

Institute for Applied Mathematical Research
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BOINC-based furnace modeling

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Relevance

Computer simulation of the combustion process is widely used in:

- industrial heat power engineering
- designing internal combustion engines
- designing furnaces

The process of burning fuel consists of many interacting processes.

Greater accuracy with small time cost is required to solve real problems.

Consequently, high performance is required.

Goal and tasks

Goal:

Conducting an experiment with the numerical modeling of combustion of firewood in a furnace using a high-performance computing system using the example of a household furnace model.

Tasks:

1. Explore methods of modeling a physical phenomenon;
2. Define the criteria for selecting software products and select software products based on the criteria;
3. Conduct the validation of the model implemented in the selected software product, by performing numerical simulation and analysis of the simulation results.

Method for modeling the movement of gases

- Large Eddy Simulation model (LES)

based on the Navier-Stokes equations:

Equation of motion:

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla) \mathbf{u} = -\frac{1}{\rho} \nabla p + \nu \nabla^2 \mathbf{u} + \mathbf{f}$$

Equation of continuity:

$$\mathbf{u} \cdot \nabla = 0$$

Filter used:

$$\bar{\mathbf{u}}(\mathbf{x}) = \iiint_D G(\mathbf{x} - \xi) \mathbf{u}(\xi) d\xi$$
$$G(\mathbf{k}) = \begin{cases} 1/\sqrt[3]{V}, & \|\mathbf{k}\| \leq \sqrt[3]{V}/2 \\ 0, & \text{else} \end{cases}$$

Methods for modeling the chemical reaction of combustion and heat transfer

Diffusion equation:

$$\rho \frac{\partial Z}{\partial t} + \text{div}(\rho v Z - \rho D \text{ grad } Z) = W$$

Energy conservation equation :

$$\rho \frac{\partial H}{\partial t} + \text{div}(\rho v H - \rho \alpha_{eff} \text{ grad } H) = R + S$$

Mathematical model of heat conductivity in a solid

- Equation of non-stationary heat conductivity:

$$\frac{\partial T}{\partial t} = \chi \cdot \nabla^2 T$$

- Received and given energy by radiation on border with air
- Convective heat exchange between air and solid

Criteria for choosing software products

- Availability of implementation the selected mathematical model
- The possibility and complexity of the implementation the chosen mathematical model in the product if model is not implemented
- Support OpenMP + MPI technology
- Adaptive types of mesh
- The complexity of using the product
- Availability of documentation
- Open source code

The most suitable products for the selected criteria

- Fire Dynamics Simulator v6.3.2 + Smokeview v6.3.2 + BlenderFDS

implementation of the selected math. models

supports only rectangular non-adaptive mesh types

- OpenFOAM + ParaView

Good for hexahedral adaptive meshes

The possibility of the implementation any mathematical model for FVM

The need to implement the chosen math. model based on existing implementations of its parts

High labor consumption of the product

Validation of software products

Used the geometric model of the furnace in STL format, created by the company PetrozavodskMash-TNP

Experiments were conducted with the following conditions:

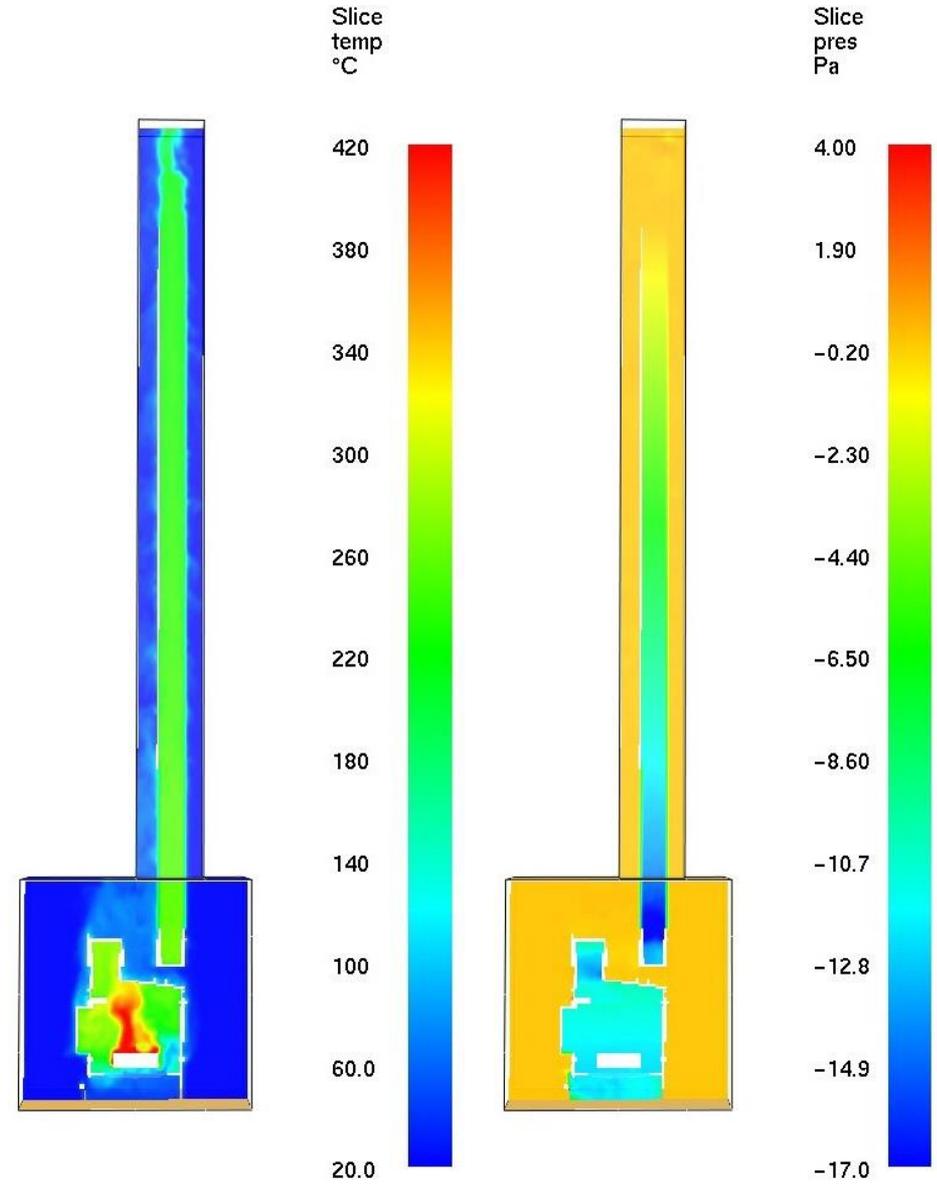
1. The temperature of the furnace walls is 20 degrees Celsius, the door is closed, the ash pan is extended by 100 mm;
2. The temperature of the walls of the furnace is 200 degrees Celsius, the door is closed, the ash pan is extended by 10 mm;
3. The temperature of the walls of the oven is 200 degrees Celsius, the door is open, the ash pan is extended by 10 mm.

It is necessary to verify the conformity of the results of a numerical simulation to the experimental data of OOO PetrozavodskMash-TNP

All calculations were conducted on the computing cluster of the Karelian Research Center of the Russian Academy of Sciences

