Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article
Special Issue

METHODS OF DESIGNING AND MANUFACTURING A HEAT EXCHANGER FOR THE SMALL-DIMENSIONAL GTEs WITH HEAT RECOVERY

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Published online: 24 November 2017

ABSTRACT

The article describes the method of calculation, design and manufacture of the the plate heat exchanger for the gas turbine plants with heat recovery. We represented the method of three-dimensional calculation, which allowed conducting a virtual experiment and clarifying the design of the heat exchanger for the given parameters. We presented the results of experimental studies, which allowed predicting and determining optimum parameters of a plate heat exchanger for various schemes of gas turbine engines with heat recovery.

Keywords: small-sized gas turbine engine, heat exchanger, the method of designing, improving the design, increasing efficiency.

1. INTRODUCTION

The problem of increasing the efficiency of gas turbine engines is associated with the fact that the requirements for the efficiency of aircraft engines and power plants are steadily increasing. According to the economic strategy for the period up to 2030, the domestic demand for fuel and energy resources will grow by 1.6-1.7 times by 2030 as against the level of 2005 in Russia. This problem is especially relevant for the small-sized gas turbine engines. Increasing the efficiency of gas turbine engines is possible due to heat recovery. At present, the role of the small-sized gas turbine engines is being significantly expanded in the energy and aviation industries. They received the most widespread when solving the problems of small energy.

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doi: http://dx.doi.org/10.4314/jfas.v9i7s.85

Also, the small-sized gas turbine engines have great prospects for their use in the unmanned aerial vehicles.

At the same time, the effectiveness of heat recovery depends on the heat exchangers to a large extent. The use of plate heat exchangers in the small-sized gas turbine engines with heat recovery makes it possible to significantly reduce the mass and overall dimensions [1]. One of the most effective methods to increase the efficiency and effectiveness of gas turbine engines with heat recovery is the intensification of heat exchange processes. This method allows reducing the dimensions of heat exchange equipment and, accordingly, its cost. The creation of gas turbine engines with acceptable mass-size and performance indicators requires further improvement of the methods of calculation and design of the compact heat exchangers, as well as further analysis of the conditions for the rational coordination of the parameters of the heat exchanger and the engine. The manufacturing technology is of particular importance, since the parameters of the heat exchanger effectiveness depend on it.

Despite many studies carried out in this area, there is an open question on improving the methods of design, calculation and manufacture by integrating the existing knowledge, taking into account the modern capabilities of computer technology and production. The main disadvantage of existing development methods is the large amount of time spent on these stages. The solution to this problem can be the use of three-dimensional calculation and design programs that allow combining some of the study stages, thereby reducing the time and taking into account a greater number of factors affecting the process, presenting the calculation results in a visual form (velocity, temperature, pressure profiles). To improve the design and increase effectiveness, it is necessary to more accurately represent the processes occurring within the object under study, and take into account all the factors, including structural and technological, affecting the processes under study as a whole.

Thus, it follows from the above that it is objectively useful and timely to develop a method based on an integrated approach to calculating, designing and manufacturing a heat exchanger using three-dimensional numerical calculation.

The method of three-dimensional calculation allows conducting a virtual experiment and clarifying the design of the heat exchanger for the given parameters [2]. The program of analytical calculation for the given parameters of the plate makes it possible to evaluate the feasibility of using the heat exchanger design for the subsequent deeper estimated 3D-study. The use of a parameterized geometric model of the plate and the equipment of the heat exchanger significantly reduces the time for the design, calculation and manufacture of the heat exchanger.

2. PROBLEM STATEMENT

Despite many studies carried out in this area, there is an open question on improving the methods of design, calculation and manufacture by integrating the existing knowledge, taking into account the modern capabilities of computer technology and production.

The main disadvantage of existing development methods is the large amount of time spent on these stages. The solution to this problem can be the use of three-dimensional calculation and design programs that allow combining some of the study stages, thereby reducing the time and taking into account a greater number of factors affecting the process, presenting the calculation results in a visual form (velocity, temperature, pressure profiles).

Such a comprehensive approach to the study of factors affecting the processes in a heat exchanger is often not implemented in the modern scientific literature devoted to the study of heat exchangers. To improve the design and increase effectiveness, it is necessary to more accurately represent the processes occurring within the object under study, and take into account all the factors, including structural and technological, affecting the processes under study as a whole.

The use of complex thermodynamic cycles (heat recovery) in the aviation and energy industries is justified by an increase in fuel efficiency and a decrease in the cycle irreversibility. The main node that determines the recovery efficiency is the heat exchanger, therefore it is necessary to establish the requirements, which could be satisfied by this node. The main requirements are as follows: work at high temperatures (up to 1,000 K) and pressures (up to 400 kPa), as well as minimum weight-size parameters. The plate heat exchangers with a heat transfer surface of the "Frenkel packing" type satisfy the requirements the most of all [3].

