Development of a mobile power plant for thawing frozen soils

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Abstract. The article proposes a new device for radiation-convective heating of working fluids, which can be used in particular for emergency and repair and construction works for heating of frozen soil, concrete, road surface and other building materials. The studies were carried out as part of implementation of the Innovation Assistance Fund for Energy Sector Enterprises.

1. Relevance of research

The essence of thawing and defrosting of frozen soil is to change the structural state of one of the components - water (transition from solid to liquid) when additional energy is introduced from outside without disturbing the structural state of the soil itself. When using a number of methods for preparing frozen soils for exploitation by introducing additional energy, the same thermophysical processes occur in soil, which in the literature are called methods of artificial thawing of soil. Defrosting of frozen soil is a complex thermodynamic process occurring in an inhomogeneous capillary-porous medium, complicated by the presence of ground moisture phase transitions.

The search for new technological solutions and soil preparation systems for repair, construction and emergency work is an important task in northern latitudes due to their harsh natural and climatic conditions [1-6]. The increased mechanical strength of frozen soils impedes their exploitation by conventional technical means, which necessitates the preliminary preparation of such soils. The following basic methods of soil preparation in winter conditions are used: thawing followed by exploitation of thawed soil, preliminary mechanical loosening and exploitation of frozen soil. Mechanized methods are currently the most common, but usage of special means of loosening or cutting into separate pieces in a complex urban underground economy is difficult and sometimes impossible due to technical requirements and safety considerations. In urban conditions, the problem of exploitation of frozen soils arises, first of all, in front of emergency, municipal and energy supply services and organizations. A large number of emergency situations in winter is associated with ruptures of pipelines for various purposes. The recovery time of site depends on the speed of the repair team of the damaged pipeline. Another important aspect of the problem raised above is preparation of soil before construction - a task that arises before construction organizations conducting work in the winter period. The use of special means of loosening or cutting the soil does not allow the mixture to be used without a sufficient amount of thawed soil for erecting embankments, filling trenches and sinuses of pits due to the impossibility of good compaction, as it leads to subsidence of soil after...
thawing. In such conditions, usage of alternative methods of soil preparation during repair and construction and emergency work expands the technical capabilities of the organization and allows one to ensure the efficiency of the work being done. These tasks can be solved with the help of organization of soil thawing [7].

2. Review of existing devices and analysis of its efficiency

Currently, there are various studies in the field of frozen soils, including [8, 9], as well as methods and devices for heating frozen soils [10], among which there are devices of convective, radiation, and chemical types. Among the most used are thermomats of various modifications and manufacturers. Despite their wide distribution, their use in real conditions is accompanied by a very long warm-up period. A device is known (Pat. 2208741RU F24D5/08), comprising a housing, the inner side of which is made with a cavity, to specify the channel in which the furnace tube is installed. The heating unit has a burner associated with the first end of pipe, and the first fan device connected with pipe, to move the gaseous products of combustion through the pipe from the first end to the second end. The housing has a hole on its upper surface, the hole is connected to the second fan device for directing air into the channel inside the housing, and a heat transfer plate installed between the pipe and the hole, while the heat transfer plate is shaped so that it surrounds the upper surface of pipe in order to absorb radiation from it and to exclude the penetration of air from the hole directly to the pipe, as a result of which the air is heated by the heat exchanger plate before passing down through the lower end of the channel.

The drawbacks of the device are that the heat flux generated by movement of heated air due to its heating from the heat exchange plate will always be less than the heat flux created by movement of hot flue gases (as proposed in the claimed solution), so the device heat output will be low and it will not provide warming of the working fluid (for example, thawing the mass of frozen soil in the winter). In addition, the device does not use the heat of exhaust gases, which significantly reduces the efficiency of installation.

Also, there exists device (Pat. 2161672RU E01C23/14), comprising a housing in which there is a chamber having an inlet for receiving hot gas from the burner and a radiating surface with many holes. The holes in the radiating surface are of such dimensions that the hot gas heats the radiating surface to create radiation heat transfer to the asphalt surface and pass through the holes to create the conventional heat transfer to the asphalt surface.