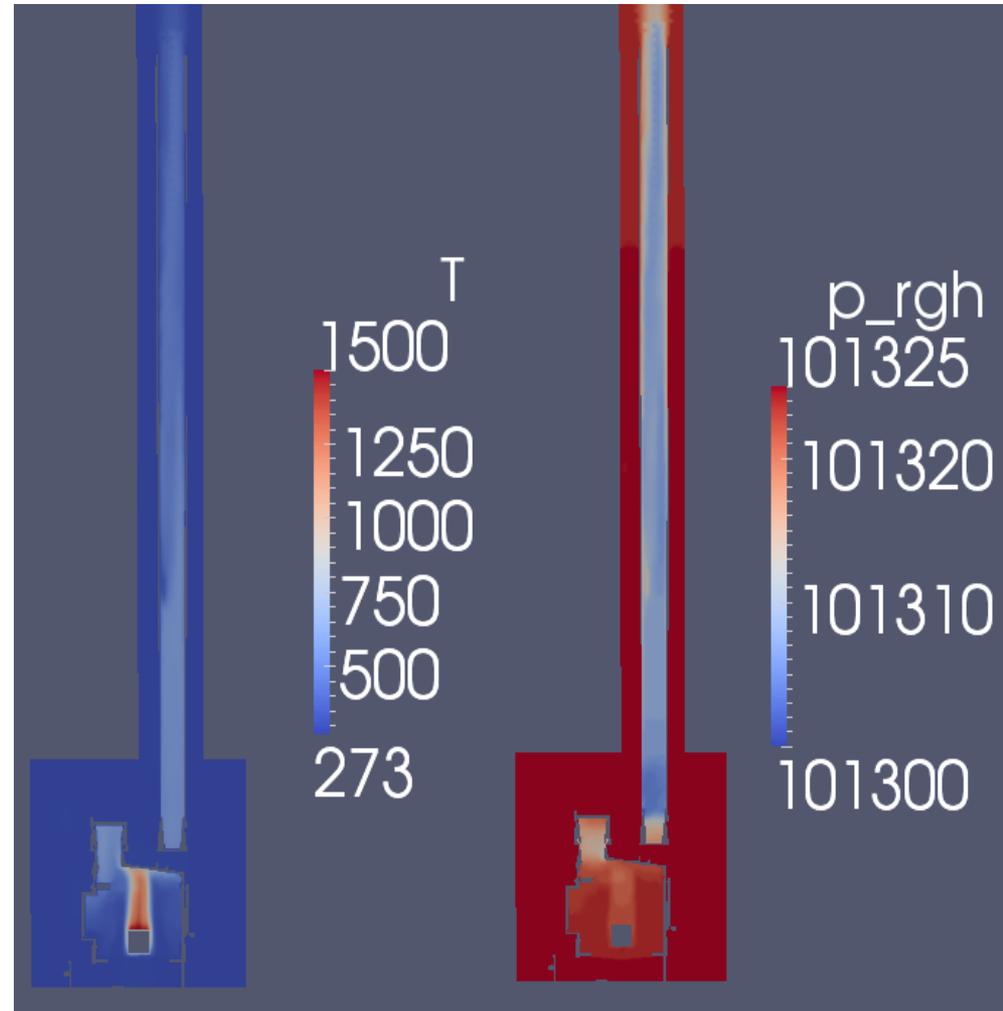
Analysis of the results of a numerical simulation for the software product FDS

- The results of modeling the thrust in the furnace (flow velocity, pressure) are in **good agreement** with the experimental data.
- The results of the smoke simulation are **close** to the experimental data.
- The results of simulating the temperature of gases are in **good agreement** with the experimental data.
- The results of modeling the temperature on the furnace surface have a **significant difference** from that obtained experimentally.



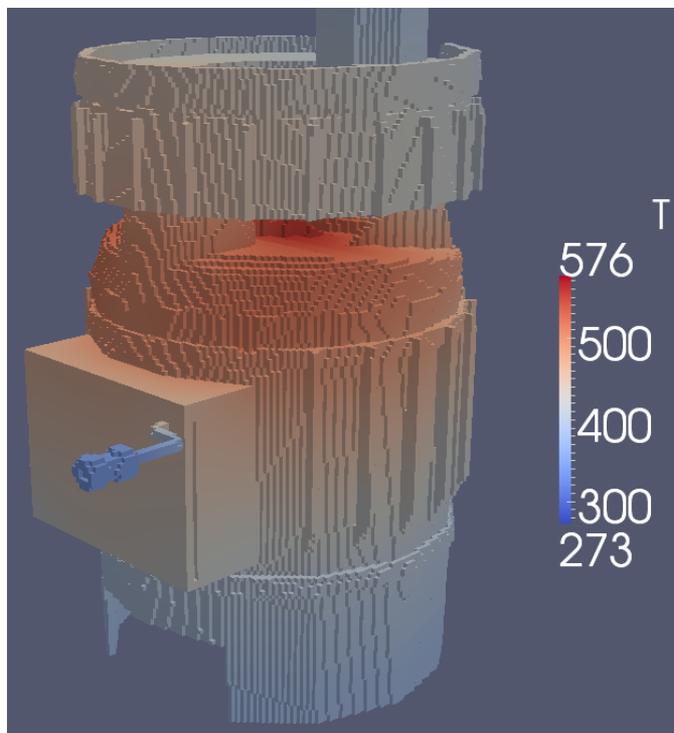
Analysis of the results of a numerical simulation for the software product OpenFOAM