A comparison of the intensity of heat transfer in a smooth channel and at the crossing angle of heat exchange surface of the "Frenkel packing" type of 37° shows that an increase in the plate crossing angle leads to an increase in the number of Nu by 1.4-1.6 times and a pressure loss ratio by 1.5-1.7 times compared with a smooth channel.

The features of heat exchange surfaces largely determine the weight-size parameters of heat exchangers. This article considers the thermo hydraulic features of heat transfer surfaces of the "Frenkel packing" type and the variation of this surface, which represents the continuous wavy corrugations. Figure 1 shows the designations for geometric parameters.

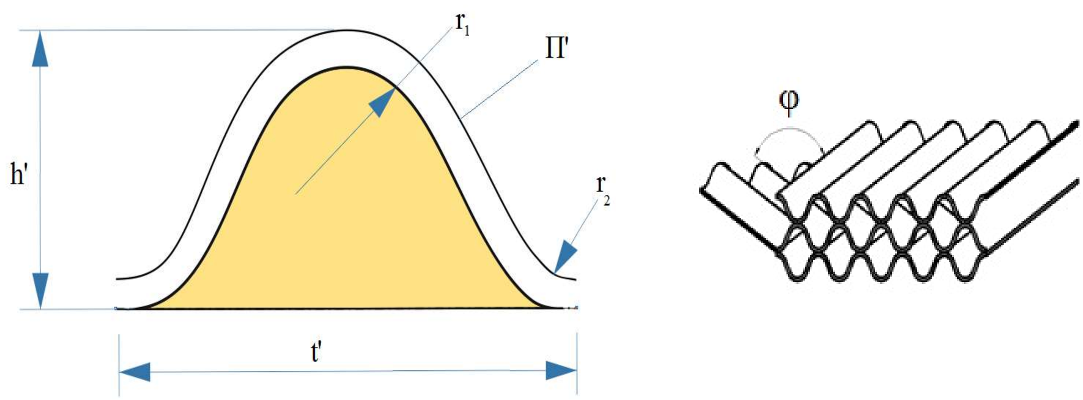


Fig.1. Corrugation geometric parameters

As the analysis result, we concluded that the equivalent diameter de had no appreciable effect on heat transfer. The height of plate profile has a more noticeable effect on the heat transfer intensity. Also, the intensity of heat transfer is influenced by the corrugation crossing angles on adjacent sheets φ. If the angle φ is increased from 0 to 96 °, the heat transfer ratio is increased by 3.8...4.2 times, and the resistance ratio - by 11-18 times. We noted the same influence factors for the heat transfer surface with wavy continuous channels. As a study result, we obtained a range of geometric parameters satisfying the effectiveness and compactness requirements of the heat exchanger.

Thus, it is advisable to make plates with the following geometric parameters: the height of the corrugation profile in the range of h' = 0.84...2.5 mm, the corrugation crossing angle in the range of φ = 65°...100°, the corrugation pitch - t' = 2...2.6 mm.

3. MANUFACTURING TECHNOLOGIES

The operating temperatures of heat exchangers for the GTE of a complex cycle reach 1,000 K with short-term castings up to 1,050 K and pressures up to 400 kPa.

The main requirements for the heat exchangers are as follows:

- the design should withstand at least ten thousand thermal cycles without loss of tightness.
- the heat exchanger design should withstand vibration.
- the matrix material should withstand burn-out and other damage throughout the life cycle of the heat exchanger. The maximum material burn-out should be within the range of up to 0.005 mm per 10,000 hours.
- the heat exchanger should have a minimum weight and a high degree of manufacturability. With a high material cost, the heat exchanger manufacturing technology should provide the maximum material utilization factor and the relative simplicity of manufacture.

When comparing the heat exchangers of lamellar and shell-and-tube types, it should be noted that each of them has its advantages and disadvantages.

The advantages of shell-and-tube heat exchangers include high strength and resistance to cyclic and vibration loads, low hydraulic resistance and the possibility of using capillary tubes with a wall thickness of up to 0.1 mm at the pressures up to 10 Bar. The disadvantages include the difficulty of sealing pipes into the tube grid (the temperature loads up to 1,000 K can withstand only the rolling-out method without the use of welding). As a consequence of this technological feature - the restriction on the minimum tube diameter The minimum tube diameter is limited to 5 mm.

The advantages of plate heat exchangers include a relatively simple design, manufacturability, possibility of welding the entire heat exchanger in such a way that it will have seams of equal strength to the base material. The effectiveness of the plate heat exchanger is 15...25% higher than the tube heat exchanger. The disadvantages are the thickness of the matrix material and the work at lower pressures (up to 4 bar), higher than for the tubes.

