Laser gas analysis in solving geological and production problems

P.Ya. Antropov et al.

It is now possible to handle complex problems in economic areas by combining various research lines; there are various scientific problems in the field of oil and gas that require special apparatus that employ the latest methods of physics, mathematics, geophysics, and geology, which have been solved by the combined efforts of representatives of all these sciences at Moscow Engineering Physics Institute.

Here we consider the design of laser gas analyzers in application to direct prospecting for oil and gas fields, forecasting earthquakes, monitoring enrivonmental contamination, and laser borehole logging.

Laser methods of gas analysis recently developed allow for remote monitoring of gases, and a single instrument can cover long distances and provide fast response (2). If laser instruments are to be widely used, they should not only have high performance but also be relatively cheap and simple to use.

Absorption-type laser gas detectors are promising from this viewpoint, for example, the Iskatel'-1 gas-leak detector (1).

New laser detectors have been developed for methane (the Iskatel'-2 and Luch) and for CO_2 (Fluorite), of which the first is intended for long-term observation (over 1 hr.) and whose sensitivity is higher by two orders of magnitude than that of the Iskatel'-1, while the others are entirely new instruments.

The Iskatel'-2 is intended for continuous determination of methane content in air entering via a sampling tube. This can be used in stationary and mobile laboratories (on ground vehicles, helicopters, etc.). The limit of detection is $2 \times 10^{-5}\%$ CH_4 (the background content of methane in air is about $10^{-4}\%$). The response time is governed by the length of the sampling tube and is 3-15 sec; the dimensions are 19 x 32 x 150 cm^3, mass 40 kg.

The working principle is a double-beam one (fig. 1); the radiation with $\lambda_1 = 3.3922$ μm from the laser 1 is split by devices 2, 3, and 4 into two equal beams, which pass through reference cell 5 and the measuring cell 6, with the first filled with nitrogen and the second continuously flushed with air. If there is methane in cell 6, the intensities of the beams transmitted by cells 5 and 6 become unequal. The optoelectronic unit, devices 2, 3, 7, and 8, records the difference and thus defines the amount of methane in cell 6.

The Luch is intended for continuous and automatic determination of the mean content of methane directly in open air over a path length l up to 100 m. The results are almost independent of the weather conditions. The limit of detection is $5 \times 10^{-6}\%$ CH_4; the response time (1-15 sec) is governed by the recording method (pen recorder, meter, or oscillograph). A two-wave method is employed (3). The laser emits in turn equal-amplitude pulses at λ_1 and λ_2 (3.3912 μm), of which the second is absorbed much less strongly by methane than is the first. If there is methane on path L, the amplitudes of the λ_1 and λ_2 pulses are not equal. The optoelectronic unit records the inequality and determines the amount of methane on the path L.

The Fluorite is intended for continuous determination of CO_2 in air. Direct measurement of the absorption is employed. Radiation with $\lambda_3 = 4.218$ μm is absorbed by the carbon dioxide in the measuring cell of length 1 m. The intensity of the transmitted radiation defines the amount of CO_2 in the cell. The limit of detection is $5 \times 10^{-3}\%$ (background content of CO_2 in air is $3 \times 10^{-2}\%$). The response time is determined by the parameters of the sampling system and is 3-15 sec.

We give here some results obtained with these laser systems and discuss promising lines for future use.

Translated from Ispol'zovaniye metodov lazernogo gazoanaliza dlya resheniya ryada geologicheskikh i promyslovykh zadach, Sovetskaya Geologiya, 1979, no. 10, p. 92-98. Co-authors with Antropov are G.A. Gabrielyants, I.P. Zhabrev, V.M. Kolobashkin, A.I. Popov, Ye.A. Popov, and Ye.D. Protsenko. Antropov is deceased.

