Improving the efficiency of the process of technological machines in the context of rational environmental management

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Abstract. The development of the timber industry complex, its current state and prospects show the need for a new resource-saving, environmentally and economically reasonable approach to the organization of the logging process, rational nature management. In recent years, the issues of ensuring the sustainability of development based on careful use of available resources and the environmental safety of production have been discussed. Today logging machines are an integral part of the timber harvesting process chain, and their efficiency directly affects their productivity and the quality of round timber. The paper presents and scientifically substantiated a design solution that increases the efficiency of the process of harvesting machines in freezing temperatures, which allows you to maintain their productivity and the quality of harvested round timber, reducing the proportion of generated logging waste in the form of technological raw materials.

1. Introduction
In the context of the modern development of the timber industry complex, the issue of rational nature management arises. During logging operations, logging waste is usually generated. One of the types of logging waste is technological raw material, the share of which is wood pulp formed during the operation of a logging machine in an emergency mode [1]. As the analysis of the geographical location of forest areas has shown, most of the harvested timber is located in places that are characterized by severe frosty winters, where there is temperature below -40 ° C, heavy snowfalls and blizzards [2]. The analysis of practical experience has shown that when logging equipment operates in low temperatures, freezing of the moving elements of equipment occurs, which leads to the failure of the main components and assemblies. As a result of mechanically removing icing, operators and mechanics for the repair and maintenance of forestry equipment face with the problem of limited access to icing places, and when exposed to thermal devices or open fire, it is not uncommon for attachments to catch fire or control units fail. One of the ways to solve this problem is to develop and introduce into the design a movable device for heating attachments. As a thermal agent, it is proposed to use exhaust gases from an internal combustion engine (ICE), which have a temperature above 350 ° C [3]. The analysis of the results of the work of modern researchers [4-8] showed that today, the issue of heating moving elements by exhaust gases performing complex movements during operation has not been solved. As a result, the purpose of this research is to develop a design for a device for heating...
attachments of forestry machines using exhaust gases from an internal combustion engine as a thermal agent.

2. Methods and materials
With regard to scientific problems, a complex of modern research methods was used: numerical modeling, mathematical planning and statistical analysis. To assess the values of freezing temperatures and the duration of their impact on logging machines, a statistical analysis of climatic data on the territory of cutting areas of the Angara-Yenisei region was carried out. The object of the study was a Ponsse Scorpion forestry machine equipped with an H6 harvester head and a C50 manipulator. To calculate the thermal parameters of the exhaust gases, a diesel engine calculation method was used. During the research, a quantitative relationship was established between the temperature of the heating element ($t_{h.el.}$) with ambient temperature ($t_{amb.}$), the inner diameter of the tube ($d_{in.}$), the outer diameter of the tube ($d_{out.}$), the temperature of the exhaust gases at a given point ($t_{ex.g.}$) and temperature at a given point on the outer wall of the tube ($t_{out.}$).

3. Results and discussion
When processing the results of the thermal calculation presented in Table 1, equations were obtained that describe the dependence of the surface temperature of the heating element on the geometric characteristics of the heating system and surrounding temperature.

**Table 1. Temperature indicators at a given point.**

| Ambient temperature, °C | Tube diameter Inside | Tube diameter Outside | Gas temperature in the tube, °C | Tube outer wall temperature, °C |
|-------------------------|----------------------|-----------------------|-------------------------------|--------------------------------|
| -30                     | 25                   | 30                    | 43.5                          | 24.44                          |
| -30                     | 32                   | 37                    | 30.0                          | 14.8                           |
| -30                     | 38                   | 43                    | 19.8                          | 7.0                            |
| -30                     | 46                   | 51                    | 7.7                           | -2.7                           |
| -30                     | 50                   | 57                    | 2.7                           | -9.9                           |
| -20                     | 25                   | 30                    | 49.7                          | 33.0                           |
| -20                     | 32                   | 37                    | 37.3                          | 23.9                           |
| -20                     | 38                   | 43                    | 27.8                          | 16.5                           |
| -20                     | 46                   | 51                    | 16.4                          | 7.2                            |
| -20                     | 50                   | 57                    | 11.4                          | 0.2                            |
| -10                     | 25                   | 30                    | 55.4                          | 40.9                           |
| -10                     | 32                   | 37                    | 44.1                          | 32.3                           |
| -10                     | 38                   | 43                    | 35.2                          | 25.3                           |
| -10                     | 46                   | 51                    | 24.6                          | 16.4                           |
| -10                     | 50                   | 57                    | 19.7                          | 9.7                            |
| 0                       | 25                   | 30                    | 60.6                          | 48.1                           |
| 0                       | 32                   | 37                    | 50.3                          | 40.1                           |
| 0                       | 38                   | 43                    | 42.2                          | 33.5                           |
| 0                       | 46                   | 51                    | 32.3                          | 25.2                           |
| 0                       | 50                   | 57                    | 27.6                          | 18.8                           |

