Министерство науки и высшего образования Российской Федерации
НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ
ТОМСКИЙ ГОСУДАРСТВЕННЫЙ УНИВЕРСИТЕТ (НИ ТГУ)

Механико-математический факультет

УТВЕРЖДАЮ:
Декан ММФ ТГУ

Л. В.Гензе

Рабочая программа дисциплины

Современные методы моделирования тепломассопереноса

по направлению подготовки

01.04.01 Математика

Направленность (профиль) подготовки :
Математический анализ и моделирование (Mathematical Analysis and Modelling)

Форма обучения
Очная

Квалификация
Магистр

Год приема
2023, 2024

СОГЛАСОВАНО:
Руководитель ОП
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Е.А.Тарасов

Томск – 2023

1. Цель и планируемые результаты освоения дисциплины

Целью освоения дисциплины является формирование следующих компетенций:

ОПК-1 Способен формулировать и решать актуальные и значимые проблемы математики.

ПК-1 Способен самостоятельно решать исследовательские задачи в рамках реализации научного (научно-технического, инновационного) проекта.

Результатами освоения дисциплины являются следующие индикаторы достижения компетенций:

ИОПК 1.1 Формулирует поставленную задачу, пользуется языком предметной области, обоснованно выбирает метод решения задачи.

ИПК 1.1 Проводит исследования, направленные на решение отдельных исследовательских задач

2. Задачи освоения дисциплины

– **получение знаний** о современных методах моделирования процессов тепломассопереноса; о методе решеточных уравнений Больцмана и методе конечных разностей.

– **приобретение умений** самостоятельно определять цели математического моделирования и правильно ставить задачи.

– **выработка навыков** работы с открытой интегрируемой платформой OpenFOAM и с CAD – системами при выполнении математического моделирования задач механики жидкости и газа; применения этих знаний для дальнейшей научной работы.

3. Место дисциплины в структуре образовательной программы

Дисциплина относится к Блоку 1 «Дисциплина (модули)».

Дисциплина относится к части образовательной программы, формируемой участниками образовательных отношений, предлагается обучающимся на выбор.

4. Семестр(ы) освоения и форма(ы) промежуточной аттестации по дисциплине

Первый семестр, экзамен

5. Входные требования для освоения дисциплины

Для успешного освоения дисциплины требуются компетенции, сформированные в ходе освоения образовательных программ предшествующего уровня образования.

6. Язык реализации

Русский

7. Объем дисциплины

Общая трудоемкость дисциплины составляет 4 з.е., 144 часов, из которых:
-лекции: 32 ч.

Объем самостоятельной работы студента определен учебным планом.

8. Course content

Chapter 1. Introduction to modern methods of heat and mass transfer.

1.1 Introduction to heat and mass transfer. Convection. Conduction. Radiation.
1.2 Governing equations describing heat transfer processes.
1.3 Classes of numerical methods for solving differential equations. Finite difference method, finite element method.
1.4 Classes of numerical methods for solving differential equations. Finite volume method, Lattice Boltzmann methods.
1.5 General overview of OpenFOAM based on finite volume method .
1.6 Unsteady heat conduction problems. Examples.
1.7 Natural convection problems. Examples.
1.8 Natural convection combine with radiation problems. Examples.

Chapter 2 The use of FDM and LBM for solving problems of heat and mass transfer

2.1 FDM: approximation, stability, difference schemes
2.2 Initial and boundary conditions
2.3 Application of FDM in diffusion and convection problems
2.4 Mathematical foundations of LBM
2.5 Dimensions of the problem. Lattice structures. Forces. Source terms
2.6 Setting initial and boundary conditions. Convergence and accuracy of the solution. Selection of parameters for numerical solution
2.7 Solving problems of diffusion by LBM
2.8 Solving problems of convection by LBM

9. Students' progress active monitoring

During the implementation of the course, classical educational technologies are used – lectures, practical classes, and independent study of materials by students, testing knowledge through tests, colloquia and exams. To conduct ongoing monitoring of the SSW, the teacher can conduct small tests at the beginning of each lesson.

The questions of the colloquia and the exam are a generalization of the questions of the current control tests and allow assessing the level of competence formation and understanding of the formation of the physical picture within these sections.

