

## THE DRAFT OF THE EXHAUST GAS HEAT EXCHANGER AND USING OF WASTE HEAT FROM INTERNAL COMBUSTION ENGINES

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**Abstract:** The paper discusses about the use of heat exchangers for stationary combustion engines and cogeneration units. The paper is dedicated to the problem of unused thermal energy in stationary engines. It analyses possibilities of accumulation of heat energy and its possible application in various fields. The paper deals with the classification of heat exchangers and with the subsequent description of design solutions of heat exchanger types used in agiven field. It solves the draft of exhaust gas heat exchanger for stationary combustion engines according to the required parameters of internal combustion engine and verifies the correctness of the design by subsequent simulations in the simulation program ComsolMultiphysics.

**Keywords:** heat exchangers, cogeneration unit, waste heat, combustion engines, draft, simulation.

### Introduction

Nowadays, if we omit alternating economic crisis we can talk about ecological time. Energetics has a great impact just on these aspects. It is due to the increasing energy demands of human society, on which—environmental burden and efficiency of energy use are highly dependent.

The possibility of how to reduce energy consumption is the way of creative savings. Reduction in fuel consumption can be utilized in a direction, which deals with the production of several types of energy and also of the products from the primary source at the same time [3, 4]. This category can include cogeneration (Fig. 1), trigeneration and polygeneration. It is not as easy to find a use for the heat as in the case of electrical energy. Nevertheless, there are several options offered here, such as use of heat for hot water or direct water heating and its subsequent use for houses or large objects, depending on the performance of the cogeneration unit itself. Another option would be to use the absorption unit to transform heat to cold, making it possible to extend services to the production of cold water, for example for supply of air conditioners.

For all these systems the energy transformation is a decisive method of how to submit it. In case of heat, an inseparable part of most of the systems called the

thermal coupling node is used for this intention. There are various types of heat exchangers, coolers, condensers etc. Heat exchangers, which can be used for the generation of thermal energy from the exhaust gases and its subsequent use in other applications belong to the most common devices nowadays.

### Use of heat exchangers in cogeneration units and stationary internal combustion engines

Using of stationary internal combustion engine to generate electricity (Fig. 2) or in other applications, arise a waste heat [1]. In most cases, this heat is not used in any way, but nowadays more and more forcing producers and consumers invest in technologies that can leverage the potential of unused energy and contribute to cost saving. Exhaust gas heat exchangers started to be used to this end. An exhaust heat exchanger is positioned on the exhaust pipe, removing the heat of flowing exhaust gases, which could be used for various applications. Exhaust gas temperature at the start of the exhaust pipe is in the range 500-700°C. It means that exhaust gases offer a great potential for utilization of waste heat. Exhaust gases in most of cases heat up the liquid, which can be subsequently used in several ways [5].

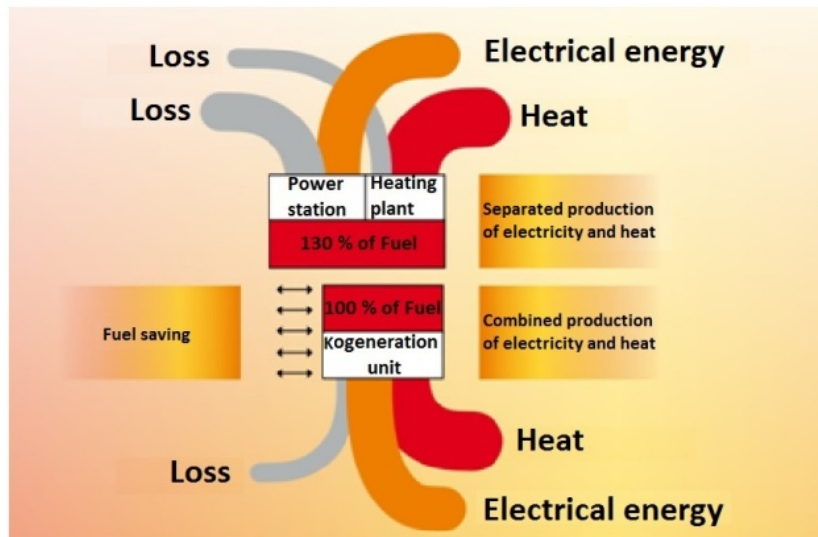
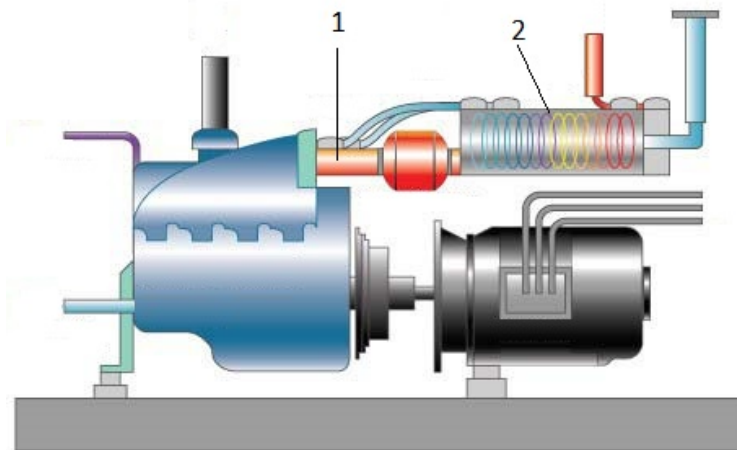


