Laser Systems for the Pollutants Control in the Oil and Gas Industry

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Abstract. The questions of the laser technologies application in oil and gas industry and the scope of laser systems for the atmosphere, sea and underground waters control are considered in this article. Options of creation and using of the lidar for environmental monitoring, technological control and search of the hydrocarbons fields in various natural and technogenic conditions are offered. The main attention is paid to the Raman lidar for the sensing of the oil hydrocarbon molecules in the atmosphere. It is shown that such a lidar measurement time for the 10^{15} cm^{-3} concentration of the studied molecules at the ranging distance up to 200 m doesn't exceed 265 microseconds. Creation of the fluorescent lidar for the sea water and the underground waters of the coastal area monitoring will allow to solve a problem of their pollution. Recording of the pollutants concentration spatial distribution can serve as the basic data for the solution of the inverse problem of the identification of pollution sources. The suggested methods have simple hardware realization and allow to diagnose the high-concentrated flows of the weighed particles and also hydrocarbons in the sea and underground waters.

1. Introduction

Laser technologies are applied in the most various fields of economic activity and their application sphere constantly extends, including, and the oil and gas branch. Examples of the laser methods using are in search of hydrocarbons fields, monitoring of their output objects, processing, transportation and storage in various countries. The laser systems various by the form the radiator (crystal, gas, etc.), to the wavelength, the interfaced use of several lengths of waves, the applied methods (combinational dispersion, differential absorption, fluorescence), placement conditions (stationary, mobile by land or to reservoirs, aircraft, space basing, wells) are possible in all directions of oil and gas branch using. The lidar or laser system is designed for each case.

2. The offered methods relevance

The lasers using gives a number of advantages in comparison with other methods. First, this is good space and time permission - very exact definition of the place and time of detection of the set object, to within microseconds and meters quality. Secondly, efficiency of the substance detection and data transmission on the panel, actually in real time. Thirdly is the possibility of the measuring and monitoring continuity. Fourthly, the variety of the methods, designing technologies and conditions of the devices placement. Fifthly, a possibility of the fast algorithm transformation of the taken measurements, in compliance with the changed situation. As a result, all this allows to construct the laser system for the most various objects - molecules, chemical compounds, liquids, aerosols or to make complex lidar system [1-8]. The relevance of the laser methods is defined also by the fact that the long-term nature of the various chemical compounds and particles loss from the atmosphere leads to change of the chemical and particle size distribution of soils, biogeocenoses degradation and increase in the population incidence [9-11]. Feature of laser technologies is the binding of the lidar to the chemical composition of hydrocarbons, weather and geochemical conditions of target medium and the devices placement condition. Therefore, actually there are no universal devices (or it is difficult to pick up and finish them) for all combinations of natural and technogenic factors. Besides them the separate types of application demand the certain technologies using. the laser complex demanding carrying out preliminary studies for the purpose of definition of optical characteristics of an object of monitoring and concrete parameters of system is projected for each concrete oil and gas field and landscape geochemical conditions. The various options of the laser technologies application in the field of oil and gas production are considered in this work.

3. Raman lidar for the sensing of the oil hydrocarbons molecules in the atmosphere

The main environment which is exposed to pollution in oil and gas branch is the atmosphere. The Raman lidar application is the most expedient for the hydrocarbons molecules sensing in the atmosphere. The hydrocarbons molecules in the gas form concentration level which can be measured by such a lidar is low permissible concentration level (LPL) for the atmospheric air. We will consider the Raman lidar optical layput as in [12] (Figure 1).

