Specialized alarm-initiating device for early detection of coal self-ignition

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Abstract: The existing methods of fire detection are based on the registration of physical phenomena associated with the processes of combustion or smouldering, such as elevated temperature, the release of combustion products, changes in the chemical composition of the air, thermal radiation. Sensor elements of the devices detecting those features stay at a distance from the source of ignition. This result in postponed time of fire registration in comparison with its occurrence. Accordingly, the more time it takes, the more significant damage a fire can cause. The work studies the design of alarm-initiating device developed at Irkutsk National Research Technical University. The device is to detect the evidence of incipient self-ignition at the stage of self-heating before a fire starts, and it is applicable to coal and other substances that are likely to ignite spontaneously. The main feature of the invention is that the temperature measurement and air sampling are carried out directly in the places that are at more risk of self-ignition. In addition, the device is energy-independent due to the original design of the power supply element. Moreover, the measurement of several parameters of the fire environment significantly increases the reliability and credibility of the self-ignition detector.

1. Introduction

Russian coal industry is one of the main branches of fuel and energy complex and an essential part of national economy. With all its importance, the industry includes extraction, storage, transportation and use of coal that are the sources of environmental hazards and other risks. Numerous studies have found that a significant part of accidents occurred in coal industry are fires and explosions, leading to many victims, dramatic property losses and environmental damage. The significant part of self-ignition of coal caused these hazardous incidents.

In order to prevent the risks of spontaneous coal combustion resulting from self-heating, as well as to develop a device that can detect signs of such a threat in before-the-fact manner, it is necessary to have a clear understanding of these processes. Effectively, coal is quite a complex object for researchers. Due to the great variety of both its physical and chemical properties and various external conditions at different stages of its life cycle, the processes of its self-heating and self-ignition are still insufficiently examined. Thus, the existing theoretical models are mainly probabilistic in nature, but there is no generally accepted approach covering all the processes. Nevertheless, the methods to detect spontaneous coal combustion are constantly improving, and they result in innovative techniques. All existing fire detection methods are based on the fact that any phenomena, including self-heating and self-ignition, lead to physical manifestations of these processes, specifically, a change in temperature, gas composition, the appearance of smoke particles, the presence of electromagnetic radiation of different ranges and others. For a developer of alarm-initiating device, the basic aspect is...
the critical value of the measured parameter, as it indicates the beginning of the fire. However, the dynamics of the self-heating process is also an essential characteristic of this action, as gives the understanding of the probability that self-heating of coal may turn into its self-ignition.

In recent years, alarm-initiating devices that are general-purpose detectors have become widespread. They are qualified as multi-criteria and multi-sensor, and they proved to be efficient by reducing the time of fire detection and better protection against false activations [1 – 7]. This approach is applicable and effective for both general-purpose detectors and specialized alarm-initiating devices. A specialized detector will be more effective, as endogenous fires differ significantly from exogenous ones. Thus, general-purpose detectors in this case cannot provide the sufficient level of fire safety.

2. Purpose
The purpose of this work is to present the design and principle of operation of a specialized multisensor detector of an aspiration type, developed by S. Timofeeva, G. Smirnov [8].

3. The design of the alarm-initiating device
The device is a combined aspiration-type detector, and it can be used to detect a fire in the bulk of combustible material. The use of the device is based on the property of solid combustible materials that is self-heating due to the gradual accumulation of heat during exothermic reactions, which can lead to self-ignition. This property determines the design of the device, the power supply of which is a thermoelectric generator with Peltier element. Gas mixture sampling and temperature measuring take place directly in the mass controlled substance. The measuring chamber and the electronics module are externally located. A chamber with electric drive enables the aspiration of gas mixture.

The device consists of the following main units:
1. The intake pipeline with a cone-shaped tip at one end (for the convenience of immersion in the mass of coal), an opening with a filter (for sampling air from the mass of coal) and a temperature sensor.
2. Measuring chamber with detectors (smoke and CO) and piston-type aspirator.
3. Thermoelectric generator with Peltier element.
4. Electronics module.

This design of the device ensures its operation in accordance with the stated requirements. Due to the intake pipeline, immersed in the mass of coal, the measurement of the controlled parameters take place in the most likely location of self-ignition. This feature enables the minimum possible time of self-ignition detection, so it minimizes damage and losses in case of emergency. Measurement, processing and formation of the alarm message take place in the remote unit, outside the aggressive environment. This increases the reliability of the device. The piston design of the aspirator provides increased accuracy of measurements and, consequently, high reliability of the transmitted signal.

Figure 1 shows the design of the device. Figure 2 represents the cross-section of the intake pipe 3. Figure 3 gives schematic diagram of the invention.