The drawbacks of the device are that the heat flux is generated only by radiation from a special surface heated by flue gases; such device has a lower efficiency as compared with the stated solution due to only one heat transfer component – radiant. If convective flow appears here, it will be insignificant.

The device closest to the claimed device is that (Application No. 20100117129 published on November 10, 2011), containing a housing with a smoke tube located in it, at one end of which a gas burner is installed with gas and air channels, at the other end is fan with air heater with reflective screen, while the pipe is U-shaped or Π-shaped; the air heater is connected by one channel to the air supply pipe to the gas burner, and the other channel is connected via gas exhaust pipe to inlet fan and a fixed or rotating outlet divider, which, in turn, is placed between the fire tube and the reflective screen, and is made or curved expanding channels.

The main disadvantage of this device is rapid overheating and failure of fan, which creates the convective movement of hot gases, and placing equipment in a single package increases the weight of device and complicates its operation. In addition, such a device must be connected to the mains, which is impossible under the conditions of use.

Thus, our development is relevant and can find direct application in various sectors of energy and utilities.

3. Description of the installation construction

The purpose of the device being developed is to improve the quality, reliability and efficiency of devices used to heat working fluids, improve the methods of surface heating and warming of frozen
soil, concrete, road pavement by radiation-convective method, with minimum energy and time requirements, taking into account the environmental safety requirements with emissions of exhaust gases into the air, the detection and study of defects in the working bodies.

This goal is achieved by the fact that device for heating the working bodies includes a housing with a smoke tube located therein, at one end of which a gas burner is installed with channels for supplying gas and air, at the other end is a fan, an air heater, and a reflective screen. The pipe is U-shaped or Π-shaped; the air heater is connected by one channel to the air supply pipe to the gas burner, and the other channel is connected via a gas exhaust pipe with an inlet fan and a fixed or rotating outlet divider, which, in turn, is placed between the fire tube and the reflective screen, and is made or curved expanding channels.

The main equipment of the invention includes a burner device using which the organization of fuel and air mixing with formation of fuel-air mixture and maintaining its sustainable combustion is carried out, a fire tube in which the torch develops and flue gases move, as well as the pipe is heated to create radiation -convective heat transfer from the pipe to the environment, a fan (smoke exhauster), which induces the movement of flue gases from the burner unit along the entire length of the smoke tube to its outlet on the air heater. In air heater, heat is exchanged between the outgoing flue gases and cold air, as a result of which the source air is heated to a temperature of 100..250 °C, which ensures high efficiency (up to 85-90%) and increases the combustion efficiency of the mixture. In the upper part of the working space of apparatus, above the smoke tube and fan, there is a reflective screen that includes a layer of thermal insulation. To create radiation-convective heat transfer the divider is placed in the apparatus, which carries out movement of flue gases in working space of body, bounded by a reflective screen and heated by working fluid. The divider can be made in the form of straight or curved expanding channels, combined into a single system of cylindrical shape, which can be both stationary and rotating under the action of a moving stream of flue gases.

The temperature range during operation of device is flexible. It is determined by tasks and depends on the properties of working fluids, parameters and operating modes, as well as climatic conditions of operation.

Figure 1. Schematic diagram of the installation.

Figure 1 shows a schematic diagram of the installation, which consist of base part 1 and cap 2. The base part includes electric generator 3 and heat generator, which includes heat-insulating body 4, fan unit 5, burner 6, combustion chamber 7, air grill 8, power control system 9 and gas fuel supply 10. Electric generator 3 is equipped with a cap for filling by liquid fuel 11, exhaust gas pipe 12 and air supply nozzle 13. Base part 1 is installed on an uneven ground surface using telescopic legs 14. A separate cylinder 15 is provided for gas fuel supply. The cap 2 includes a swirler 16. The base part and cap are connected by a corrugated tube 17. To move the base part and the cap 2, the handles 18 are arranged.