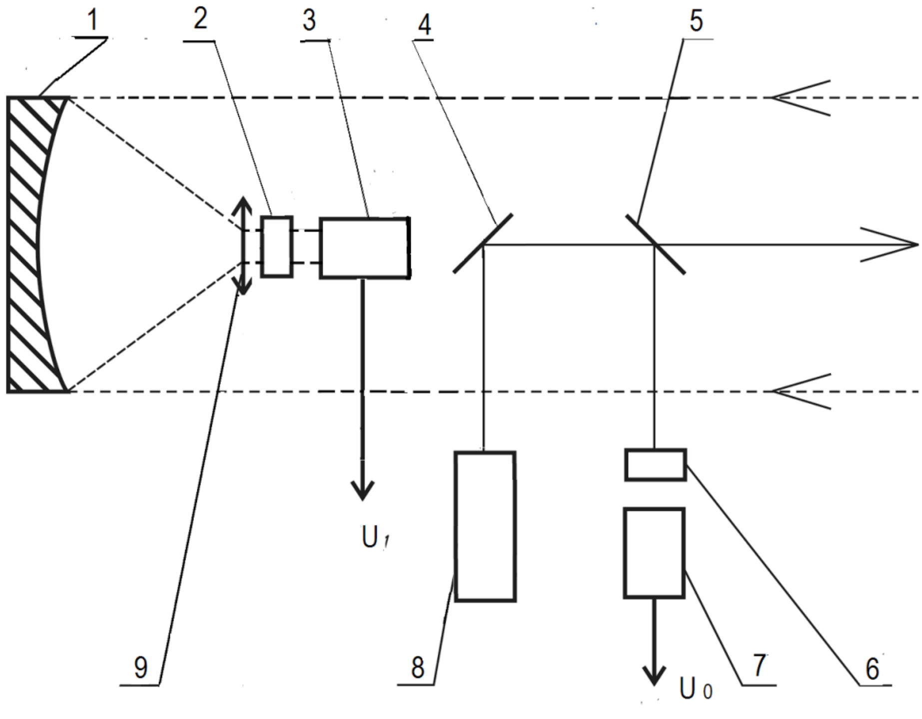

Figure 1. Raman lidar optical layout: 1-spherical mirror, 2, 6-interferential light filters, 3, 7-photodetectors, 4 mirror with $R \sim 1$, 5-glass plate, 8 – laser, 9 – lens.

The optical axis of the receiving telescope is directed along the laser beam in this layout. The knowledge of the Raman differential cross sections by these molecules at the laser radiation set wavelengths is necessary for the Raman lidar sensing of the hydrocarbons molecules in the atmosphere. For this purpose we have executed the calibration experiment (as well as in [13]) and the Raman back scattering differential cross sections in special cuvette were measured by the Raman signals dependence on the ranging distance. The calibration procedure was consisted of the Raman power measurement for the nitrogen molecules at the 607 nm wavelength. Using our lidar parameters for the 607 nm wavelength the Raman differential cross section value has been calculated by the lidar equation [7] for the nitrogen molecules at the 532 nm laser radiation wavelength and its average value was equal $(d\sigma/d\Omega) = (5.2 \pm 0.9)\cdot 10^{-31}$ cm^2/sr. This value taking into account the wavelength dependence will be well coordinated with data for the 337 nm wavelength in [14] where was given for the nitrogen molecule the value $3.5\cdot 10^{-30}$ of cm^2/sr. Our calculated value at the 337 nm wavelength is equal to $3.2\cdot 10^{-30}$ cm^2/sr.

Then the Raman differential cross section value has been measured for hydrocarbons molecules. Its average value is equal $(d\sigma/d\Omega) = (15.1\pm 0.8)\cdot 10^{-30}$ cm^2/sr which with taking into account wavelength dependence of the laser radiation well corresponds to value $93.5\cdot 10^{-30}$ cm^2/sr for the butane molecule and the 337 nm wavelength from [14]. Recalculation of our value for the isobutane molecules at the 337 nm laser radiation wavelength gives the $93.8\cdot 10^{-30}$ cm^2/sr.

Let us consider the numerical solution of the lidar equation [7] with a distance step of 7.5 m. For our experimental situation we will take the hydrocarbon molecules concentration of $N(z) = 10^{15}$ cm^{-3} as these molecules LPL in atmospheric air is equal $2.1\cdot 10^{15}$ cm^{-3}. The YAG-Nd laser second harmonic radiation pulse at the 532 nm wavelength have duration of 10 ns and energy of 10 mJ. The laser generation and the studied molecules Raman line wavelengths are equal, respectively, 532 nm and 629 nm. We will take the atmospheric relaxation coefficient values at these wavelengths from [7] are equal to 0.17 and 0.16 km^{-1} and the lidar equation numerical solution at three wavelengths of 532, 355 and 266 nm and the range of sensing distance from 10 m to 200 m have been fulfilled. The decision results presented in Figure 2 show that lidar can register such a studied molecules concentration at the of 355 nm laser radiation wavelength in average 10 times quicker, than at the 532 nm wavelength.