The thermogenerator EMF based on the Peltier element provides independent power supply to the device due to the Seebeck effect enabling the appearance of EMF in a closed electrical circuit consisting of sequentially connected dissimilar conductors, the contacts between which are at different temperatures. In this case, the "hot" contact of the thermoelectric element is located in the mass of the controlled sample of coal (by transferring the thermal energy of the heated coal through the in-taking pipeline), and the "cool" contact is at the ambient temperature. As coal and other similar combustible materials (peat, grain, wood waste, etc.) stay in the air environment that contains oxygen, the exothermic reactions constantly occur in them, so the temperature inside the mass of coal will always be higher than the ambient temperature. Due to this, the thermogenerator is continuously in the mode of electricity accumulation, and the device is in a state of readiness for operation. Since a radio channel transmits the alarm messages, the device has no external connecting loops. This make its operation autonomous, highly reliable and easy to use.
Figure 1. The design of alarm-initiating device: 1 – tip (cone-shaped); 2 – temperature sensor; 3 – intake pipeline; 4 – electrical insulation; 5 – air duct; 6 – thermal electrical insulation; 7 – intake pipeline shell; 8 – protect device trigger sensor; 9 – bi-metal safety plate; 10 – gauge of ambient air temperature; 11 – Peltier element; 12 – heat-sink; 13 – inlet valve; 14 – sensor of initial piston position; 15 – gas analyzer; 16 – smoke sensor; 17 – piston; 18 – measuring chamber; 19 – measuring chamber case; 20 – threaded shaft; 21 – sensor of end piston position; 22 – compensation port; 23 – display unit; 24 – alarm message formation unit; 25 – motor; 26 – logic; 27 – control unit; 28 – signal processing unit; 29 – reference voltages generator; 30 – outlet valve; 31 – intake opening; 32 – air filter.

There are two pipes to establish the basis of the detector construction. The external pipe made of steel forms the intake pipeline shell (7). The internal pipe made of high thermal conductivity material is the intake pipeline (3). There is a heat-insulating gasket (6) between the pipes.

Figure 2. A cross-section of the intake pipeline.

A conical tip (1) made of metal with high thermal conductivity is attached to one end of the intake pipeline shell (7) with the electrical insulating gasket (4) between (1) and (7) to install the device easily in the controlled mass of combustible agent. Inside the tip, there is a two-pole temperature
sensor (2). One of its sensor contacts is connected to the intake pipeline (3), and another one is attached to the intake pipeline shell (7). This location of the temperature sensor ensures maximum accuracy of data and a rapid reaction of the system. There is an intake opening (31) located close to the cone-shaped tip (1) with an air filter (32) inside. Through the filter (32) and the air duct (5) of the intake pipeline (3), the gas-air mixture enters the measuring chamber (18) by means of the aspirator. The measuring chamber case (19) is attached to the second end of the intake pipeline shell (7). The measuring chamber (18) is a cylinder with a piston (17) inside, driven by an electric motor (25) and having a threaded shaft (20) on its axis. Inside the measuring chamber (18), there are smoke (16) and gas (15) sensors, inlet (13) and outlet (30) valves, a compensation port (22) on the measuring chamber case (19) located in its non-functional part, sensors of the initial (14) and end (21) piston positions. The choice of piston rather than blade aspirator system ensures the constancy of the measured volume of the gas-air mass and the required cyclicity of measurements.

Close to the measuring chamber (18), there is a thickening on the intake pipe (3), and it extends beyond the intake pipeline shell (7). The thickening is made in the form of a plane with Peltier element (11) attached to it by its "hot" side to enable the operation of the thermoelectric generator. To prevent Peltier element (11) from overheating in the area adjacent to the thickening, there is a bi-metal safety plate (9). A heat-sink (12) with a gauge of ambient air temperature (10) is attached to the "cool" side of Peltier (11) element. The bi-metal plate (9) has a protect device trigger sensor (8) attached to it. The use of Peltier element as a power source makes the device energy-independent. As the amount of energy provided by the thermogenerator increases proportionally with the rise of the temperature difference on the plates of the Peltier element, speed of the piston goes up. In this regard, in a situation that could lead to the risk of self-ignition of the measured sample, the measurement cycles are shorter, which improves the reliability of the device.

The measuring chamber case (19) has an electronics module attached to its rear side. The module includes a reference voltage generator (29), a signal processing unit (28), a display unit (23), a logic (26), an alarm message formation unit (24). The reference voltage generator (29) converts the potential difference on the plates of the Peltier element (11), depending on the temperature difference, into the levels of supply voltages enabling the functioning of electricity consumers and becoming a buffer.
storage of electricity. The signal-processing unit (28) converts the electrical signals of the sensors into a code sequence for further processing by the logic unit (26). The control unit (27) determines the entire operation of the device depending on the incoming signals and the established algorithm. Display unit (23) used for visual inspection shows the values of the measured parameters, their compliance with the control values. The alarm message formation unit (24) is a radio transmitter for translating information to the control and receiving device, and it can have additional functions of light and sound alarm.

The set of technical solutions used in this design clearly shows the direction of its further development and improvement of the device and its modifications.

4. Summary and Conclusion
The proposed alarm-initiating device has a number of significant advantages compared with the devices used:

1. The measured parameters are monitored directly inside the mass of bulk combustible material by placing the sensitive element that controls the temperature and air intake for other sensitive elements in the remote measuring chamber through the detector's structural element, which improves the accuracy and reliability of the detector.

2. The device is powered by a thermoelectric generator that generates electricity due to the temperature difference between the heated mass of the test sample and the colder environment, which together with the use of a radio transmitter as a driver of alarm messages ensures its autonomy and mobility.

3. The ability to fine-tune the device (the ratio of temperature levels, concentration of smoke particles and indicator gases) may allow detection of spontaneous combustion sites at the stage of self-heating for each specific type of controlled substance.

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