P. Ya. Antropov et al, 1981

→ XX: VTJ
XX: RJP

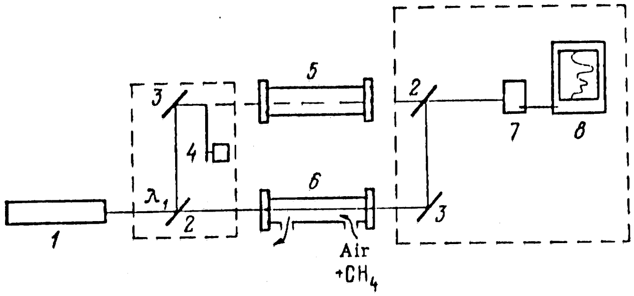

FIGURE 1. Working principle of the Iskatel'-2.

1 - laser, λ_1 = 3.3922 µm; beam splitting unit: 2 - semitransparent mirror, 3 - reflecting mirror, 4 - rotating half-disk, 5 - reference cell, 6 - working cell; measuring unit: 7 - photocell, 8 - signal processing and recording unit.

A current problem in petroleum geology is to develop direct methods of locating economic concentrations of hydrocarbons at depth, particularly with a view to reducing the large amount of drilling sometimes required to demonstrate that oil and gas traps are empty. Various forms of direct geochemical method are used in the examination of trace amounts of hydrocarbon gases that migrate from pools into surface strata and the atmosphere. Although it is quite possible for regular distributions of hydrocarbons to occur above pools by diffusion and infiltration, the performance of surface and subsoil gas surveys is poor because of the rapid gas exchange between the atmosphere and the subsoil air, in addition to other geological and geochemical factors that tend to disperse these low concentrations of hydrocarbon gases. It has therefore been proposed that drilling should be performed in appropriate areas to depths of 300-500 m for geochemical survey purposes. Although this is a reasonable suggestion, it is a costly one, and it is better to first evaluate the viability of a gas survey by means of new specialized apparatus adapted for geological situations.

Gas surveys performed in various areas indicate that the performance is considerably higher in regions of elevated tectonic activity; Dadashev has shown for Azerbajan (in 1974-5) that there is an elevated trend of methane and heavy hydrocarbons in the subsoil layer in the period of onset of tectonic activity, the levels rising to 8×10^{-3} and 12×10^{-3}%, while the background values are less than 10^{-4}%. The disturbed equilibrium is soon restored, and within 2-4 days the gas concentrations in the subsoil stabilize at the background level.

The theoretical principles of gas surveying go with the available practical results to define ways of improving the performance of direct geochemical methods particularly by examining areas of elevated seismic activity or by the use of artificial mechanical disturbance in seismically stable regions provided that rapid surveys can be performed with high accuracy over large areas.

Since 1974, measurements have been made of the time variations in the background methane over various geological structures in periods preceding and following artificial tremors. A study of this kind was performed on the structure containing no appreciable amounts of oil and gas. About 160 six-liter samples of air were examined with the Iskatel'-2. The methane contents were determined for samples taken at various points in the locality at various times, and the levels were found to vary by a substantial factor, while the fluctuations in the methane level at one point made it difficult to establish the tremor's effect on the background methane. However, when the results were averaged over a large number of samples taken from different points it was found that the mean methane content in the air was raised from 4.6×10^{-4}% to 5.9×10^{-4}% by the tremor. It was also found necessary to perform continuous monitoring of the methane background directly over the structure.

In 1976 and 1978, the Luch-1 was used in continuous observations of the methane background before and after artificial tremors in known deposits. Within two hours after the tremor the background methane began to rise. The rise within an hour was by a factor 5 (from 10^{-4} to 5×10^{-4}%), which was followed by a fall to the initial value in about the same time (fig. 2). The diurnal variations in the methane content showed very much smaller time derivatives. After this large burst in methane, there were two less prominent peaks.