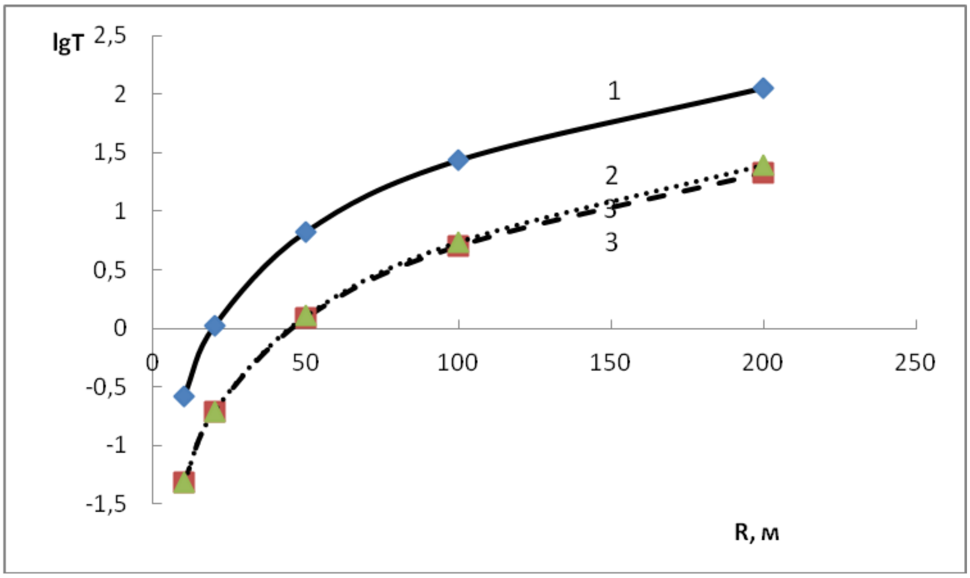

Figure 2. The logarithmic plot of the dependence of the measurement time *T* calculated by the lidar equation (in ms) on the sensing distance *R* (in m) for three wavelengths of the lasers 532 (1), 355 (3) and 266 (2) nm.

These results analysis shows that measurement time by such Raman lidar variant (for the studied hydrocarbons molecules concentration level of 10^{15} $см^{-3}$) at the 355 nm laser radiation wavelength and the sensing distance up to 200 m lies in the range of 265 μs - 25 ms. Therefore hydrocarbons molecules concentration registration is possible at the LPL concentration. This kind lidar can be used also for the monitoring of the objects which are in water up to 100 m with spatial resolution up to 5 m. The bottom and benthonic objects can be examined up to the depth of 100 m.

4. Fluorescence laser system for the water areas hydrocarbons pollution sensing

The coastal part of the sea water area experiences the biggest anthropogenic strain. The weighed particles and hydrocarbons both from oil products, and from sewage are the main pollutants. The continuous control, both pollutants sources and their distribution in bulk water is necessary for decrease in the pollution intensity. Now such a control is exercised incidentally, in the case of an adverse situation, but not in the real time, with use of the various types fluorimeters [14, 15].

Application as a radiation source of the pulse laser in ultra-violet spectrum range will allow to increase the fluorimeter temporary and spatial resolution and also to rise the measurements accuracy by the expense of the laser radiation high power. The laser system with two channels of registration – Mie elastic scattering on the weighed particles and fluorescence on hydrocarbons molecules can be used for this purpose. They differ by the wavelengths of the laser radiation used for sensing. For the Mie scattering registration the YAG-Nd laser second harmonic at the 532 nm wavelength pulse of 10 ns and pulse energy up to 20 mJ is used. It allows to get spatial resolution not less than 3 m along the sensing direction up to the depth of 70 m. The scattering signal amplitude will be directly proportional to the weighed particles concentration in the measuring volume which is formed as a part of the cylinder with a diameter equal to the diameter of the receiving telescope field of vision (in our case it is 400 mm) with a length not less than 3 m. This telescope collects the scattered radiation via the interferential light filter for the FEU-79 type photodetector which signal is entered into an electronic oscilloscope on the basis of the personal computer for further processing.

