3-D simulation using for hydraulic calculation of the heat accumulator

Olha Kletska[1,*], *Anatoliy* Falendysh[1], *Arthur* Kagramanjan[1], and *Andrey* Onishchenko[1]

[1]Ukrainian State University of Railway Transport, Feuerbach Square 7, 61050 Kharkov, Ukraine

Abstract. The article is devoted to the peculiarities of hydraulic calculation of the heat accumulator in the software environment for 3D modeling - SolidWorks. Based on the results of the calculation, the values of the distribution of the velocities of the water flow and the distribution of the static pressure in the given plane of the heat accumulator were obtained, which eventually made it possible to identify the problem areas in the three-dimensional model and obtain the values of the pressure difference.

1. Introduction

One of the way to improve the ecological and economic indexes of the diesel locomotives that are in "a hot" reserve, is to use alternative sources of warming up such as a heat accumulator.. The functioning mode of this device is based on a latent heat of phase transitions of chemical substances, that is when the engine is running it is charged with heat, and during the storage of the locomotive in the "hot" reserve, the heat accumulated by the accumulator is spent for preheating the diesel locomotive.

For the purpose of optimisation of a choice of the additional equipment (a storage battery, the water pump) at the installation of the heat accumulator on a diesel locomotive hydraulic calculation on already constructed 3D sample pieces in program SolidWorks environment and in particular its module for simulation of a current of fluids and gases - Flow simulation is carried out.

Flow simulation software is fully integrated into SolidWorks for the calculation of liquid and gas flows inside and outside the SolidWorks model, and also calculates heat transfer from, to, and between these models by convection, radiation and thermal conductivity using computational fluid dynamics (CFD) technologies.

The correct choice of the water pump allows to pick up more precisely a storage battery that raises time of autonomous operation of a diesel locomotive and increases its ecological compatibility and fuel efficiency as a whole.

The problems in the field of energy accumulation based on the heat of phase transition are occupied scientists from the different countries such as W. Youssef, Y.T. Ge, S.A. Tassou «CFD modelling development and experimental validation of a phase change material (PCM) heat exchanger with spiral-wired tubes», Luca Constantin, Daniel Dragomir-Stanciu, lonut Vasile Crismaru «Optimization of heat exchange in a heat accumulator with latent heat storage», Shilei Lu, Tianshuai Zhang, Yafei Chen «Study on the performance of heat storage and heat release of water storage tank with PCMs». However in one operation it is not mentioned hydraulic losses in examined devices and their influence on accessories choice at concrete field environment [1-4].

Nomenclature

ΔP Pressure difference (Pa)

2. Problem statement

The problem of environment protection is global for the whole world, therefore reduction of ejections of soiling substances with burnt gases is one of directions under its decision. Today the railway transport takes not the last place among sources of soiling substances in the presence of the big diesel park where as a heat-power plant uses an internal combustion engine.

Therefore, the first step in reducing pollutant emissions is to reduce reduction of fuel costs by diesel locomotives, both in the performance of shunting and trunk works, and when locomotives are in the "hot reserve". Due to some physical properties of construction and cost materials for the normal operation of a diesel locomotive, regardless of whether the driver's controller positions according to the specifications of the manufacturer, the temperature of water and oil should be not less than 40 °C. And the geographical position of Ukraine and the climatic conditions of operation of diesel locomotives require, to maintain them during heat-away the sludge at the required temperature level, by running the engines idling, or to warm them from an external source of energy - that is, warming up is an integral part of their operational cycle.

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[*] Corresponding author: gurao@ukr.net

One of the way to improve the environmental and economic performance of diesel locomotives in a "hot" reserve is to use alternative heat sources such as a heat accumulator (HA). This device, the principle of which is based on the latent heat of phase transitions of chemical substances, that is, when the engine is running it is charged with heat, and during storage of the locomotive in the "hot" reserve, the heat accumulated by the accumulator is expended on heating the diesel locomotive.