Fig. 1. Cogeneration principle [6].



1 - Exhaust gas pipe, 2- Exhaust gas heat exchanger

Fig. 2. Position of exhaust gas exchanger in a stationary combustion engine [1].

## Heat exchanger

A device used for targeted heat energy transfer from one heat medium to another one, according to the second law of thermodynamics, is called a heat exchanger [2]. These facilities present a large group and can be found in many kinds of systems without our knowledge. Another division is quite normal according to the method of heat transfer, i.e. whether there is contact between the media etc.

Heat exchangers are divided into:

- recuperative - media are separated by a solid impermeable wall and not coming into contact;
- regenerative - occurs periodically substituted flow, heating and cooling media in the defined area;
- contact - media come together in the same time in contact without chemical reaction, and then are separated;

- mixing - media are in a certain place mixed and continue as a mixture.

Design with shaped tubes represents different tube axis arranged in the shape of a helix, spiral (Fig. 3) etc., located in the shell.

Exchangers in design tube in tube are among the simplest devices in the above category. It's occurred like dismountable and non-dismountable which are exclusively for pure thermal media.

The most commonly used type of heat exchanger is recuperative. This group primarily includes tubular and plate heat exchanger. From the point of view of the flow, it is the most common counter-flow design, which results in better heat distribution than in a parallel flow design.

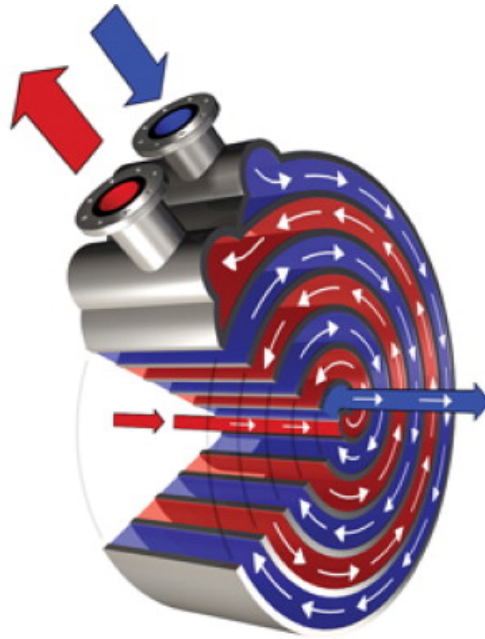


Fig. 3. Spiral tube heat exchanger [7].

### Tube heat exchanger

In this type of exchanger, heat exchange takes place between the tube and the tubular-space. Tubular space normally consists of pipes or tubes of circular cross section, but we can also encounter cross-sections of other shapes such as oval, square etc. To reduce the dimensional parameters of tubular exchangers we can use different means to increase the area of the pipe from

the side of the pipe as well as the tubular space. For example, ribs are used for this purpose.

Tube heat exchangers can be divided according to the construction into ones (Fig. 4, 5, 6):

- with shaped tubes;
- with straight pipes:
  - tube in tube;
  - tube in the shell.



Fig. 4. Shell & tube heat exchanger [8].

