pressure of the high-pressure water jet cleaning technology is 2-35 MPa; the working pressure is about 70-270 MPa for cleaning under scaling condition, great impact force will be generated in the operation, so the working area should be closed and equipped with corresponding safety operating personnel and protective devices. One person operates the cleaning equipment, and another observes the equipment operation and immediately stops the pump and releases pressure when encountering any emergency \(^9\). Therefore, a classification test is needed in actual cleaning work until a proper pressure rating is reached.

As for high-pressure water jet cleaning, high-pressure and high-speed water jet is generated by ordinary clear water using high-pressure plunger pump and specially designed nozzle, and thus adhesive substances inside the oil pipeline and at its outer wall will be directly peeled off and scoured under powerful impact force and water wedge effect, so as to reach the goal of cleaning the oil pipe body. The high-pressure water jet oil pipeline cleaning technology has the advantages of high energy efficiency, high cleaning degree, not needing pressure vessel, high cold cleaning safety, not using chemical agents, no pollution, conservation of water resources, high automation degree, low operating cost, etc. It reduces chemical actions, saves time and operating cost, and truly realizes high-efficiency cleaning.

Using ordinary tap water as the medium, the high-pressure water jet cleaning technology is of low cost; the oil pipeline shows up the natural metal color after cleaning, the quality is high, and no further cleaning step is needed after the cleaning is completed. Its cleaning efficiency is incomparable to chemical cleaning and sand blasting cleaning. Cleaning advantages are shown in Table 1. However, it also has a defect, that is, a certain safety risk in personnel operation, so operating safety protection plan and management and protective measures should be formulated.

| Table 1. Index advantages of high-pressure water jet cleaning technology |
|-----------------------------|-------------------------|
| Efficiency                  | Increase rate 82%        |
| Cleaning time               | Decrease rate 75%        |
| Usage amount of chemical solvent | 90%                      |
| Usage amount of water       | 80%                     |

6. Technological process of intelligent oil pipeline cleaning

1) Before cleaning, the cleaner places a self-propelled cleaning robot at the service port of initial cleaning point or places a winding engine in the pipeline from the linking well, and then uses visual system to detect, record and take photos of current situation of the pipeline at parts connecting horizontal pipes, and the results will be used for producing a complete report.

2) Oil dispersant is poured into the water tank outside the pipeline according to the design proportion in order to improve the use efficiency.

3) The cleared oil dirt is collected and transported out of the pipeline with a special oil collection box or towing robot.

4) The magnetic track is used to attract the pipe wall and prevent slipping phenomenon during the cleaning process so that the robot can steadily move forward in the oil dirt-containing pipeline.
5) With a high-definition miniature surveillance camera, the imaging becomes clearer. Under full-screen operation, the robot can freely rotate and walk within 360°, so no dead angle exists in the pipeline cleaning. The internal conditions of the cleaned pipeline are photographed and recorded the second time using a detection robot or camera, so as to evaluate the cleaning effect.

6) For a vertical oil pipeline, the self-propelled tracked pipeline robot is configured with a high-definition miniature surveillance camera, which can monitor the actual conditions and obstacles in the pipeline at any time. Following the operating principle of differential mechanism, turning and vertical crawling functions are started and then cleaning is continued along the vertical pipeline.

7) After the cleaning work is up to specification, the next subsection will be cleaned. The cleaning task in one day should be completed between two linking wells, and the self-propelled cleaning robot shall not be left in the pipeline.

7. Conclusion
As the oil pipeline transport is of long distance, the pipeline is closed and the topographic fluctuation changes are great (possibly passing through high mountains and rivers), the inner wall cleaning of pipelines is considerably difficult, and then intelligent robot-based environmentally friendly oil pipeline cleaning technology will become an inexorable trend. The intelligent robot, when applied to intelligent oil pipeline cleaning, will not only solve various problems like harsh manual operation environment, high labor intensity, high risk and heavy pollution, but moreover, it can combine online quality detection of transport pipeline and evaluation of cleaning effect, so as to provide a dynamic evaluation method for transport pipeline quality. However, the ideal effect can be reached in practical application process only when a reasonable cleaning scheme is formulated by combining the engineering practice.

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