A tool for gas dynamic logging in drainage holes

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Abstract. The paper presents the design and specifications of a modular down-the-hole logging tool to analyze gas dynamics in horizontal uncased drainage holes drilled from roadways. The tool incorporates a pneumatic push bar to advance the tool in the hole together with air hose and electric cable, an electro-drive air control, inflatable removable sealer and a flow rate for gas flow from a sealed section of a hole to its mouth. The author gives recommendations on using the tool in coal mines.

1. Introduction
In coal mining, gas dynamic logging is carried out to study permeability of rocks and methane distribution in a seam. The log data are used in planning improvement of gas drainage efficiency. These studies can be based on (1) methane release from coal when drilling and (2) gas dynamic tests in sealed intervals of holes.

The first way is short of data on permeability of rocks and offers low reliability in detection of intensive gas release zones if they occur far from the hole mouth, especially in case of heavy variability of gas flow profile in the hole.

The method of logging in sealed hole intervals using two-packer devices allows investigation of coal seam properties in stationary and nonstationary flow modes, including repression of the seam with injection of gases unabsorbed by coal [1]. Procedures of implementation of such investigations and processing of obtained data, as well as fluid flow modeling using these data are well developed [2–4].

The technical problems in such selective gas dynamic logging in coal mines are constituted by the need to involve drilling equipment to bring the logging tool to the target place up to several hundreds meters away from the mouth in subhorizontal holes as well as by varied profile of holes drilled in soft rocks. The no-purpose use of the drilling machinery reduces its useful yield and increases the cost of borehole measurements.

Such problems in geophysical survey in horizontal oil and gas wells are solved using various self-propelling devices—downhole towing devices the application range of which is limited to cased holes, as a rule [5, 6].

The Institute of Mining, SB RAS developed a self-propelling two-packer tool for operation in uncased holes of any orientation; its hydraulic schematic is shown in Figure 1 [7–10]. The length of the interval between the packers is adjustable. The spacing of the packers is changed by the cylinder C. The packer 2 is arranged on the body of the cylinder while the P1 is mounted on the rod of the cylinder. When in motion, a working fluid (gas, oil-in-water emulsion) is fed through the distributor D1 and flexible hose H2 to the packer 2 and cylinder C. Under the pressure generated by the working
fluid, the enclosure of the packer P2 expands and contacts rock in this state, it acts as an anchorage for the cylinder body. The working fluid pushes the cylinder piston and moves it together with the rod depthwise the hole, and drags P1 and hoses L1–L3 behind it. Then, the working fluid, via P2 and L1, enters the packer P1; the enclosure of the latter also expands and contacts the hole walls. Pressure in the packer P2 is dropped via L2 to a discharge line. The packer P2 detaches from rock and is moved inward the hole under the action of the gas spring of the cylinder together with the cylinder body. These operations are repeated many times unit the tool arrives in the selected interval in the hole. The maximum velocity of the tool advance is not more than 50–100 m/h.

**Figure 1.** Hydraulic schematic of gas dynamic logging tool: A1—logging tool; A2—onboard station; P1 and P2—packers; C—hydraulic cylinder; D1–D3—distributors; SV—screw valve; PR—pressure regulator; Th—throttle; Sp1—high-pressure sensor; Sp2—low-pressure sensor (vacuum gage); TR—temperature sensor; PF—gas flow rate meter.

The disadvantages of this tool is high wear of packer enclosure due to multiple (hundreds times) expansion while moved toward the measurement place, as well as engineering complexity of the design.

This paper present a modular tool with a transporting system (a downhole hauler) made as a separate device usable in haulage of many instruments in uncased horizontal holes, including the two-packer gas-dynamic logging tool.

**Figure 2.** Modular gas dynamic logging equipment.
2. Design and structural features
The gas dynamic logging equipment for drainage holes consists of gas dynamic logging tool 1–3 (hereinafter GL tool), onboard technical facilities 7–10 and connection channels 4–6 (Figure 2). GL tool incorporates downhole interval sealer 1, downhole hauler 2, and downhole distributor 3. The onboard technical facilities are: hauler control 7 (to control the hauler travel in the hole), hydraulic station 8 of the sealer (pumping station), recorder with pressure sensors (P) and gas flow rate sensors (Q), as well as with compressed nitrogen source 10.

The functional hydraulic–gas–pneumatic schematic of GL tool is shown in Figure 3.

![Figure 3. Functional layout of modular gas dynamic logging equipment.](image)

The downhole hauler contains tailstock 1, inlet 2, protective corrugation 3 and pneumatic cylinder 4 with rod 5 and central channel 6. At the end of the pneumatic cylinder, socket plug 7 is arranged to connected the hauler to the sealer (Figure 4).

![Figure 4. General view of downhole hauler.](image)

The connections lines (Figure 3) are a twin high-pressure hose with internal diameter of each hose of 4–8 mm and the overall outside diameter not more than 25 mm, 150 m long, on coil 6; single high-pressure hose with inside diameter of 6.4 mm and outside diameter not more than 12 mm, 150 m long, on coil 5, PVC-enveloped steel wire with diameter of 5 mm and length to 150 m, on winch 4.
3. Operation of GL tool

In the mode of motion of the too, hauler control 7 is actuated (Figure 2). Sealer station 8 and data recorder 9 are switched off. The active part of the tool is hauler 7. The sealer is off use in this mode of operation.