The hardware complex for the registration and processing of the pulse optical signals works under the control of the LIDAR-FLUO codes. This software allows to define the weighed particles and hydrocarbons molecules in water distribution along a laser beam with a step of 3 m and to receive the pollution card of the controlled water area at the set depths.

For the studies carrying out the laser system is installed on the boat which plying on the water area measures the weighed particles and molecules of hydrocarbons concentration, fixing the meteo parameters, speed of the boat and speed of a current. All this information is necessary for creation of the concentration spatial distribution and can serve as basic data for the inverse task solution of identification of the point, the pollution sources and development of the recommendations about their elimination.

Thus these offered laser systems studies will allow to define the real situation in the water area and to develop the strategy on the sewage treatment and rain collectors and also to detect "pale" sources of the hydrocarbons in case there is no film but only water emulsion pollution.

5. Fluorescent system for the monitoring of the ground waters hydrocarbons pollution

The problem of the soil and, in general, underground waters pollution represents the difficult scientific and practical task requiring its solution. It with all evidence is exhibited by the examples of the cities of Yeysk, Novorossiysk, etc. The technogenes brings to the considerable and, as a rule, uncontrollable input of the pollutants into underground waters. One of the most widespread pollutant is the oil products. For the hydrocarbons extraction in the coastal part of the seaports the oil storages and oil terminals are created. Their leakage can lead to penetration of oil products into ground waters and further in superficial water objects. Therefore it is necessary to control operationally hydrocarbons concentration in the wells. The choice of an optimum method of their concentration measurement in the real time on all depth of the well is required for this purpose.

Now the water tests are selected from wells incidentally, from the set depth for carrying out their analysis in vitro. The AN-2, KN-1, KN-2 types devices designed on the basis of the IR - spectroscopy method or the Flyuorat-002 type device on the basis of the luminescent analysis method are used for this purpose. As a result, time of obtaining analyses results is considerably separated from time of the probing test and doesn't cover all thickness of water. It deprives of the efficiency this monitoring system for the underground waters. We have worked out the using of the submersible fluorimeter constructed on the basis of the models described above. Such a fluorimeter consists of two modules – optical and electronic. Optical one includes a radiation source – a light-emitting diode at 405 nm wavelength and a reception lens objective with a diameter of 40 mm which focuses the fluorescence light of the hydrocarbons molecules into the single-mode fiber up to 12 m long. This module will also plunge into water bulk. At other end of the fiber there is a FEU-79 type photodetector and its output signal is registered at the electronic oscilloscope on the basis of the personal computer.

For increasing in the leaks detection efficiency various fluorescent markers which can be defined in the observation wells by the fluorimeter are brought in all capacities and in other potential pollution sources. As the fluorescent marker revealed in underground waters we determine the leaking capacity, requirement and the arrangement scheme of the technological wells for water pumping before full elimination of the underground pollution. In the most responsible places it is possible of the statement of the fluorimeter indicator of this kind for the hydrocarbons monitoring in water for the purpose of the oil products leak timely detection from processing equipment and leak elimination.

As a result of the introduction of such a monitoring system the leak of the polluted waters, hydrocarbons concentration and their volume will be defined at once that will practically exclude input of hydrocarbons out of borders of the controlled territory and it will be made by the most economic way.

6. Conclusion

The offered laser systems can be used at production environmental monitoring for the hydrocarbons definition in the atmosphere, surface and underground water. The corresponding devices can have stationary, ship or air basing (at the quadrocopters). The last variant is more optimum in view of efficiency, the movement speed and low cost. And, it is possible to control not only pollution on the surface, but also in the thickness of water bulk and even to reveal the gas emanations from a bottom or the objects of the underwater oil and gas infrastructure.

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