10. Course guideline for students and exam policy

For the successful mastering of the material, students need to use the sources, information systems and databases that are presented in the list of references. Independent work of students consists in the study of lecture material, material from practical classes and independent study of additional issues, a deeper analysis of lectures with the help of additional literature. Students should be attentive to the preparation for colloquia and exams, take a responsible approach to independent work and confidently answer the questions of current control tests.

Final assessment will be carried out by holding two colloquia (for each section of the discipline); the results of the colloquium will affect the assessment in the exam.

The exam can be scored a maximum of 5 points for each question. The final grade is summed up from the grades for each question and the grades for additional questions at the request of the teacher. Below is the formula for calculating the final grade:

$$S = \frac{S_1 + S_2}{2} + 0.2 * \sum_{i=1}^{n} d_i / n,$$

where S is the final grade for the test, S_1 and S_2 points for answers to the first and second questions, n is the number of additional questions, di is the points for the i-th additional question. The final grade is rounded in favor of the student if the fraction value exceeds 0.5. When answering a question, the completeness and accuracy of the answer, the logic and reasoning of the presentation of the material, the ability to use factual material in the answer are evaluated.

When answering the questions of colloquia and tests, the completeness and accuracy of the answer, the logic and reasoning of the presentation of the material, the ability to use factual material in the answer are evaluated. To set the current progress when monitoring the SSW, it is recommended to use the following table.

Evaluation of the results of control of the SSW	Criteria
(Great)	The correct and detailed answer to the question is given. The student clearly and logically stated his answer to the question posed in the test.
(Good)	The correct answer to the question is given, but not everything is presented in detail and logically structured.
(Satisfactory)	In general, the correct answer to the question is given, but it is stated superficially and in violation of the logic of presentation.
(Unsatisfactory)	The answer is presented very superficially and in violation of the logic of presentation. The student has a very poor command of the basic models and concepts. Significant terminological and factual errors were made.
	An incorrect answer was given, a clear misunderstanding of the question in the test.

Sample list of questions for exam. Chapter 1.

1. Define thermal conductivity.
2. Define the convection heat-transfer coefficient.
3. Discuss the mechanism of thermal conduction in gases and solids.
4. Discuss the mechanism of heat convection.
5. What is the order of magnitude for the convection heat-transfer coefficient in free convection? Forced convection?
6. When may one expect radiation heat transfer to be important?
7. What is the order of magnitude of thermal conductivity for (a) metals, (b) solid insulating materials, (c) liquids, (d) gases?
8. Explain the scope of study of heat transfer.
9. How is the subject of heat transfer different from that of thermodynamics?
10. What are the three modes of heat transfer? Explain their differences.
11. What does conduction refer to? State Fourier's law of heat conduction. Why is the negative sign used?
12. How do the temperature distributions in a solid vary if its thermal conductivity varies linearly with temperature?
13. How does conduction occur in a composite wall with different materials put in (a) series and (b) parallel?
14. What do you understand by thermal contact resistance? On what parameters does this resistance depend?
15. Explain the effect of contact pressure on thermal contact resistance. What is thermal grease?
16. Define thermal conductivity. How can it be determined experimentally? What is the difference between thermal conductivity and thermal conductance?
17. Explain the mechanisms of heat conduction in gases, liquids and solids.
18. Why are metals good thermal conductors, while non-metals are poor conductors of heat?

19. Show that the radial heat conduction through a hollow cylinder depends on the logarithmic mean area of the inside and outside surfaces.
20. How does the temperature in a cylindrical wall vary?
21. What is convection? Why is it regarded as a mode of heat transfer? What are the differences between natural and forced convection?
22. Define a boundary layer. How are hydrodynamic and thermal boundary layer thicknesses different? Explain the velocity and temperature profiles for natural and forced convection heat transfer.
23. State the Newton's law of cooling. Define heat transfer coefficient. On what factors does it depend? Define overall heat transfer coefficient.
24. What is the mode of heat transfer in vacuum? Define absorptivity, reflectivity and transmissivity.
25. How can the absorptivity of an opaque body be improved?
26. What is a black body? Define emissivity and a gray body. State Stefan-Boltzmann law. On what factors does the radiant heat exchange between two gray bodies depend?
27. How is radiation heat transfer coefficient defined? What is combined convection and radiation coefficient?

Sample list of questions for exam. Chapter 2.

