

TRANSPORTNI POJAVI

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Transportni pojavi
Course title:	TRANSPORT PHENOMENA
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski (od študijskega leta 2024/2025 dalje)	Procesno strojništvo (smer)	1. letnik	1. semester	obvezni

Univerzitetna koda predmeta/University course code:	0566913
Koda učne enote na članici/UL Member course code:	6014-M

Predavanja /Lectures	Seminar /Seminar	Vaje /Tutorials	Klinične vaje /Clinical tutorials	Druge oblike študija /Other forms of study	Samostojno delo /Individual student work	ECTS
30		30			65	5

Nosilec predmeta/Lecturer:	Andrej Kitanovski, Katja Klinar
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Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

Vrsta predmeta/Course type:

Obvezni strokovni predmet na smeri Procesno strojništvo, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Process Engineering, which is an elective specialised course in other fields of study.

Jeziki/Languages:

Predavanja/Lectures:

Slovenščina

Vaje/Tutorial:

Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:**Prerequisites:**

Izpolnjevanje pogojev za vpis v Magistrski študijski program II. stopnje Strojništvo - Razvojno raziskovalni program.

Meeting the enrollment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Vsebina:**Content (Syllabus outline):**

1. Uvod v transportne pojave:
 - Osnovni delci transportnih pojavov (fononi, elektroni, fotoni, magnoni, interakcije med njimi; difuzija snovi);
 - Primeri obnašanja osnovnih nosilcev transportnih pojavov v različnih snoveh;
 - Več-fizikalni primeri transportnih pojavov;
 - Primeri praktične uporabe znanja o transportnih pojavih.
2. Osnove difuzije:
 - Difuzija - od nano-skale do makroskopske ravni - inženirski vidik;
 - Difuzija v trdninah (prevodniki, polprevodniki, izolatorji);
 - Difuzija v tekočinah (plini, kapljevine);
 - Praktični primeri in pristopi k modeliranju.
3. Nestacionarna difuzija - popis na makroskopski ravni 1:
 - Nestacionarna difuzija skozi ravno in ukrivljeno homogeno ali kompozitno steno;
 - Nestacionarna difuzija skozi pol-neskončno telo;
 - Nestacionarna difuzija pri objektih s

1. Introduction to transport phenomena:
 - Basic carriers (phonons, electrons, photons, magnons, interactions, mass diffusion);
 - Examples of basic carriers in transport phenomena in different substances;
 - Multi-physical examples of transport phenomena;
 - Examples of practical use of knowledge in transport phenomena.
2. Diffusion - basics:
 - Diffusion - from nano-scale to macroscopic level - engineering view;
 - Diffusion in solids (conductors, semi-conductors, insulators);
 - Diffusion in fluids (gasses, liquids);
 - Practical examples and modelling approaches.
3. Transient diffusion -macroscopic level 1:
 - Transient diffusion through plane, and curved homogeneous or composite wall;
 - Transient diffusion through semi-infinite body;