Based on the results of mathematical modeling, an equation describing the dependence of the external temperature of the heating element on the surrounding temperature and the diameter of supply pipes is presented as an example.

$$t_{h.el.} = 86.776 + 0.519 \cdot t_{amb.} - 0.003 \cdot t_{amb.}^2 - 1.391 \cdot d_{out.} - 0.0035 \cdot d_{out.}^2 + 0.0062 \cdot t_{amb.} \cdot d_{out.}, (1)$$
Calculations have confirmed that all the coefficients of the regression equations are significant. For complete assessment of the effect of ambient temperature and pipe diameter on the temperature of heating element, the surface shown in figure 1 is constructed using equation 1. The response surface gives fully demonstrates the dependence of the external temperature of heating element on ambient temperature and the diameter of supply pipe.

![Figure 1. Dependence of outside temperature of the heating element on ambient temperature and the diameter of the flow tube.](image)

Graphical dependence and equation 1 show that the external temperature of the heating element increases with an increase in the ambient temperature and a decrease in the external diameter of the pipe and reaches its maximum value of 60 °C at \( t_{\text{amb}} = 5 \) °C and \( d_{\text{out}} = 25 \text{ mm} \).

Based on the analysis of the research results, the design of the heating system and the diagram of its installation on the logging machine were developed. It is shown in figure 2.

The principle of device operation lies in the fact that when the internal combustion engine (1) is in operation, the exhaust gases enter the exhaust manifold (2). From the exhaust manifold, the exhaust gases are forced into the exhaust pipe (4) with an integrated cut-off (3). The cutter covers half the diameter of the exhaust pipe circumference, which facilitates the entry of exhaust gases into the heating structure system. After entering the heating pipe (6), the exhaust gases enter the boost turbine (5), which is driven not only by exhaust gases entering it under pressure, but also by an electric drive, which is necessary to lower the temperature of exhaust gases to optimum temperature, in order to effective operation of a heating device and purging the entire system from condensate after stopping the engine. From the boost turbine, pressurized exhaust gases are fed further through the system pipe to the junction of rigid pipe with a flexible metal connecting pipe (7). Installation of a flexible pipe is due to the presence of a rotary frame connection. Subsequently, the exhaust gases pass through the tube (8) to a mobile equipment and enter the flexible metal sleeve (9). Further movement of exhaust gases along the design of the heating system occurs along rigid (10), (12), (14) and flexible (11), (13), (15) tubes. After passing through the tube (15), the exhaust gases enter the coil (16), which is a heating element built into the structure of the harvester head.
Figure 2. General view of the design of heating system. 1 – internal combustion engine; 2 – collector; 3 – cutter; 4 – exhaust pipe; 5 – boost turbine; 6, 8, 10, 12, 14 – heating tube; 7, 9, 11, 13, 15 – corrugated heat-resistant hoses; 16 – serpentine tube (heating element).

The return of gases after the heating element is carried out in the opposite direction through the pipes installed together with the pipes for supplying the heating agent.

4. Conclusion
Thus, the use of the proposed design of the heating system in conditions of negative temperatures will prevent freezing of the movable elements of the attachments of timber harvesting machines. The trouble-free and continuous operation of timber harvesting machine will undoubtedly have a positive effect not only on increasing its productivity but will also reduce the amount of generated logging waste, which is wood pulp unsuitable for further use, formed during the operation of attachments in emergency mode. The statistical and mathematical equations and graphical dependencies obtained in the course of research make it possible to predict the heating temperature of the heating element depending on the ambient temperature and the design characteristics of the heating system. The analysis of the research results showed that for the optimal operation of the design of heating system of the harvester attachments, it is necessary to use tubes with an inner diameter of at least 25 mm and no more than 41 mm.

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