Features of calculation of thermal accumulators with melting heat-accumulating material: To determine the main characteristics of a thermal battery with a phase transition, a detailed description of the processes occurring in the accumulator is required, which requires taking into account the mechanisms of sufficiently fine physical processes: radiation and convection in HA, volume changes in phase transformations, anisotropic properties of heat-storage material HSM) etc. On the basis of such calculations, the parameters at each point of the accumulator capacity are determined, which makes it possible to conduct its comprehensive studies. Simplified mathematical models [8] are often used to estimate the size and basic parameters of HA in which the constancy of the HSM and coolant properties, heat transfer in only one direction, neglect of the heat capacity of HSM and a others are often used. It make possible to receive the dependences for different types of accumulators, that allow to define their basic parametres.

It is known that solidification process HSM in capsular HA consists of the stages of the formation of phases section boundary of, its movement on a stroke of the heat-carrier and its collapse. The first two stages provide close to stable parameters at the output from the HA and, naturally, are of practical interest.

3. Analysis and modelling

To estimate the dimensions HA, the cylindrical element is considered under the assumptions that the properties of the coefficient of heat transfer and the velocity of heat carriers are constant, the axial heat transfer and the changes in the properties of the HSM during melting are absent, the speed of movement, and the shape of the phase boundary are constant.

Based on the results of calculations in the SolidWorks environment, a parametric model of a capsular-type heat accumulator with a melting heat-accumulating material based on barium hydroxide a $Ba(OH)\ \cdot 8H_2O$ (fig. 1) is constructed.

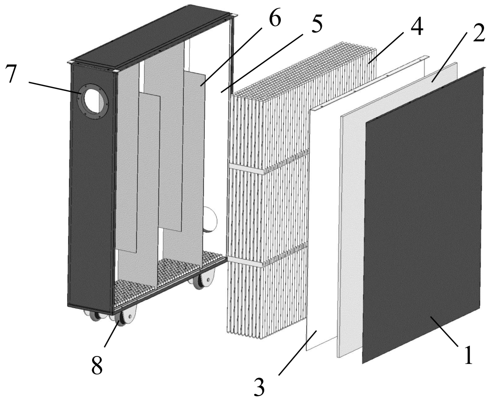

Fig. 1. Heat accumulator construction.
1. Lagging Sheet; 2. Thermal insulation; 3. A wall of the welded cage; 4. Pack of capsules; 5. The welded cage; 6. Transverse partition; 7. Outlet elbow; 8. Wheelbase.

Structurally, the model is a conventional heat exchanger made in the form of a rectangular parallelepiped. The device contains the leakproof welded cage from simple steel: with underwater and by-pass fitting pipes in which capsules with a working body are located. Capsules are hermetically sealed brass tubes. The package of capsules is assembled into a single matrix with a corridor arrangement of the latter. To improve the flow around the tubes and increase the heat transfer of the annular space, the body has transverse partitions. It should be noted that the design of the heat accumulator, that is shown in Fig. 1 is not final and can have different modifications [9].

To optimize the choice of additional equipment (storage battery, pumping water pump), when installing a heat accumulator on the diesel locomotive, a hydraulic calculation is carried out. Total hydraulic losses represent the sum of linear and local losses. The loss of friction is determined using formulas obtained as a result of theoretical or practical studies. Determining local losses is more difficult because for this, only experimental data are available. There is a wide variety of configurations of pipeline systems, therefore, there are various reasons for the occurrence of local resistances. The flow structure also can be quite complex. Therefore, the use of experimental data is limited. Flow simulation offers a different approach to solving similar problems and allows you to accurately determine the pressure loss in virtually any part of the pipeline system.

To solve this problem, this HA model was simplified and is a casing with an inlet and outlet branch pipe without thermal insulation and external cladding, wheelbase, with a set of tubes inside.

It is necessary to calculate the value of the total pressure loss, i.e. the difference between the pressure at the entrance to the heat accumulator and the pressure at the outlet from it, where the flow again becomes unperturbed.

To solve this type of problem, all the holes in the model must be closed with covers so that the internal space of the model is closed. At the inputs and outputs, the appropriate boundary conditions must be set. Covers are additional elements, with which you can close the holes (fig. 2).

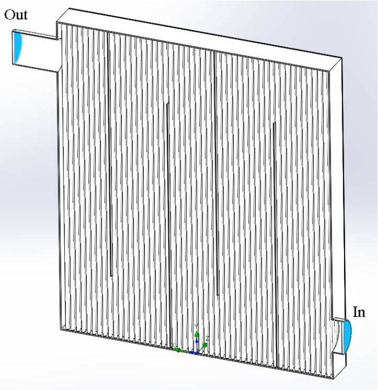

Fig. 2. Simplified HA model plugs at the input and output.

