Using radioisotope method for measuring ice layer thickness in pulp lines

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Abstract. Operating hydro-transportation systems in Russia means challenges resulting from ice formation within pipelines when idle, and even during actual operation, thus some protection of pulp lines against freezing is a must. This work is devoted to the radioisotope method for ice layer thickness measuring on pipeline walls, which is now more and more often used in practice. This is a low cost method with units and parts easily replaceable, simple by design, non-interrupting the process.

1. Introduction

Many mining and processing facilities are located in Siberia, Far North, and Far East. Those locations are well known by cold winters, severe temperature drops and very strong winds. Operating hydro-transportation systems there means challenges resulting from ice formation within pipelines when idle, and even during actual operation, thus some protection of pulp lines against freezing is a must.

Cutting heat losses during water and hydro-mixture transportation under severe climate conditions necessitates various measures to be taken. For example, those measures specifically include pipeline heat insulation, warming up pipelines with the product fluid transported or locally, routing pipelines in soil bulks [1,2].

Until now, multiple theoretical and experimental researches have been carried out to study pipeline thermal operating modes under temperatures below the freezing point both in laboratories and at industrial stages [3,4]. Yet, the designing and the operation of industrial hydro-transportation units in wintertime formulate new design and technical tasks for hydro-mixture transportation [5].

2. Materials and methods

There are methods for ice layer thickness measuring on pipeline walls. Those specifically include X-ray, radioisotope, ultrasound, nuclear magnetic, SHF, and some other methods [6-9]. Our work is devoted to the radioisotope method, which is now more and more often used in practice.

The proposed method for ice layer thickness measuring in pipelines for mineral stock transportation includes exposing the pulp flow under a narrow beam of the ionizing radiation, followed by registering the radiation that passed through the controlled environment at various points of the pipeline section points to form corresponding signals in the form of discrete increments. The next stage is the calculation of the actual ice thickness via processing the results in connection with the radiation that passed through, subject to different in intensity and in specific fluctuation nature for
various media – pipeline materials, the ice layer, and the flowing pulp.

Figure 1 illustrates the principal diagram of the device in accordance with the method disclosed. The measuring device comprises a source (4) and a detector (5) of ionizing radiation, wherein the source and the detector are located in opposite points of the pipeline portion (1) with transported flow (2) and ice layer (3) measured, configured to be capable of moving along pipeline cross-section (for example, fixed to a frame or to a bracket), as well as the secondary apparatus configured to process detector signals (6), see figure 1.

![Radioisotope measuring unit](image)

The radiation beam source may be a standard gamma-radiation unit GRB. Its operation resides on the radioisotope of Cs\(^{137}\) covered with the lead shell with a narrow slot opening to allow just a narrow gamma-radiation beam out.

The receiving end of the apparatus hosts a gamma-radiation detector. The detector receives signals that passed across the pipe to transfer the signals to the secondary apparatus capable of assessing if there is ice on the pipeline inner walls, and what may be the thickness thereof, by the radiation level drop.

Primary radiation intensity to be recorded by the detector within the said volume, in the presence and in the absence of the absorbing material, correspondingly, and the material density and thickness are in accordance with the following expression \([10,11]\):

\[
I = I_0 \cdot \exp(-\mu \rho \delta)
\]

where \(I_0\) - direct gamma radiation intensity depends on the substance density \(\rho\) with the radiation attenuation coefficient \(\mu\) and its thickness \(\delta\).

The cross section may be divided into three portions:
- 1 - is for the pipeline wall;
- 2 - is for the pipeline wall – ice;
- 3 - is for the pipeline wall – ice – pulp.

Each of the portions would correspond to its own expression describing the primary radiation intensity:

The gamma-radiation intensity for the site 1 would be:

\[
I_1 = I_0 \cdot \exp(-\mu_{st} \rho_{st} \delta_{1st})
\]

For the site 2, it would be:

\[
I_2 = I_0 \cdot \exp\left((-\mu_{st} \rho_{st} \delta_{2st} + \mu_i \rho_i \delta_{2i})\right)
\]

For the site 3, it would be:
\[ I_3 = I_0 \cdot \exp[(-\mu_{st}\rho_{st}\delta_{3st} + \mu_i\rho_i\delta_{3i} + \mu_p\rho_p\delta_{3p})]; \]  
\[ \delta_{1st} = 2R \sin(\arccos \frac{R-\Delta}{R}); \delta_{2st} = \delta_{1st} - 2R \sin(\arccos \frac{R-\Delta}{r}); \]  
\[ \delta_{2i} = 2r \sin(\arccos \frac{r-\Delta}{r}); \delta_{3st} = \delta_{2i}; \]  
\[ \delta_{3i} = \delta_{2i} - D \sin(\arccos 2\frac{R-\Delta}{D}), \]  

where \( I_1, I_2, I_3 \) - intensities of the primary radiation as registered by the sensor within the given volume in the presence of adsorbing material for, correspondingly, the 1st, the 2nd and the 3rd sites of the pipeline cross-section; \( \rho_{st}, \rho_i, \rho_p \) - densities of the pipeline steel wall, ice and pulp correspondingly; \( \delta_{st}, \delta_i, \delta_p \) - equivalent thickness of the pipeline steel wall, ice and pulp phase, correspondingly; \( \mu_{st}, \mu_i, \mu_p \) - mass attenuation coefficient for the primary radiation by the pipeline steel wall, ice and pulp flow, correspondingly; with \( \Delta \) - the distance between the pipeline edge and the point of scanning at the moment by direction of motion for the entire measuring system; \( R, r \) - outer and inner radii of the pipeline in the section given; \( D \) - the pipeline diameter [4].

3. Results and discussion

The ice layer thickness measuring method includes the cross section scanning in such a manner, that
the signal nature would change twice, and then the measuring system is to be rotated for 90°. When
passing through the pipeline cross-section, the radiation intensity is changed in accordance with the
abovementioned expressions. The border of the two media changes the first derivative of the primary
radiation intensity by movement, and the presence of this shift witnesses in favor of presence, or
absence, of ice formations on pipeline walls.

![Figure 2. Relation between radiation intensity and gamma penetration depth](image)

The theoretical correlation between the intensity of the gamma-radiation that passed through
the pipe cross-section and its penetration depth is illustrated with figure 2. The chart of figure 2 clearly
shows two curve breaks: the first one is on passing through the border between the pipeline wall and
the ice (portions 1-2, fig.2.b), while the second one corresponds to passing the border between ice and
pulp (portions 2-3, fig.2.a). It is those breaks that allow making conclusions on ice formation on
pipeline walls.

4. Conclusion

Using the methodology disclosed above would allow detecting ice formations locations and measuring
the ice layer thickness without interrupting the flow in the pulp line. This would allow implementing methodologies against ice formation in pipes efficiently, to prevent pumping equipment failures in the transportation system, thus preventing accidents resulting from pipeline failures, and, ultimately, improve the performance of the entire system. This is a low cost method with units and parts easily replaceable, simple by design, non-interrupting the process.

The developed measuring system allows efficient detection of the deposits with absolute error ±5mm, thus becoming a sufficient tool to provide reliable and efficient pipeline operation and preventing far more accidents, which would otherwise have brought irreversible environmental damage [12].

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