Open path hydrocarbon analyzer

One of the most promising application of mid-IR (3-5 μm) emitters and photodetectors is their use in open path gas analyzers (OGA) measuring small concentrations of gas emission in the atmosphere and, first of all, hydrocarbon gases (HCG) in the long paths of dozens and hundreds meters. As emitters, the existing OGAs utilize, as a rule, quartz halogen lamps [1, 2] as well as solid-state [3] or semiconductor diode lasers [4, 5].

Utilization of these emitters requires either very high power input and presence of rotating disk interrupters, or cryogen cooling systems and quite sophisticated laser wave length stabilization systems. The above factors impede wide application of OGAs for the purposes of preventing man-caused disasters and comprehensive environment monitoring.

The works on upgrading another class of emitters - the mid-IR light emitting semiconductor diodes (LED) - allow making a simple small-size OGA suitable for operation in industrial conditions in a long-term continuous recording mode.

OGA optical system utilizing the diodes described in [6] and implementing the differential absorption technique is shown in the Fig. 1. LED (1) emission is formed into a virtually parallel beam by the 68 mm effective diameter mirror (2) and through the protective light filter (3) directed to the path. The design LED emission beam divergence half-angle is about 0.2 mradn. After passing the open path and the protective light filter (4) of the detector module, emission is focused by the spherical mirror (5) on the twinned photodetector (7). To separate the waves of the operating and the reference channels by length, a composite multiplayer interference filter (6) is used having λ_{oper} = 3.40 μm, λ_{ref} = 3.07 μm and maximum transmission of ≥ 70%. FWHM of the filter transmission function comprises 0.12 – 0.14 μm. Additional optical isolation of the channels is provided by the shield (8). The optical system parts (6, 7) represent an integrated and optically tight unit with minimized volume, which makes it possible to completely exclude scattered and parasite emission coming to the input of the photodetectors.

The main characteristic of the OGA is the dependency of the received signal strength in the channels from the distance between the emitter and the photodetector (L) in condition of absence of absorption in the path - optical efficiency of the device [5]. Fig. 2 shows this dependency for a OGA operating channel (HCG absorption channel). At the final used dimensions of the emitter and mirror aberrations, optical efficiency of the device for $L \geq 20$ m follows the dependency $1/L^2$ [7]. For shorter distances, signal variation of the channels is in proportion to $1/L^{0.9}$, which, possibly, caused by blocking effect of the LED and photodetector structure components. OGA optical efficiency achieved during operation makes it possible to obtain the maximum measurable HCG concentration at the level of 5 LEC×m (where LEC stands for Lower Explosive Concentration) for methane for $L \leq 100$ m. The HCG detection threshold is limited by the photodetector self-noise and comprises ≅ 10^{-3} LEC×m.

Impulse signal from the photodetector ($\tau_{pulse} \cong 10$ μs, $f_{repeat} \cong 180$ Hz) is amplified by matched low-noise two-stage amplifier with optimized pass band, converted into a constant level signal by means of a precise selection and storing device and fed to 16-bit ADC input. The signal in a digital form is averaged within 2 sec. by the microprocessor and used for calculating HCG concentration in LEC×m units in accordance with modified formula of Buger - Lambert - Beer law:

$$C_{HCG} = [- \ln (I / I_0) / \alpha] \times 100 / C_{НПВ} ,$$

where

I – current signal value in the HCG absorption channel, I_0 – signal value in the HCG channel when no absorption presents, α - absorption factor of the gas being analyzed, $C_{НПВ}$ - concentration of the gas being analyzed, volume %, corresponding to 1 LEC.

The microprocessor-based OGA data acquisition, processing and storage system provides the following functions:

- calculates concentration of the gas being analyzed in real time and indicates its value on the built-in display every 2 sec.;
- builds up the database of measured HCG concentrations for a 90-dat period and indicated them on the display screen;
- checks the device operation;
- turns on visual and audible warning in case of exceeding the preset HCG concentration value;
- gives a message on closing the path of HCG concentration measurement.

Preliminary alignment of the optical axes of the emitting and OGA detector modules was accomplished using the viewing devices installed on the both modules or using illuminating devices based on AlGaAs lasers. Final positioning was carried out by the strength of the signal received. The adjustment procedure usually took several minutes provided absorption in the open path was minimum.

OGA field tests were carried out within the period from February to May on one of the refinery production plants with a 40 m long open path in continuous 24-hour HCG concentration monitoring mode. It is necessary to note high reliability of the device, as during this period no malfunction or failure in its operation was recorded. Fig. 3 represents the typical HCG concentration variation characteristic recorded by the OGA and stored in its database.

The peaks of HCG concentration correspond to the moments of taking liquid oil product samples in the vicinity of the measurement path. Slower and less intensive variations of HCG concentration, as a rule, are caused by diffusion from the other process plants.

Further OGA upgrading can be made by introducing thermoelectric cooling of LEDs and photodetectors, which will make it possible to noticeably enhance signal-to-noise ratio and, therefore, significantly broaden the range of HCG concentrations recorded and/or the range of measurement paths used.

For additional information see the reference [8].

References

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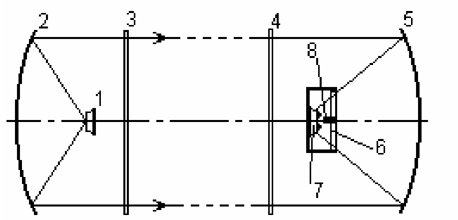

Fig.1.The optical scheme of a trace gas analyzer: 1 - IR LED; 2,5 - spherical mirrors; 3,4 - protective light filters; 6 -composite interference filter; 7 - IR photodetector; 8 - shield.

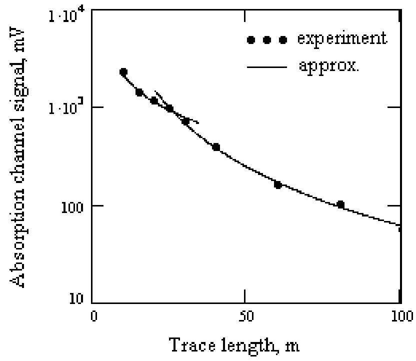

Fig.2.Absorption channel signal vs trace length.

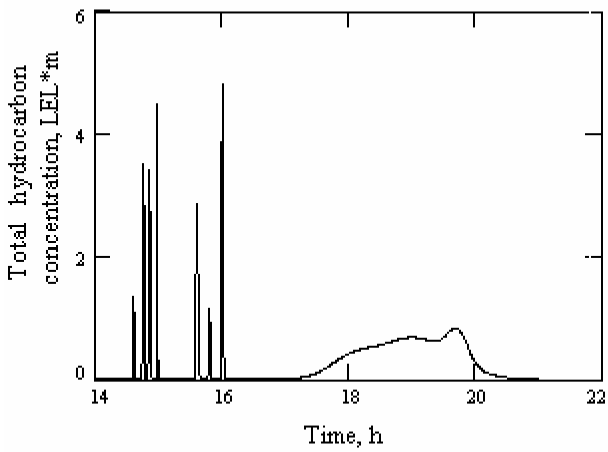

Fig.3. Hydrocarbon concentration vs time.

Photo of the sensor parts