Boundary conditions or input data for calculation, the velocity at the entrance to the heat accumulator was chosen to be a numerical value of 0.15 m / s. In order that no errors occur in the specification of the boundary conditions, we set the "Pressure" condition on the outlet. Then the mass flow at this hole will be determined automatically so that the law of conservation of mass is satisfied. The static pressure was set equal to 101325 Pa, which means that the water flow pressure at the outlet from the HA is 1 atmosphere.

The only thing that remains unknown is the value of the total pressure at the inlet and outlet. The easiest and quickest way to determine these parameters is to set an appropriate calculation purpose.

As the global purpose the average mass flow was established. The inner surfaces of the covers at the entrance and exit from the HA were chosen and the boundary conditions were marked, in which the static pressure - local purposes - was selected. The Flow simulation project is ready for calculation. It will be completed when the average values of the mass flow, as well as the static pressure at the inlet and outlet of the HA, become steady. Flow simulation will automatically generate a calculated mesh. The entire calculation area will be divided into parts, which will later be subdivided into meshes. If there is a need, the meshes will be crushed further for a more detailed resolution of the geometry of the model. The results of the construction and the drawing of the mesh are presented below (tab. 1, fig. 3).

Table 1. Results of mesh construction (Number of cells).

Meshes	1326038
Meshes in the fluid environment	471790
Meshes in a solid	854248
Fractional meshes	417027
Irreguljarnye meshes	13
The truncated meshes	0

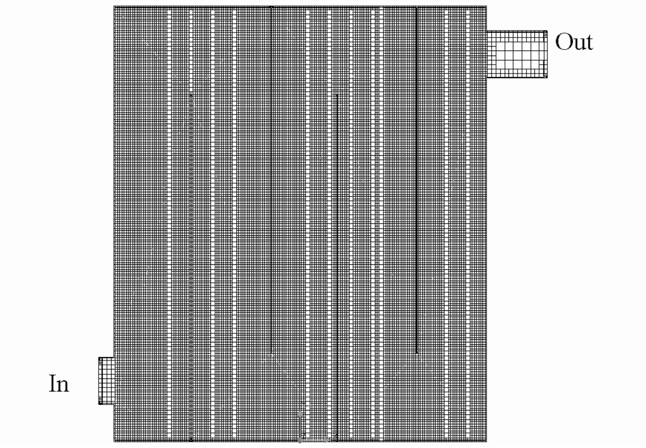

Fig. 3. Automatically generated model HA mesh.

4. Results and discussion

The results of calculation of the program are presented in fig. 4, 5, 6.

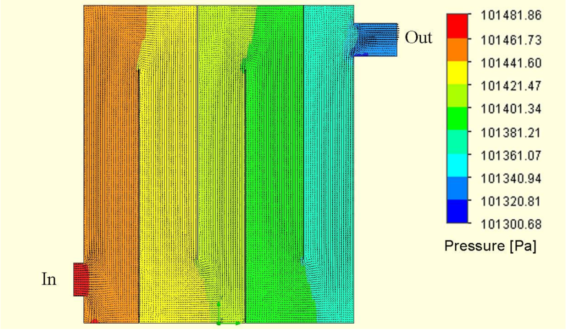

Fig. 4. Distribution of static pressure in the set plain HA.

It can be seen from the calculations that the pressure of the fluid flow decreases during the passage of the transverse partitions in the accumulator body (Fig. 4), since the presence of viscosity leads to a dissipation of energy, which eventually turns into heat. In streams of pure water, the final transition of mechanical energy to heat occurs when the individuality of the smallest vortex masses is lost, the isolated existence of which ceases due to the viscosity of the fluid.

The picture of the velocity distribution and the velocity vector is shown in fig. 5.