1. Elleptic, parabolic and hyperbolic equations.
2. Finite difference schemes
3. The Lax Equivalence Theorem
4. The von Neumann condition
5. Initial conditions in FDM
6. Boundary conditions for temperature
7. Boundary conditions for velocity
8. Solving the problem of thermal conductivity by FDM
9. Solving the problem of natural convection by FDM
10. The Distribution Function
11. The Equilibrium Distribution Function
12. The Boltzmann Equation
13. The Collision Operator
14. Time Step Algorithm in LBM
15. Discretisation in Velocity Space
16. Non-dimensionalisation
17. Discretisation of the PDF and EDF
18. Velocity Sets
19. Stability analysis in LBM
20. Lattice Boltzmann Accuracy
21. Initial conditions in LBM
22. Boundary conditions in LBM
23. Forces and source terms
24. Choice of Simulation Parameters
25. Solving problems of diffusion by LBM
26. Solving problems of natural convection by LBM

11. Education technologies and methodical support for course realization

a) Online course on TSU LMS platform «IDo» - https://lms.tsu.ru/course/view.php?id=6387 б) Tests and exam materials for this course (https://www.tsu.ru/sveden/education/eduop/)

12. Course literature and resourses

a) Primary course literature.

1. Kruger T., Kusumaatmaja H., Kuzmin A., Shardt O., Silva G. Viggen E.M. The Lattice Boltzmann Method. Springer International Publishing Switzerland 2017.
2. Mohamad A. A. Lattice Boltzmann Method: Springer-Verlag London Ltd., part of Springer Nature 2019.
3. Smith G. D. Numerical Solution of Partial Differential Equations: Finite Difference Methods. Clarendon Press. Oxford, 1985.
4. Lynch D.R. Numerical Partial Differential Equations for Environmental Scientists and Engineers: A First Practical Course: Springer-Verlag US., p.338.
5. Levenspiel O. Engineering Flow and Heat Exchange: Springer Science, 2014, P. 398.

b) Additional ***course literature.***

6. Wolf-Gladrow D.A. Lattice-Gas Cellular Automata and Lattice Boltzmann Models. Springer-Verlag Berlin Heidelberg, 2000.
7. Succi S. The Lattice Boltzmann Equation for Fluid Dynamics and Beyond. Clarendon Press. Oxford, 2001.
8. Sukop M.C. Thorne Jr. D.T. Lattice Boltzmann Modeling. Springer-Verlag Berlin Heidelberg, 2007.
9. Shang D. Free Convection Film Flows and Heat Transfer: Springer-Verlag Berlin Heidelberg, 2006, p. 408.
10. Eslami M. R. Finite Elements Methods in Mechanics: Springer International Publishing Switzerland, 2014, p. 370.

c) Databases and information and reference systems

- http://e-science.sources.ru/
- http://www.coursera.org/
- https://ocw.mit.edu/index.htm

13. Software list and internet resourses

Microsoft Windows 7, Microsoft Windows 10
Microsoft Office 2010
Microsoft Visual Studio 2015, Intel Fortran/C/C++ Compiler 15
Mathcad 15, Maple 15, Matlab R2015;

Resourses:
– TSU library E-catalog – http://chamo.lib.tsu.ru/search/query?locale=ru&theme=system
– TSU E-library – http://vital.lib.tsu.ru/vital/access/manager/Index
– http://e.lanbook.com/
– http://www.studentlibrary.ru/
– https://urait.ru/
– https://znanium.com/
– http://www.iprbookshop.ru/

14. Education and technical equipment

Classical audiences with a whiteboard, a projector and a computer with a pre-installed Microsoft Office 2010 office suite will use for lectures. Classrooms 314, 316, 319 will use for practical classes and independent work of students.

№№314, 316
PC (13 pcs)

- LCD monitor BENQ 21.5”
- CPU Intel core i5-2400, 3.40 GHz
- RAM: 4 GB
- HDD 500 GB
- Nvidia GTS 450

№ 319
PC: (13 pcs)

- Monitor LG 24"
- CPU Intel Core i7-4790 3.60GHz
- RAM 16 GB
- HDD 1 TB

15. Teaching staff

Associate professor, PhD, Igor Miroshnichenko
Associate professor, PhD, Nikita Gibanov