- The results of modeling the thrust in the furnace (flow velocity, pressure) are in **good agreement** with the experimental data.
- The results of the smoke simulation are in **good agreement** with the experimental data.
- The results of modeling the temperature of gases are **close** to the experimental data.
- The results of modeling the temperature on the surface of the furnace are **close** to the experimental data.

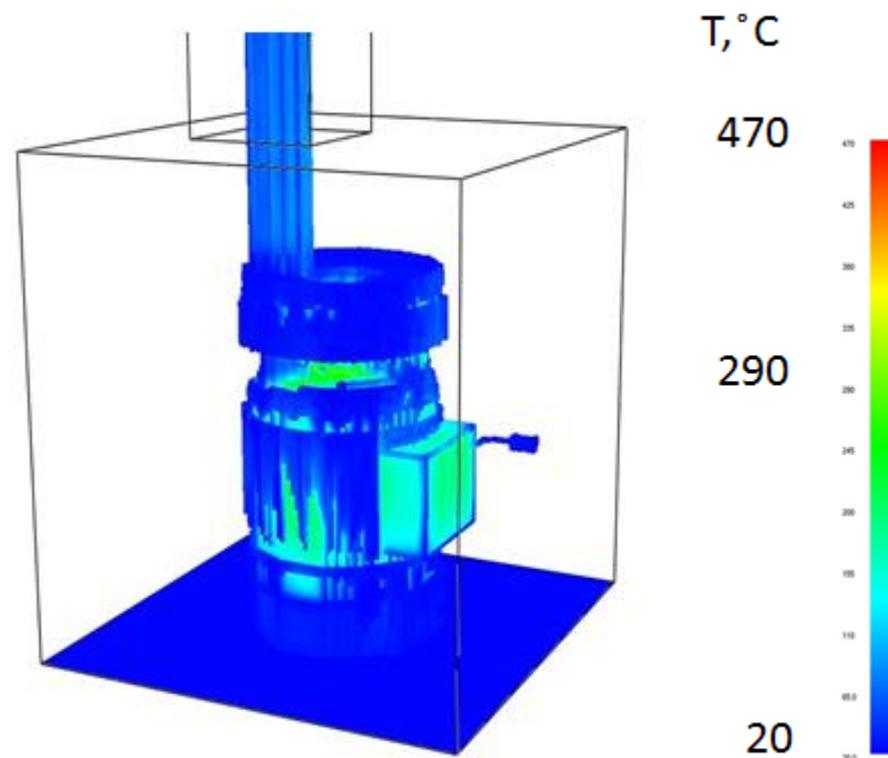


Results of calculating the temperature of the furnace walls

OpenFOAM



FDS



Continue of research

- The next problem is to optimize such furnace parameters as the dimensions of the chimney ducts of the furnace and also the height and diameter of the chimney.
- This optimization means that it is necessary to find the minimum values of the parameters for which the furnace is capable removing combustion products from the furnace.
- Thus, there is a reduction in the consumption of materials in production furnaces and a decrease the volume occupied by the furnace.

Planning of the computing on BOINC

- This task requires a lot of independent simulations (with different dimensions of the chimney), where one simulation requires a large amount of RAM, so the use of the cluster becomes inefficient.
- Therefore, we decided to create a BOINC project to perform distributed computing on PCs with 8GB of RAM

Conclusion

Thus, the goal of the work was achieved and as a result of the work the validation of OpenFOAM software was successfully conducted. In the future, it is planned to optimize furnace parameters such as the dimensions of the chimney ducts of the furnace, as well as the diameter and height of the chimney using BOINC.

Thank you for attention