These two experiments show that joint use of artificial tremors and rapid methods of

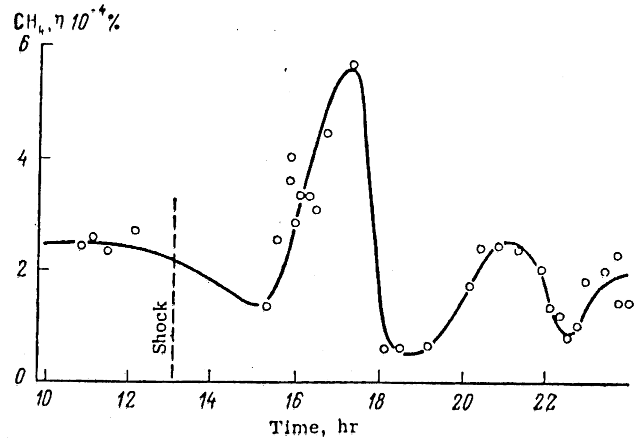

FIGURE 2. Variations in the content of methane in air as a result of seismic shock to the ground.

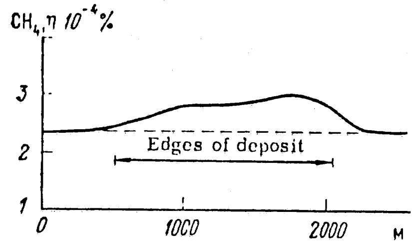

FIGURE 3. Variations in methane content in air above a petroleum deposit.

surveying can provide an efficient tool for direct prospecting for oil and gas.

In 1977, the Applied Geophysics Research Institute and the State Hydrometeorological Commission collaborated in using an improved Luch-2 apparatus in research on fields in the western part of the West Kuban trough. These showed that it is of interest to monitor the methane background without the use of artificial tremors under favorable geological conditions. For example, in a line across the Anastasiyev-Troitskiy field from SW to NE, the laser gas survey showed an excess methane content over the background of 15-25%, within the outer boundary of the deposit (fig. 3), by comparison with the mean for the locality, which was 2.4×10^{-4}%.

Data from a single line within an exploited field cannot indicate the resolving power of the laser system, since the air is extensively contaminated by petroleum products. However, the detection of an elevated methane concentration in the air above the deposit indicates that research should be continued on laser methods in order to accumulate reliable information for interpretation purposes.

These experiments showed that the laser method is reliable, rapid, and of high accuracy. A final decision on the general use of the method requires continuation of these experiments on structures with known economic oil and gas pools and also on empty ones.

One of the immediate objects in developing the Iskatel'-2 was for use in detecting gas leaks from underground city gas networks and major pipelines without digging. This mobile laboratory has been used for some years by the Ministry of the Gas Industry for this purpose, and it is capable of operating continuously while moving with speeds of 10-15 km/hr. The economic saving from using one such instrument is 320,000 rubles per year. An interesting application of the Iskatel'-2 and Luch-2 is in the monitoring of environmental contamination in oil and gas fields.

A current major topic is forecasting the place, time, and force of earthquakes. Research by the USSR Academy of Sciences has demonstrated that various phenomena precede earthquakes. These precursors include substantial variations in the compositions of water and gases. Observations during earthquakes (Tashkent 1966, Dagestan 1970, Isfara 1977, and Gazli 1976) have been made over a large area, and for some days there were changes by factors of 10 or more in the levels of various elements in groundwater and gases. Observations in recent years in Central Asia and Dagestan have shown that the most information is provided by variations in hydrocarbons and CO2.

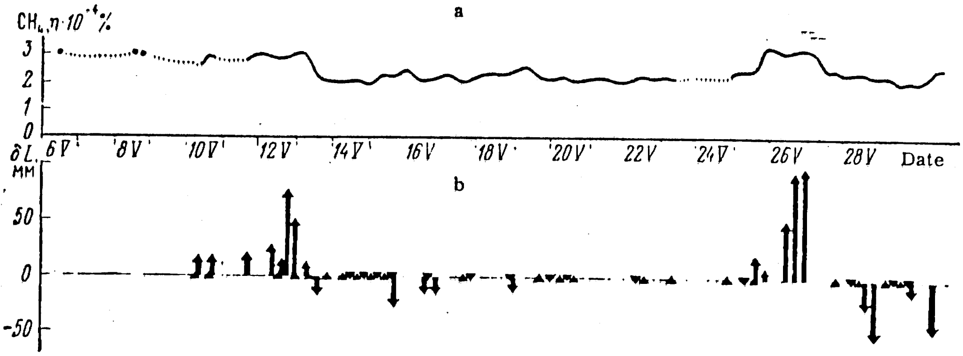

FIGURE 4. Comparison of the variations in methane content in air (a) with the displacement δ L of the crust in a seismically active region.