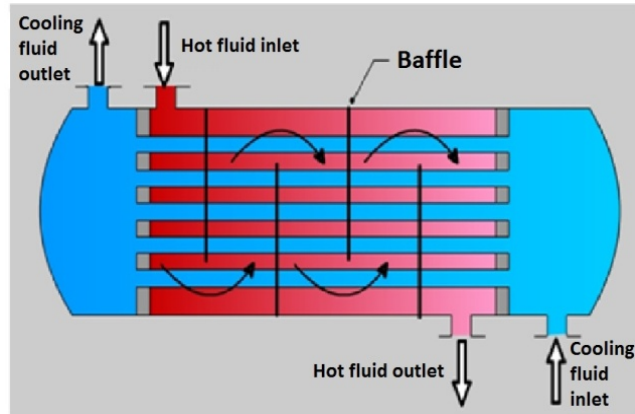


Fig. 5. Tube heat exchanger with baffles.



Fig. 6. Real construction of tube heat exchanger with baffles [9].

In general, the tube exchanger with jacket is the most commonly used heat exchanger, where the main structure consists of a tube bundle placed in the shell of a cylindrical shape. These exchangers are manufactured at many different versions, depending on the configuration of inlet and outlet orifices, pipes, construction attachment of different thermal dilatation of tubes and plastics etc. This type of heat exchanger typically includes partitions that perform two basic functions. The arrestment of tubes results in a reduction of bending and vibration and also directs the flow of media that is purposely altered to the cross-flow that increases the intensity of heat transfer. Disadvantage of this system is that with the inclusion of partitions it creates higher pressure drop.

Tube heat exchangers are characterized by good heat resistance and affordable price. However, their disadvantages are small compactness and high weight. In the case of the pipes with small diameter, in which the aqueous medium is dirty, gradual decrease of the cross-section pipe up to its complete clogging is expected.

### Plate heat exchanger

Plate heat exchangers are based on a patent that has already been registered in 1878 by a German inventor Albrecht Dracke. This principle, when one liquid cools another liquid and liquids flow on both sides of group thin metal plates, became the basis for the construction of the heat exchanger - commercial plate pasteurizer Alfa Laval.

Plate heat exchangers were developed and structurally modified for more than 130 years into devices that are used in thousands of different applications in all industries. A plate heat exchanger was previously designed for heating and cooling of milk, but now is commonly used for heating and cooling in industrial processes and it is the basis of air-conditioning in buildings or it provides heating of hot water for hundreds of millions of people.

This type of heat exchanger is characterized with a row of lying plates which bear shaped reinforcements, create

turbulence of heat transfer medium and enlarge the heat-conveying surface. The heat transfer medium, as shown in the figures 7, 8, flows between the slabs of small thickness, whereby the heat is transmitted between substances mainly convective. Plate heat exchangers can be sorted into dismountable and non-dismountable. Non-dismountable exchangers usually occur in the brazing or

welding design, which can also be used in case of the aggressive heat transfer medium. The main advantage of plate heat exchangers is its high performance per unit area and also low weight and small size which is for the same performance about 5 times smaller than in tubular heat exchangers. However, the benefits are offset by higher prices and demanding production technology.

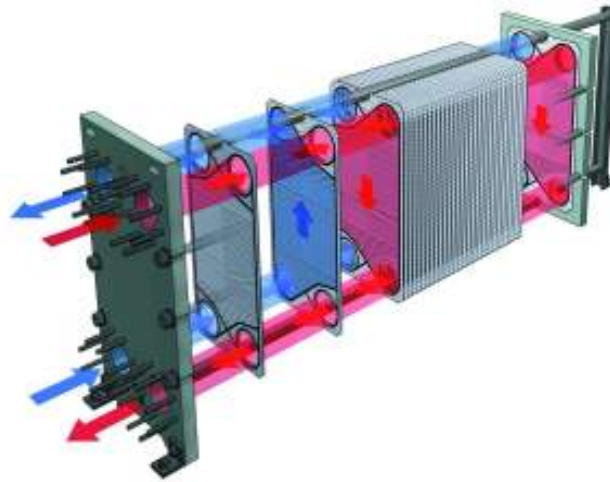


Fig. 7. Plate heat exchanger [10].

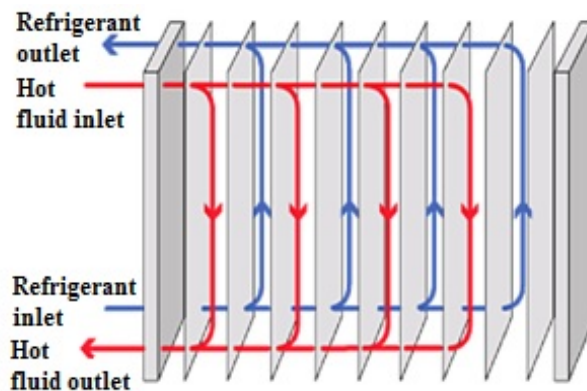


Fig. 8. Fluid flow in plate heat exchanger [11].