To create a hot coolant I, consisting of flue gases II from the combustion of gas fuel III and air IV in generator 3, combustion of liquid fuel V with exhaust gases VI is provided.
Figure 2 shows the layout of the installation on the ground VII for heating a limited area F.

4. Features of the installation operation

The device works as follows. The base part 1 is transferred using handles 18 to the ground VII, set horizontally using telescopic legs 14. The cap 2 is placed using handles 18 on the surface of the working fluid in the zone of its warming up F. The base part 1 and cap 2 are connected using corrugated tube 17. The cylinder 15 is placed at a distance of at least 1 m from the base part and connected to it with a gas rubber or rubber-polymer hose (conventionally not shown), after which the gas reducer of the cylinder is opened (conventionally not shown).

Refueling of electric generator 3 is carried out through a cover for filling with liquid fuel 11. Starting is performed using a control unit (conventionally not shown). Due to the combustion of the fuel-air mixture consisting of liquid fuel V and air IV, electrical energy is generated, which will ensure the smooth operation of the heat generator. The resulting products of combustion are removed through the exhaust pipe 12.

After starting the generator and exiting it to a stationary mode, the heat generator is turned on and the heating mode is selected through the power control system 9 and the gas fuel supply system 10. The fan unit 5 is turned on, forcing air IV from the environment through the air grill 8 to the burner 6. At the same time gas fuel III is supplied to it through the gas fuel supply system 10 from the cylinder 15, where it mixes with air, forming a gas-air mixture that burns in the combustion chamber 7. At the same time, flue gases II are exhaled, which are guided along the combustion chamber to the output of the heat source, are mixed with air IV, forming hot coolant I.

Through corrugated pipe 17 hot coolant I is sent to cap 2, at the entrance to which swirl 16 is located, in which the flow of hot coolant I is twisted, thereby creating a circulation movement of the medium under cap 2. After the heat generator comes to a stationary mode, the plant capacity is controlled using a regulation system power 9.

When using the device as a source of thermal energy during technical and energy inspections of various construction elements, structures, buildings, convective heat transfer is made to the material under examination, and its thermal characteristics and latent defects are determined by the nature of heat flow distribution. The survey is carried out in accordance with the method of determining the density of heat fluxes (GOST 25380-82) passing through single-layer and multilayer enclosing structures of residential, public, industrial and agricultural buildings and structures during experimental research and under their operating conditions, as well as by non-destructive testing of the thermal type (GOST 18353-79), used in the study of thermal processes in products.

The advantage of the proposed device is that, compared with other means of heating, heating, heating working fluids, for example, frozen soil, concrete, pavement, the proposed device operates autonomously without being connected to power supply systems, does not depend on the quality of the installation surface (up to 30% slope of the surface) and its condition (ice, water, sand). At this, fast speed and great depth of heating of the working fluid is achieved.
In addition, depending on the heating area of working fluid, various cap configurations can be selected: according to the surface shape (round, square, etc.), according to the surface size (from a zone of 0.25 m\(^2\) to 2 m\(^2\) and more). Usage of this device makes it possible to carry out research on identification of internal defects in working fluids by non-destructive testing in the most inaccessible places in any cap position (horizontally, vertically).

The proposed device is mobile and can be serviced by a brigade of two people.

Thus, the proposed device allows one to solve the problem of heating, and warming of working fluids (frozen soil, concrete, pavement) by radiation-convection method during emergency and repair and construction works, to improve the quality, reliability and efficiency of devices of this class used to heat any working bodies, conduct energy and technical surveys of various construction elements, buildings, and structures, ant to carry out flaw detection of working bodies.

5. Experimental data
As shown by computational and experimental studies of the device in [11] for convective thawing of frozen sandy soil, conducted by the Department of Heat and Gas Supply and Ventilation of Vologda State University, the depth of thawing increases according to dependencies similar to those determined by various well-known mathematical models and experimental data. In this case, the convective method of heating allows defrosting the working fluids several times faster than the other known methods.