These effects occur because of deformation occurring in the crust resulting from tectonic movements of individual blocks. Stress redistribution occurs at the earthquake focus, and the exact position of observation determines whether one finds a sharp increase in the concentrations caused by compression or a reduction due to tension.

If gas geochemistry is to be used effectively in forecasting earthquakes, the observations must be virtually continuous and cover large areas. It is practically impossible to achieve this by traditional methods of sampling and subsequent analysis. On the other hand, laser systems can operate automatically and transmit the data to a center.

The Luch-2 and Fluorite systems have been used in experimental continuous monitoring of methane and CO_2 in the air over the Ashkhabad seismic polygon. The most interesting results were obtained on the methane background (fig. 4). Observations during this period on the weather (temperature, air pressure, and wind speed and direction) showed that there was no appreciable correlation with the methane content in the air.

Parts a and b of Figure 4 show that there is a fairly close correlation between fluctuations in the methane level in air and the strengths of crustal movements. Naturally, much more extensive studies lasting several years and covering many analogous areas are required in order to provide a reliable confirmation that the methane background can be used in predicting earthquakes. Future research may also be concerned with other atmospheric gases that are affected by earthquakes.

Experiment has shown that it is possible to combine a helium-neon laser (λ_1 and λ_2) with a helium-xenon one ($\lambda_5 = 3.3676\ \mu m$) in a pulsed laser absorption system to provide continuous separate analysis for methane and other hydrocarbons. This makes it possible to identify strata containing oil and gas by measuring the concentrations and compositions of the hydrocarbon gases directly on the drilling solution. Existing industrial geophysics methods are designed to examine strata rich in oil and gas, and they use indirect features that reflect the variations in various geophysical parameters, which are correlated with the petrophysical features. Only gas logging methods provide the hydrocarbon concentrations directly, but such measurements are made at the mouth of the borehole and involve various errors. It has long been suggested that hydrocarbon gas concentrations should be measured directly in the borehole itself.

It has been shown theoretically and practically that the mud received definite amounts of hydrocarbon gases during the drilling of a productive stratum and when the column has become lined with clay. Existing gas-logging systems essentially determine the volume of hydrocarbon entering the mud during drilling of productive strata. The laser gas logging method can be performed in an unlined borehole when the drilling of a particular section has been completed. A substantial advantage of this method is that one measures the concentrations of the hydrocarbon gases directly opposite the oil-bearing ranges. Areas containing oil and gas can thus be examined separately by parallel recording of the levels of methane and heavy hydrocarbons.

Laser systems are readily adapted to automatic measurement and remote control, so this problem can be handled by lowering miniature laser probes such as the Iskatel'-2 into unlined boreholes.

The general use of laser absorption systems should provide a considerable economic advantage in various economic fields.

REFERENCES

1. Blokhin, V.G., Bobrov, V.A., et al., 1973, A MOBILE LABORATORY FOR LOCATING LEAKS OF GAS FROM UNDERGROUND PIPELINES: Gaz. Prom., no. 11, p. 23-25.

2. Kil'dal, H., and Bayr, R., 1971, A COMPARISON OF LASER METHODS OF REMOTE DETECTION OF ATMOSPHERIC CONTAMINANTS: IIER Trudy, v. 59, no. 12, p. 5-29.

3. Harrison, H.J., 1966, METHANE GAS DETECTION USING A LASER: Trans. Soc. Min. Eng., no. 4, 428-432.