**Draft of exhaust gas heat exchanger**

Draft of exhaust gas heat exchanger was realized according to these input parameters (Table 1). Based on

the input values the parameters of the exhaust gas heat exchanger were calculated. They are as follows (Table 2).

Tab. 1. Input parameters for draft of heat Exchange.

Required power	4.4 kW	Exhaust gas side		Cooling liquid side	
		Flow	82.5 m <sup>3</sup> /h	Flow	0.69 m <sup>3</sup> /h
		Inlet temp.	584°C	Inlet temp.	89.5°C
		Outlet temp.	≈115°C	Outlet temp.	≈95.6°C



Tab. 2. Calculated parameters of the exhaust gas heat exchanger.

Structural design	
Calculated power	4.8 kW
Number of pipes	48
Length of heat exchanger	1000 mm
Volume of heat exchange area	2.03 m <sup>2</sup>

Based on the calculated parameters exhaust gas heat exchanger was designed and modelled (Fig. 9). Flow direction of working substance cross the heat exchanger

was chosen like a counter-flow, as can be seen in Fig. 10.

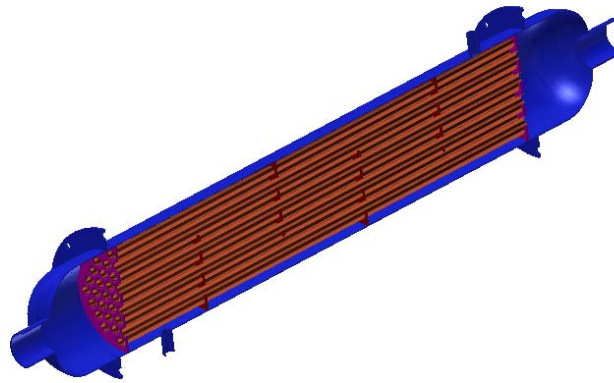


Fig. 9. 3D model of designed exhaust gas exchanger.

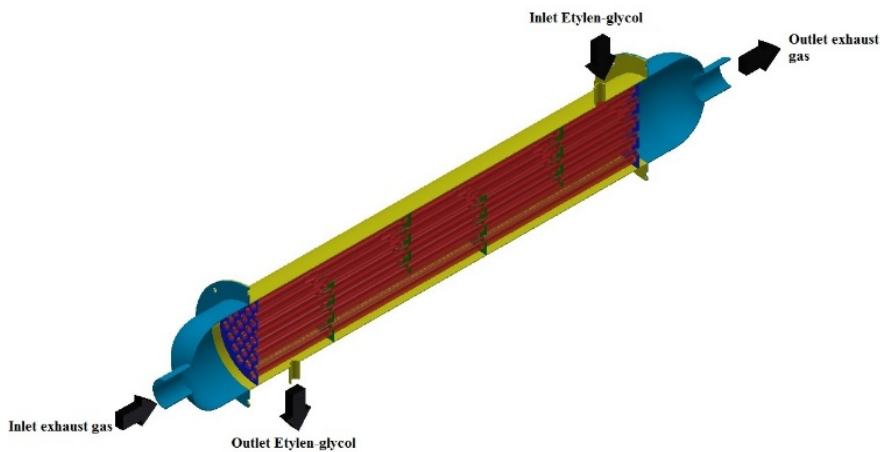


Fig. 10. Flow direction of working substances cross the heat exchanger.

On the proposed exhaust gas heat exchanger simulations of flow of exhaust gases and heat transfer were made in a 3D simulation program COMSOL Multiphysics. The

results of the simulation are presented in the figures 11, 12, and 13.

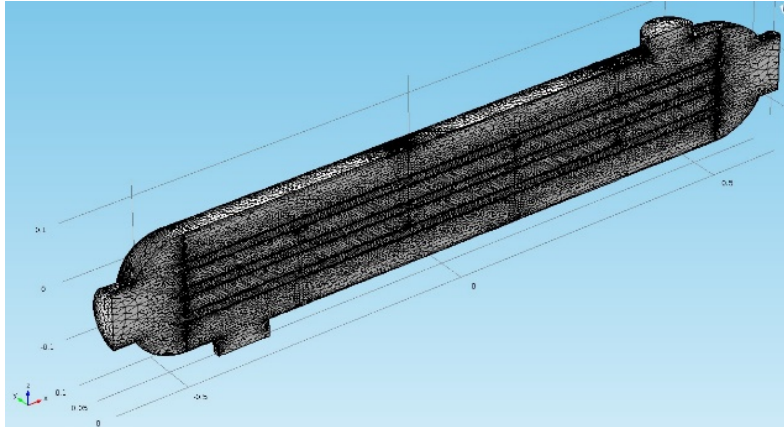


Fig. 11. Layering of the mesh in the model.