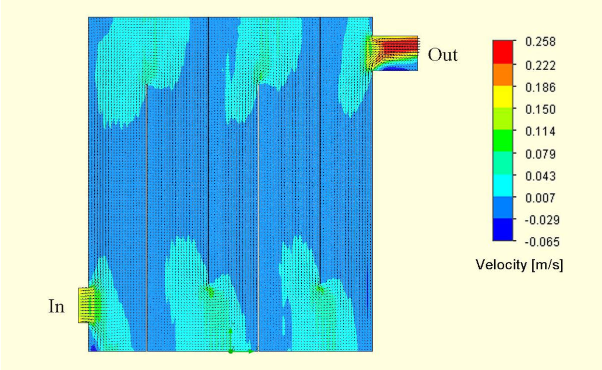

Fig. 5. Water stream movement in HA.

As in the first case, the velocity increases with the passage of the next transverse partition, which is accompanied by a drop in pressure. On the scale there are also velocities with a negative sign; these areas of blue colour show the zone of the reverse flow.

During the calculation of this task, a message appeared: "The appearance of the reverse flow at the boundary". It warns that at the hole where the boundary pressure condition was specified, in addition to the outflow, an inverse current is formed. In this problem, the reverse flow penetrates into the outgoing stream. When the reverse flow is formed, the accuracy of the results obtained is reduced. Moreover, in some cases, the convergence of goals can not be achieved at all (that is, the value of the goal will not become stable).

As the warning has not disappeared, it was necessary to discontinue calculation and increase the length of the outlet branch pipe at the exit of the heat accumulator so that there was no reverse flow at the border.

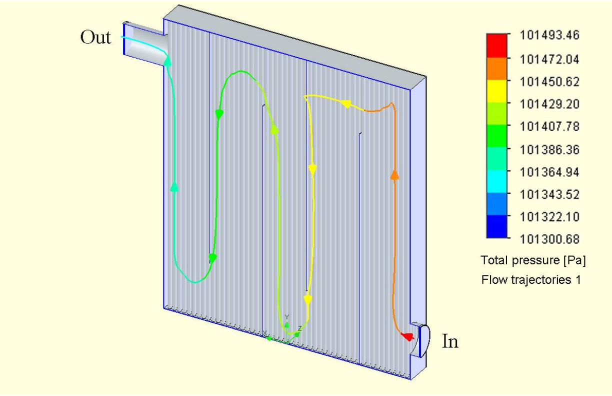

Fig. 6. Water stream trajectory in HA.

From the assaying of the received results follows that hydraulic losses of water pressure in the thermal accumulator amounted $\Delta P = 192{,}78$ Pa.

5. Conclusions

On the basis of hydraulic losses, we optimally select the water pump for pumping coolant through the cooling system of the locomotive, as well as the storage battery for its drive, that in turn increases the autonomous life of the diesel locomotive, which means that it increases its environmental friendliness and fuel efficiency.

Due to the fact that the design of the heat accumulator varies depending on the design features of the locomotive and the type of work performed by it, as well as the absence of typical HA projects, that is, the complete lack of experimental data, the use of Flow simulation allows the design engineer to obtain not only a numerical solution of the task, and visualization of the peculiarities of the "narrow" places of the design developed by him.

References

1. W. Youssef, Y.T. Ge, S.A. Energy Conversion and Management **157** (2018)
2. L. Constantin, D. Dragomir-Stanciu, I.V. Crismaru, Procedia Technology **19** (2015)
3. S. Lu, T. Zhang, Y. Chen, Energy and Buildings **158** (2018)
4. A.Z. Homich, O.I. Tupitcy`n, A.E. Simson, *E`konomiia topliva i teplotekhnicheskaia modernizatciia teplovozov* (M.: Transport, 1975)
5. V.V. Oshovskii`, D.I. Okhrimenko, A.Iu. Sy`soev, Seriia «Himiia i himicheskaia tekhnologiia». Vy`pusk No **15** (2010)
6. A.A. Aliamovskii`, *Komp`iuternoe modelirovanie v inzhenernoi` praktike* (SPb: BKHV - Peterburg 2005)
7. *SolidWorks Flow Simulation 2012*, Technical Reference (2012)
8. V.D. Levenberg, M.R. Tkach, V.A. Gol`strem, Akkumulirovanie tepla, pp. 49–74 (Kiev, Tekhnika, 1991)
9. A.O. Kagramanian, A.V. Onishchenko, Zaliznichnii` transport Ukraïni: naukovo-praktichnii` zhurnal, **1**, pp. 49-51 (2011)