For the given working conditions, the all-welded matrices of plate heat exchangers are most suitable. To meet the temperature requirements, the heat transfer matrix plates should be made of heat-resistant alloys based on nickel with high chromium content. In this work, the plates were made of a heat-resistant alloy 20X23H18. However, there were also other alloys of domestic production with satisfactory characteristics.

The technological and constructive structure engineering study is of great importance. The correct choice of filler material, welding modes and after welding heat treatment will eliminate the formation of hot cracks and ensure the preservation of heat-resistant properties of the alloy in the welding area. Closed circular seams made by micro plasma welding exclude the possibility of the concentrator appearance. Roller seam welding, used in this work to assemble the heat exchanger plates into envelopes, allows excluding the increased metal stresses due to the narrow area of thermal influence of such seams. These and other measures repeatedly increase the design resistance to vibration and thermal cycles.

At present, the most technologically advanced method of the corrugated plate manufacturing is blanking. However, the blanking of thin metal sheets (0.2 mm) is a complex process, requiring detailed work. There are other ways to create the plate heat exchangers, one of which is the method of laser sintering (3D-printing).

4. METHOD ALGORITHM

When designing the GTE of a complex cycle, it is advisable to fit the heat exchanger into an existing design, as this will reduce the material and time costs for designing a new GTE with improved parameters. However, the existing methods for calculating the heat exchangers are based on the effectiveness that should be obtained for the GTE, then calculating the required heat exchange surface area. In this situation, it is advisable to start from the heat exchange surface area, since it is initially set a limited volume, in which the heat exchanger is to be fit [4, 5]. Thus, it will be possible to vary the dimensions and efficiency of the heat exchanger. Figure 2 shows the method algorithm, taking into account the design features of the heat exchanger for the existing small-sized GTE schemes.

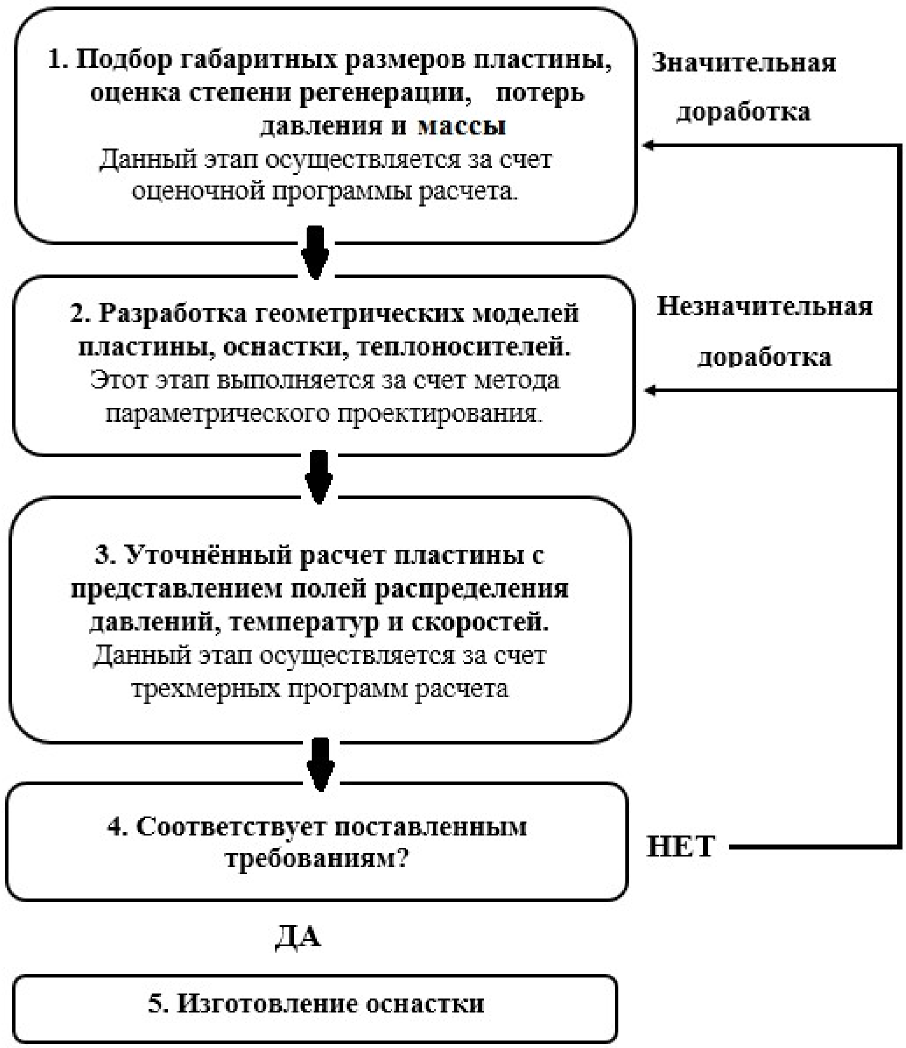
Based on this, it is possible to formulate the main tasks that need to be addressed when developing the method:

1. Development of parameterized geometric models of a plate, mountings and calculation models of heat carriers.
2. Development of the method of three-dimensional numerical calculation of the conjugate problem of heat transfer and gas dynamics.
3. Verification of the three-dimensional numerical calculation method.
4. Conducting the estimated 3D-study for obtaining the criterial dependencies and developing an evaluation calculation program based on them.

Based on the results of the work done, we developed a parametric model, which is a set of dependencies and given parameters, summarized in the table. If one of the parameters is changed, the model is automatically rearranged [6]. The time spent to create a 3D-model for research is significantly reduced.

We developed a three-dimensional numerical calculation method based on the SST (Menter model) turbulence model, which relates to the RANS numerical method. The choice is justified by the fact that this model is adapted to the description of laminar and turbulent flows.

We developed the estimated three-dimensional method for the object under study, the main advantage of which is the possibility of qualitative evaluation of temperature, velocity profiles, as well as pressure profiles, determination of stagnant areas, places of possible overheating. This method allows justifying the choice of design, reducing the risk of error in field trials.



Подбор габаритных размеров пластины, оценка степени регенерации, потерь давления и массы Данный этап осуществляется за счет оценочной программы расчета.	Selection of the overall plate dimensions, evaluation of the degrees of recovery, loss of pressure and mass This stage is carried out due to the estimated calculation program.
Разработка геометрических моделей пластины, оснастки, теплоносителей Этот этап выполняется за счет метода параметрического проектирования.	Development of geometric models of a plate, mountings, heat carriers This stage is performed by the parametric design method.
Уточненный расчет пластины с представлением полей распределения	Qualified calculation of the plate with a representation of the profiles of pressure,

давлений, температур и скоростей Данный этап осуществляется за счет трехмерных программ расчета.	temperature and velocity distribution This stage is carried out through the three-dimensional calculation programs.
Соответствует поставленным требованиям?	Does it correspond to the given requirements?
ДА	YES
НЕТ	NO
Значительная доработка	Significant revision
Незначительная доработка	Insignificant revision

Fig.2. Algorithm of the calculation, design and manufacture method

Based on the given results obtained after verification, it can be asserted that this calculation method is operational and allows making a preliminary assessment of the thermal and hydraulic characteristics of the heat exchanger.

5. CONCLUSIONS

The method presented allows evaluating the heat exchanger design with the specified dimensions, input and output parameters, such as: temperature, pressure, flow rate. This makes it possible to fit the heat exchanger into the existing GTE design. The main calculation results are the degree of recovery and pressure loss.

This method was used to develop a GTE comprehensive cycle to meet the following requirements:

- increasing the GTE effectiveness by 15-20%;
- reduction of fuel consumption by 25-30% compared to the engine without a heat exchanger;
- ensuring compactness of the GTE design;
- minimal increase in overall parameters in comparison with engines without heat exchangers.

In the GTE design, the combustion chamber heat pipes and heat exchanger modules are integrated into a single unit. The heat exchanger modules and the heat pipes are uniformly arranged around the circumference, with the heat pipes placed between the heat exchanger modules.

In the design process, we considered two heat transfer surfaces: with continuous wavy corrugations and a surface of the "Frenkel packing" type. Due to the analytical calculation program, it was possible to select the optimum dimensions of the plate and meet the requirements for pressure loss and effectiveness. The parametric design method allowed obtaining the geometric 3D-models for the stamp manufacture and preparing the plate and heat carrier models for 3D-research. The computer simulation of the experiment showed the expediency of using a surface of the "Frenkel packing" type.

Thus, the implementation of the method proposed allows solving the tasks for the GTE with heat recovery with minimal material costs in a short time, as well as creating a model range of highly efficient heat exchangers of various sizes and purposes. It should be noted that the method developed is applicable for various heat exchange surfaces, however, when considering other surfaces, an adjustment of the estimated calculation program, manufacturing technology and parameterized models of the heat exchanger geometry are necessary.

SUMMARY

The author confirms that the data presented does not contain any conflict of interest.

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How to cite this article:
Siluyanova M V. Methods of designing and manufacturing a heat exchanger for the small-dimensional gtes with heat recovery. J. Fundam. Appl. Sci., 2017, *9(7S), 925-934.*