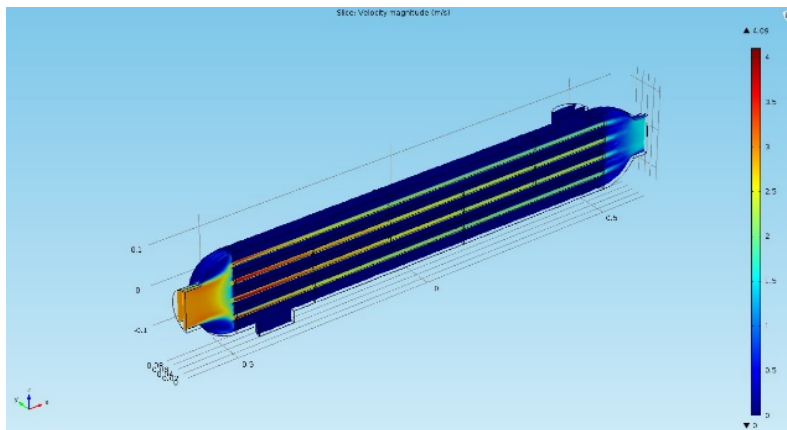


Fig. 12. Simulation of velocity magnitude of exhaust gas heat exchanger in m/s.

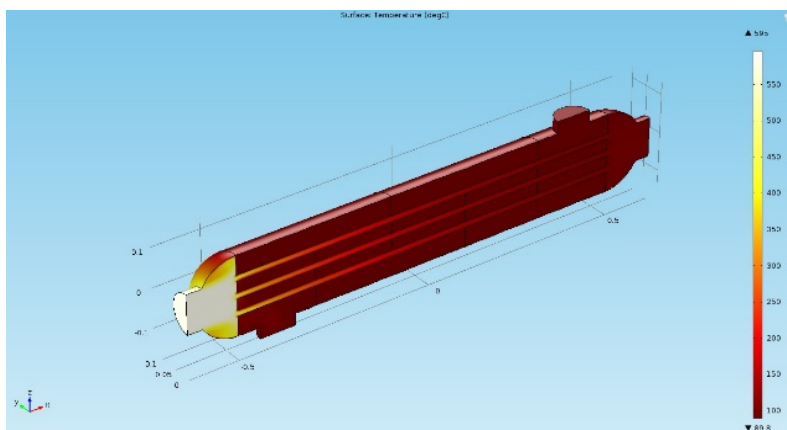


Fig. 13. Temperature of exhaust gas heat exchanger in °C.

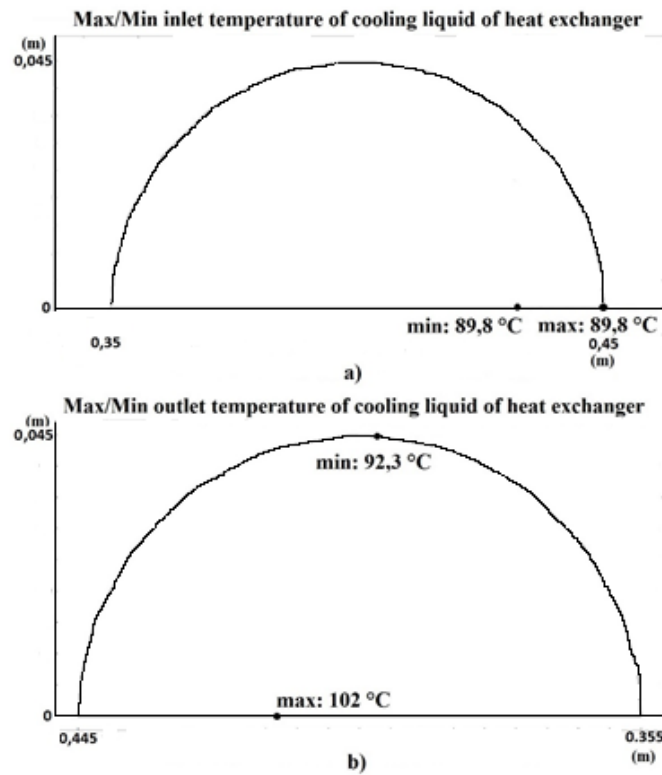


Fig. 14. Comparison of temperatures between inlet and outlet cooling liquid.