Compressed air is fed to 7 from a mine air duct via the low-pressure hose (Figure 3). Valve VN2 is put into position Hauler. Valve VN3 is open. The compressed air pressure is monitored visually on manometer MN2. The air fed to the control is dedusted and demoisted by filter F1.

From filter F1 air goes to electro-driven distributor D2. The second outlet of D2 is connected, via the high-pressure hose, to the left cavity (shown on the left in the drawing) of the two-way cylinder of the hauler.

The first inlet of distributor D2 is connected via valve VN2 and the high-pressure hose to the inlet of distributor D1. In the mode of motion of the tool, the outlet of D1 is connected to the cavity depicted on the right in Figure 4.

To start movement, the electronics of the controller is powered. The impulses from the outlet of an adjustable impulse generator go through a match circuit to an actuator of distributor D2. As D2 is actuated, the cavities of the pneumatic cylinder switch from feed to discharge of compressed air; in this case, it is always such that one cavity is fed with compressed air while the other is drained from it. The piston of the pneumatic cylinder performed to and fro motions as a result. When piston 6 is pushed from cylinder 4, spring-actuated tailstock 1 (Figure 4) runs into the hole wall. The body of pneumatic cylinder 4 is moved into the hole and pushes two packer sealer 1 connected to plug 7 (Figure 2).

When arriving in the selected interval, the hauler is switched off by cutting off air fed to the control using valve VN3 (Figure 3) and by de-energizing the control electronics.

The mode of measurement engages hydraulic station 8 of the sealer and data recorder 9 with compressed nitrogen source 10 (Figure 2). The hauler control is switched off.

The first step in the gas dynamic measurements is sealing of the measurement interval. For this purpose, pump Pm1 via valve KO1 injects water from tank 1 to packers P1 and P2 (Figure 3). The pressure in the packers is visually controlled using manometer MN.

Air is let out from the hydraulic system of the sealer using valve V1 and throttle Th1. The air drain is carried out under water feed under pressure of 0.2–0.5 MPa. When water pressure exceeds 0.5 MPa, the valve V1 closes. The water flow rate via throttle Th1 is 3 times less than the rated flow rate of pump Pm1 at the average speed of work.

In differential pressure measurement, the pressure in the packers is raised to 5 MPa, in repression measurements (nitrogen feed)—to 10 MPa. When water is feed in the packers, distributor D1 is actuated and switches the air line from the pneumatic cylinder of the hauler to the packer interval of the sealer.

In the measurement mode, valve VN2 is put in position Recorder. Depending on the method of gas dynamic measurement, one of three position switches is on (although normally they are off). The switcher is put in position MAX and, if the gas flow rate via BF1 is less than 5 l/min, is put in position MIN (for better accuracy of measurements in case of low gas flow rates, sensor BF2 can be used). If necessary, the air flow rate is adjusted using throttles Th2 or Th3.

When compressed nitrogen is fed in the packer interval, valve VN5 is switched on. Pressure of nitrogen is set by reducer KP1 by manometer MN3. Manometer MN4 is used to control nitrogen pressure in tank T4. When measurements are taken in the mode of gas inflow, valve VN4 is switched on. The gas is drain via valve KO2 to the mine methane drainage system.

The gas pressure is measured by strain gauge meter VR1 (model LKH-412-100). The electronics of the recorder also includes flow rate meters BF1 (M-1000SLPM, 5–1000 l/min, ±0.2 l/min, analog outlet), BF 2 (M-5SLPM, 0.025–5 l/min, ±0.01 l/min, analog outlet), independent recorder BR3-1 of field instrumentation platform SCOUT (SST Bureau, Saratov).

The key parameters of the developed equipment to implement gas dynamic logging in gas drainage holes are compiled in the table 1.
Table 1. The main characteristics of the tool

| Description                                      | Value          |
|--------------------------------------------------|----------------|
| Length of tool                                   | 2500 mm        |
| Diameter of tool                                 | 60 mm          |
| Weight of tool                                   | 9 kg           |
| Number of packers                                | 2              |
| length of packers                                | 500 mm         |
| Number of high-pressure connecting hoses (HPH)   | 3              |
| Diameter of flow passage in HPH                  | 4–8 mm         |
| Pressure in packers                              | to 15 MPa      |
| Diameter of hole                                 | 76–105 mm      |
| Length of hole                                   | to 150 mm      |
| Orientation of hole                              | horizontal ±15°|
| Pressure range                                   | 0.05–25 MPa    |
| Frequency range                                  | 0–1000 Hz      |
| Pressure accuracy                                | 0.02 MPa       |
| Temperature of formation fluid                   | 0–80 °C        |
| Temperature accuracy                             | 0.001 °C       |
| Formation fluid flow rate                        | I:5–1000 l/min, ±0.2 l/min; II:0.025–5 l/min, ±0.01 l/min |
| Digitization period                              | 0.25, 0.5, 1.0 ms |
| Bits of data recording                           | 15             |
| Independent recording period at digitization of 1 ms, not less | 250 h |
| Travel velocity in hole                           | 40–80 m/h      |

4. Conclusions
The modular tool has been developed for the gas dynamic logging in uncased drainage holes in coal mines.

The tool is advanced inside the hole by a downhole hauler with pneumatic drive. The hauler as an independent module can be used in sets with various purpose downhole devices.

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