So, for example, when 15 kW thermal energy is supplied to a sandy soil from combustible reduced natural gas for 3 hours, the depth of heating of frozen soil of the 40%-moisture with an initial temperature of -10 °C at outside air temperature -2 °C with periodic removal of the thawed part of the pit was 1 m, which is approximately 30 times faster than using devices based on heat transfer due to thermal conductivity (thermomats) [12,13].

For such indicators as specific power of heating per 1 m\(^2\) of soil, the time of thawing to a depth of 0.5 m, the cost of thawing, expressed in monetary terms (RUB/h·m\(^2\)), as well as heating temperature, the proposed installation is more efficient. Considering such indicators as size and weight of the installation, the thermomat is more attractive from the point of view of movement and transportation, however, taking into account its low efficiency during thawing (about 30 hours), these advantages are relegated to the background. In view of the fact that the second analogue – a device for heating the soil and concrete WACKER NEUSON E700M is designed for large areas of warming up (up to 400 m\(^2\)), for such conditions, such device is inefficient. Similar results confirm viability of the proposed technical solution and are the basis for implementation of the installation in power supply and utility companies.

6. Conclusions
The authors have proposed a new method for warming frozen soils for municipal power industry using a mobile power plant operating on organic fuel and providing a warm layer of frozen soil in the cramped conditions of the urban environment. The installation is multifunctional for various fields of activity, including heat and power engineering and construction, and can be used as a source of thermal energy for heating any working fluids of various orientations in space, detecting internal defects in working fluids by thermal non-destructive testing method, during emergency and repair construction works for heating, warming frozen soil, concrete, road pavement and other building materials.

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References
[1] Ivanova A, Pavlov S, Akimov L and Zakharova L 2018 Zoning of the territory with snow removal using snow melting plants MATEC Web of Conferences 170 p 02023
[2] Nikolskiy S and Pertseva O 2017 Substantiation of Reference Method for Determining Concrete's Freeze-Thaw Resistance J. of Physics: Conference Series 790(1) p 012023
[3] Vishnyakov I E, Borchsenius S N, Kayumov A R and Rivkina E M 2016 Mycoplasma Diversity in Arctic Permafrost BioNanoScience 6(4) pp 516–9
[4] Nikolskiy S and Pertseva O 2016 Accuracy evaluation of rapid method for concrete’s frost resistance determination Advances and Trends in Engineering Sciences and Technologies – Proc. of the Int. Conf. on Engineering Sciences and Technologies, ESaT 2015 pp 335–40
[5] Lessovaia S N, Dultz S, Plötze M, Andreeva N D, Polekhovsky Y, Filimonov A and Momotova O 2016 Soil development on basic and ultrabasic rocks in cold environments of Russia traced by mineralogical composition and pore space characteristics Catena 137 pp 596-604
[6] Leksin V N and Profiryev B N 2017 Socio-economic priorities for the sustainable development of Russian arctic macro-region Economy of Region 4 pp 985–1004
[7] McRoberts E C and Morgenstern N R 1974 The stability of thawing slopes Can. Geotech. J. 11(4) pp 447–69
[8] Tukada K and Ogawa S 1997 Failure criterion of unsaturated soils subjected to freezing and thawing Ground freezing pp 327–32
[9] Nixon J F and Morgenstern N R 1973 Practical to a theory of consolidation for thawing soil Permafrost. 2nd Int. Conf. On Permafrost, Washington, D.C.
[10] Taylor G S and Luthin J N 1978 A model for coupled heat and moisture transfer during soil fruzing Canad. Geotech. Journal 15
[11] Sinitsyn A A 2013 The calculation of the characteristics and of the geometrical sizes of power devices European Applied Sciences 4
[12] Sinitsyn A A 2013 Simulation of fire engineering processes in energy devices aimed at their optimization and improvement of reliability Life Science Journal, the Acta Zhengzhou University Oversea Version. Marsland Press: New York 10 pp 442–7
[13] Mukhametshina R M, Petrov A V 2018 Technics and Technology of Transport 1 (6) p 13 URL: http://transport-kgsasu.ru/files/N6-13EB118.pdf