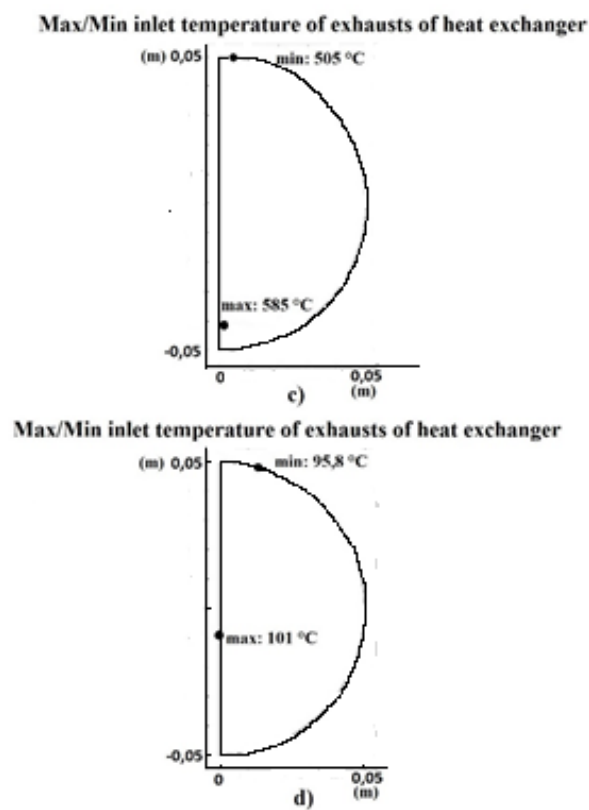


Fig. 15. Comparison of temperatures between inlet and outlet exhausts.



In figure 14, 15 the comparison between inlet a) and outlet b) temperature of cooling liquid and between inlet temperature c) and outlet temperature d) of exhaust gases can be seen. Inlet temperature of cooling liquid is 363 K (89.85°C) and mean outlet temperature of cooling liquid is 370 K (97°C). Inlet temperature of exhaust gases is 857 K (584°C) and mean outlet temperature of exhaust gases is 373.3 K (98.2°C). The simulation shows that the draft is correct, because outlet temperatures of working substances are very similar to the required parameters. Cooling liquid side required outlet temperature  $\approx 96.5^\circ\text{C}$  vs outlet temperature from simulation =  $97^\circ\text{C}$ . Exhaust gas side required outlet temperature  $\approx 115^\circ\text{C}$  vs outlet temperature from simulation =  $98.2^\circ\text{C}$ .

## Conclusions

The aim of the paper was to calculate and design a 3D model of the exhaust gas heat exchanger and create a

simulation of the proposed model in COMSOL Multiphysics based on the input parameters. The simulations were performed under conditions of the internal combustion engine warmed up to the operating temperature. As the comparison of required and simulated temperatures has shown, the draft of the exchanger is correct. In the future, the simulation under the condition of a cold combustion engine will be made (Fig. 16). After verifying the correctness of the draft by created simulations the real model of exhaust gas heat exchanger will be made. Subsequently the measurement of heat exchanger connected to the real combustion engine will be performed in order to validate the correctness of the draft.

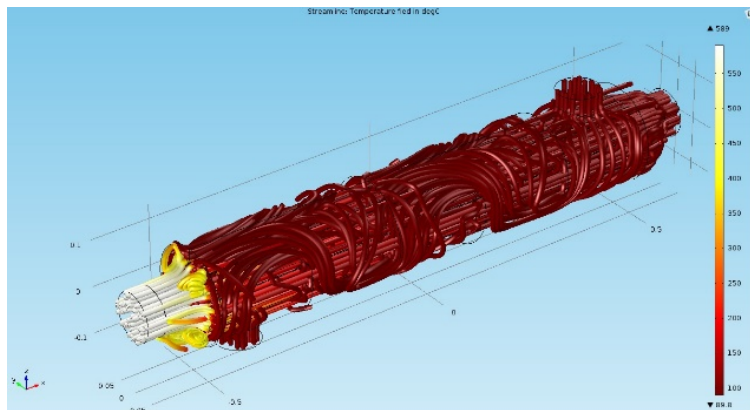


Fig. 1: Fig. 16. Streamline in exhaust gas heat exchanger.

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