<p>konstantnimi ali periodičnimi robnimi pogoji;</p> <ul style="list-style-type: none"> - Eksaktna metoda izračuna nestacionarne difuzije; - Praktični primeri in pristopi k modeliranju. <p>4. Nestacionarna difuzija- popis na makroskopski ravni 2:</p> <ul style="list-style-type: none"> - Nestacionarna difuzija pri nehomogenih materialih; - Nestacionarna difuzija pri faznih spremembah v trdninah; - Praktični primeri in pristopi k modeliranju. <p>5. Več-dimenzijska difuzija:</p> <ul style="list-style-type: none"> - Dvodimenzijska difuzija (analitični pristopi); - Modeliranje in numerično reševanje nestacionarne difuzije (z izbiro praktičnih problemov); - Modeliranje in numerično reševanje več-dimenzijskih problemov (z izbiro praktičnih problemov). <p>6. Prisilna konvekcija snovi 1:</p> <ul style="list-style-type: none"> - Enačbe mejne plasti; - Meje sistemov; - Praktični primeri in pristopi k modeliranju. <p>7. Prisilna konvekcija snovi 2:</p> <ul style="list-style-type: none"> - Obtekanje teles; - Notranji tokovi; - Porozne structure; - Zmesi tekočin; - Praktični primeri in pristopi k modeliranju. <p>8. Naravna konvekcija snovi:</p> <ul style="list-style-type: none"> - Osnove naravne konvekcije; - Vpliv naklona površine; - Vpliv hrapavosti površin; - Praktični primeri in pristopi k modeliranju. <p>9. Transportni pojavi v večfaznih sistemih:</p> <ul style="list-style-type: none"> - Absorpcija /desorpcija; - Adsorpcija/desorpcija; - Ostali kemijski procesi; - Praktični primeri in pristopi k modeliranju. <p>10. Sočasni prenos toplote in snovi:</p> <ul style="list-style-type: none"> - Primeri Izhlapevanje/ Kondenzacija; - Primeri Sublimacija/Desublimacija; 	<ul style="list-style-type: none"> - Transient diffusion through bodies with constant or periodic boundary conditions; - Exact calculation methods for transient diffusion; - Practical examples and approaches to modelling. <p>4. Transient diffusion – macroscopic level 2:</p> <ul style="list-style-type: none"> - Transient diffusion in non-homogeneous materials; - Transient diffusion in phase changes in solids; - Practical examples and approaches to modelling. <p>5. Multi-dimensional diffusion:</p> <ul style="list-style-type: none"> - Two-dimensional diffusion (analytical approaches); - Modeling and numerical solutions for transient diffusion (with examples from practice); - Modeling and numerical solutions of multi-dimensional problems (with examples from practice). <p>6. Forced mass convection 1:</p> <ul style="list-style-type: none"> - Boundary layer equations; - System interfaces; - Practical examples and modelling approaches. <p>7. Forced mass convection 2:</p> <ul style="list-style-type: none"> - Flow over a body; - Internal flows; - Porous structures; - Mixtures of fluids; - Practical examples and modelling approaches. <p>8. Natural mass convection:</p> <ul style="list-style-type: none"> - Natural convection basics; - The influence of inclined surfaces; - The influence of surface roughness; - Practical examples and modelling approaches. <p>9. Transport phenomena in multi-phase systems:</p> <ul style="list-style-type: none"> - Absorption /desorption; - Adsorption/desorption; - Other chemical processes; - Practical examples and modelling approaches. <p>10. Simultaneous heat and mass transfer:</p>
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<ul style="list-style-type: none"> - Primeri sočasnega prenosa toplote in snovi z različnimi mehanizmi; - Pristopi k modeliranju. <p>11. Prenos in vodenje toplote v naprednih materialih in fluidih:</p> <ul style="list-style-type: none"> - 2D materiali in grafen; - Metamateriali in kompoziti; - Nanofluidi in suspenzije delcev; - Fazno spremenljivi fluidi – nosilci latentne toplote; - Praktični primeri in pristopi k modeliranju. <p>12. Več-fizikalni mehanizmi transporta toplote v trdninah:</p> <ul style="list-style-type: none"> - Peltier in Seebeckov efekt; - Spin Seebeckov in Spin Peltier efekt; - Toplotni Hallov efekt; - Kalorični efekti; - Praktični primeri. <p>13. Več-fizikalni sistemi transporta toplote v tekočinah 1:</p> <ul style="list-style-type: none"> - Magnetohidrodinamika; - Ferohidrodinamika in magnetne tekočine; - Praktični primeri in pristopi k modeliranju. <p>14. Več-fizikalni sistemi transporta toplote v tekočinah 2:</p> <ul style="list-style-type: none"> - Elektrohidrodinamika; - Digitalna mikrofluidika; - Praktični primeri in pristopi k modeliranju. <p>15. Toplotni-kontrolni elementi:</p> <ul style="list-style-type: none"> - Toplotna stikala; - Toplotne diode; - Toplotni regulatorji; - Toplotni tranzistorji; - Toplotni tokokrogi in toplotno računanje; - Praktični primeri in pristopi k modeliranju. 	<ul style="list-style-type: none"> - Examples Evaporation/Condensation; - Examples Sublimation/Desublimation; - Examples of simultaneous heat and mass transfer with different mechanisms; - Approaches to modeling. <p>11. Heat transfer and guidance of heat in advanced materials and fluids:</p> <ul style="list-style-type: none"> - 2D materials in graphen; - Metamaterials and composites; - Nanofluids and particle suspensions; - Phase change fluids – carriers of latent heat; - Practical examples and modelling approaches. <p>12. Multi-physical mechanisms of heat transport in solids:</p> <ul style="list-style-type: none"> - Peltier in Seebeck effect; - Spin Seebeck and Spin Peltier effect; - Thermal Hall effect; - Caloric effects; - Practical examples. <p>13. Multi-physical systems of heat transport in fluids 1:</p> <ul style="list-style-type: none"> - Magnetohydrodynamics; - Ferrohydrodynamics and magnetic fluids; - Practical examples and modeling approaches. <p>14. Multi-physical systems of heat transport in fluids 2:</p> <ul style="list-style-type: none"> - Electrohydrodynamics; - Digital microfluidics; - Practical examples and modeling approaches. <p>15. Thermal control elements:</p> <ul style="list-style-type: none"> - Thermal switches; - Thermal diodes; - Thermal regulators; - Thermal transistors; - Thermal circuits and thermal computing; - Practical examples and modeling approaches.
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Temeljna literatura in viri/Readings:

1. Klinar, Katja; Kitanovski, Andrej. Učni pripomoček pri predmetu Transportni

pojavi : zbirka rešenih nalog. Ljubljana: Fakulteta za strojništvo, 2023.
[COBISS.SI-ID [139991299](#)]

2. Incropera, Frank P. et al. Fundamentals of heat and mass transfer, 2007
[COBISS.SI-ID [12387634](#)]
3. Gašperšič, Branko. Prenos toplote, 2001 [COBISS.SI-ID [111288064](#)]
4. Kaviany, Massoud. Heat transfer physics, 2008 [COBISS.SI-ID [30583301](#)]
5. Jiji, Latif Menashi. Heat convection (2nd edition), Springer, 2009, [COBISS.SI-ID [1541997023](#)]

Cilji in kompetence:

Objectives and competences:

Cilji:

1. Spoznati lastnosti osnovnih gradnikov in fenomenov transportnih pojavov v različnih snoveh in v različnih fizikalnih sistemih.
2. Pridobiti znanje na področju modeliranja in analitičnega ter numeričnega reševanja transportnih pojavov v enostavnih in več-fizikalnih sistemih.
3. Seznaniti se s praktičnimi primeri na področju transportnih pojavov ter pristopu inženirskega reševanja.
4. Seznaniti se z najnovejšimi dognanji na področju transportnih pojavov ter implementacijo teh na različnih področjih inženirstva.

Splošne in predmetno-specifične kompetence:

1. S1-MAG, P2-MAG: Sposobnost za opredelitev, razumevanje in obvladovanje temeljnih znanstvenih in aplikativnih problemov s področja transportnih pojavov.
2. S2-MAG, P4-MAG, P5-MAG: Širitev sposobnosti kritičnega, analitičnega in sintetičnega mišljenja pri reševanju problemov s področja transportnih pojavov. Sposobnost fizikalnega, matematičnega in numeričnega modeliranja problemov s področja transportnih pojavov. Razvijanje novega znanja in razumevanja transportnih pojavov z implementacijo najnovejših dognanj

Objectives:

1. To obtain characteristics of basic carriers and phenomena of their transport in different substances and different physical systems.
2. To obtain knowledge in modeling, and analytical and numerical solving of transport phenomena problems in simple and multi-physical systems.
3. To gain knowledge and skills with practical problems in the field of transport phenomena and their engineering solutions.
4. To become familiar with newest research activities in the field of transport phenomena, including their implementation in different domains of engineering.

Basic and subject-specific competences:

1. S1-MAG, P2-MAG: Sposobnost za opredelitev, razumevanje in obvladovanje temeljnih znanstvenih in aplikativnih problemov s področja transportnih pojavov.
2. S2-MAG, P4-MAG, P5-MAG: The broadening of critical, analytical, and synthetic thinking in solving the transport phenomena problems. The ability for physical, mathematical, and numerical modeling of problems from the field of transport phenomena. The development of new knowledge and understanding of transport phenomena with the integration of the newest research findings in the

na področju. 3. S10-MAG, P7-MAG: Sposobnost uporabe sodobnih raziskovalnih metod in postopkov. Sposobnost raziskovanja in prenašanja znanja v prakso na področju transportnih pojavov s pomočjo implementacije sodobnih raziskovalnih metod ter optimizacijo različnih procesov.	field. 3. S10-MAG, P7-MAG: The ability for using modern research methods and approaches. The ability to perform research and transfer knowledge into practice from the field of transport phenomena, including the implementation of modern research methods and optimization of different processes
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Predvideni študijski rezultati:

Intended learning outcomes:

<p>Znanja:</p> <p>Z2: Poglobljeno teoretično, metodološko in analitično znanje z elementi raziskovanja, ki je osnova za razumevanje in implementacijo rešitev na področju transportnih pojavov.</p> <p>Spretnosti:</p> <p>S2.1: Obvladovanje načrtovanja kompleksnih procesov transportnih pojavov v inženirstvu, s pomočjo analitičnega ali numeričnega reševanja problemov ter z uporabo različnih numeričnih orodij (npr. Matlab, Python, Ansys Fluent, Ansys Multiphysics).</p> <p>S2.3: Sposobnost razvoja in implementacije izvirnih dognanj/stvaritev s področja aplikacije transportnih pojavov, ki jih je oseba sposobna na podlagi kritične analize implementirati.</p>	<p>Knowledge:</p> <p>Z2: In-depth theoretical, methodological and analytical knowledge with elements of research, which is the basis for understanding and implementation of solutions in the field of transport phenomena.</p> <p>Skills:</p> <p>S2.1: Mastering the design of complex transport phenomena processes in engineering, with the aid of analytical, numerical modeling and with the use of different numerical tools (i.e. Matlab, Python, Ansys Fluent, Ansys Multiphysics).</p> <p>S2.3: The ability to research, develop and implement original findings/creations in the field of transport phenomena applications, which a person is able to implement upon the critical analysis.</p>
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Metode poučevanja in učenja:

Learning and teaching methods:

<p>P1: Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov.</p> <p>P3: Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri.</p> <p>P4: Laboratorijske vaje z namenskimi didaktičnimi pripomočki (Tranzientna</p>	<p>P1: Auditorial lectures including solving the problems from selected - for domain characteristic - theoretical and practically useful problems.</p> <p>P3: Classroom tutorials where theoretical knowledge is supported by computational examples.</p> <p>P4. Laboratory work with dedicated didactic tools (Transient and steady-</p>
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<p>in stacionarna difuzija v trdninah, Dvo-dimenzionalna difuzija, Prisilna konvekcija snovi – obtekanje teles, Sočasni prenos toplote in snovi, Adsorpcija-desorpcija, Kondenzacija – različni primeri, Vodenje toplote v 2D materialih, Peltier-Seebeck efekt, Kalorični efekti, Toplotni kontrolni elementi).</p> <p>P5: Uporaba študijskega gradiva v obliki (skripta-zapiski predavanj, e-verzija predavanj).</p> <p>P6, P14, P15: Interaktivna predavanja podprta z video vsebinami, on-line simulacijami konkretnih primerov in virtualnih eksperimentov.</p> <p>P8, P9: Skupinsko delo pri reševanju problemov z izdelavo in predstavitvijo aplikativnih seminarskih nalog (vključuje razprave in diskusije, viharjenje možganov, projektno delo).</p> <p>P12: Individualizirane domače naloge v spletni učilnici.</p>	<p>state diffusion in solids, Two-dimensional diffusion, Forced mass convection over the body, Simultaneous heat and mass transfer, Adsorption-desorption, Condensation – different examples, Heat guidance in 2D materials, Peltier-Seebeck effect, Caloric effects, Thermal control elements)</p> <p>P5: The use of study material in the form (lecture notes, e-version of lecture presentations).</p> <p>P6, P14, P15: Interactive lectures supported with video material, on-line simulations of particular problems, and virtual experiments).</p> <p>P8, P9: Team work in solving problems with the seminary work/presentation of applied problems (includes group-analysis and, brainstorming, project work).</p> <p>P12: Individualized homeworks in web-classrooms.</p>
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Načini ocenjevanja:	Delež/ Weight	Assessment:
Teoretične vsebine (predavanja).	40,00 %	Theroretical contents (lectures).
Teoretične vsebine in računski primeri (vaje).	40,00 %	Theory and examples (coursework).
Delo ter sodelovanje pri laboratorijskih vajah /individualni seminar ali skupinski projekt.	20,00 %	Work and collaboration during laboratory exercises / individual or group seminary work.

Ocenjevalna lestvica:	Grading system:
5 - 10, pri čemer velja, da je pozitivna ocena od 6 - 10	5 - 10, a student passes the exam if he is graded from 6 to 10

Reference nosilca/Lecturer's references:

<p>Andrej Kitanovski:</p> <p>1. SWOBODA, Timm, KLINAR, Katja, KITANOVSKI, Andrej, YALAMARTHY, Ananth Saran, MUÑOZ ROJO, Miguel. Solid-state thermal control devices. Advanced electronic materials. Mar. 2021, vol. 7, iss. 3, f. 1-28, ilustr. ISSN 2199-160X. https://onlinelibrary.wiley.com/doi/10.1002/aelm.202000625,</p>
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- <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=125519>, DOI: 10.1002/aelm.202000625. [COBISS.SI-ID [47223811](#)].
2. KLINAR, Katja, SWOBODA, Timm, MUÑOZ ROJO, Miguel, **KITANOVSKI, Andrej**. Fluidic and mechanical thermal control devices. *Advanced electronic materials*. Mar. 2021, vol. 7, iss. 3, f. 1-30, ilustr. ISSN 2199-160X. <https://onlinelibrary.wiley.com/doi/10.1002/aelm.202000623>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=125502>, DOI: 10.1002/aelm.202000623. [COBISS.SI-ID [47218691](#)]
 3. POREDOŠ, Primož, LORBEK, Luka, VIDRIH, Boris, LJUBENKO, Andrej, **KITANOVSKI, Andrej**, POREDOŠ, Alojz. Transient heat transfer simulation of fresh and frozen food compartments in a household two-door refrigerator. V: TEIXEIRA, José Carlos (ur.). *ECOS 2018 : proceedings of the 31st International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems*, June 17th to 21st 2018 - Guimarães, Portugal. Guimarães: University of Minho. 2018, 13 f., ilustr. [COBISS.SI-ID [16135195](#)]
 4. POREDOŠ, Primož, PETELIN, Nada, VIDRIH, Boris, ŽEL, Tilen, MA, Qiuming, WANG, Ruzhu, **KITANOVSKI, Andrej**. Condensation of water vapor from humid air inside vertical channels formed by flat plates. *iScience*. [Online ed.]. Jan. 2022, vol. 25, iss. 1, str. 1-26, ilustr. ISSN 2589-0042. <https://www.sciencedirect.com/science/article/pii/S2589004221015352?>, DOI: 10.1016/j.isci.2021.103565. [COBISS.SI-ID [87969539](#)],
 5. KLINAR, Katja, VOZEL, Katja, SWOBODA, Timm, SOJER, Tom, MUÑOZ ROJO, Miguel, **KITANOVSKI, Andrej**. Ferrofluidic thermal switch in a magnetocaloric device. *iScience*. [Online ed.]. Feb. 2022, vol. 25, iss. 2, str. 1-15, ilustr. ISSN 2589-0042. <https://www.sciencedirect.com/science/article/pii/S2589004222000499>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=134893>, DOI: 10.1016/j.isci.2022.103779. [COBISS.SI-ID [96902659](#)]

Katja Klinar:

1. **KLINAR, Katja**, SWOBODA, Timm, MUÑOZ ROJO, Miguel, **KITANOVSKI, Andrej**. Fluidic and mechanical thermal control devices. *Advanced electronic materials*. Mar. 2021, vol. 7, iss. 3, f. 1-30, ilustr. ISSN 2199-160X. <https://onlinelibrary.wiley.com/doi/10.1002/aelm.202000623>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=125502>, DOI: 10.1002/aelm.202000623. [COBISS.SI-ID [47218691](#)]
2. **KLINAR, Katja**, VOZEL, Katja, SWOBODA, Timm, SOJER, Tom, MUÑOZ ROJO, Miguel, **KITANOVSKI, Andrej**. Ferrofluidic thermal switch in a magnetocaloric device. *iScience*. [Online ed.]. Feb. 2022, vol. 25, iss. 2, str. 1-15, ilustr. ISSN 2589-0042. <https://www.sciencedirect.com/science/article/pii/S2589004222000499>, <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=134893>, DOI: 10.1016/j.isci.202103779. [COBISS.SI-ID [96902659](#)]
3. **KLINAR, Katja**, MUÑOZ ROJO, Miguel, KUTNJAK, Zdravko, **KITANOVSKI, Andrej**. Toward a solid-state thermal diode for room-temperature magnetocaloric energy conversion. *Journal of applied physics*. 2020, vol. 127, no. 23, str. 234101-1-234101-10. ISSN 0021-8979. <https://repozitorij.uni-lj.si/IzpisGradiva.php?id=124217>, DOI: 10.1063/5.0006120. [COBISS.SI-ID [19703299](#)],

4. PETELIN, Nada, VOZEL, Katja, **KLINAR, Katja**, TOMC, Urban, KITANOVSKI, Andrej. Evaluation of the performance of a thermal switch capacitor in a magnetocaloric device. V: *Refrigeration science and technology proceedings : 26th IIR International Congress of Refrigeration, Paris, France, August 21-25, 2023*. Paris: Institut international du froid = International Institute of Refrigeration, 2023. Vol. 2, str. 103-112, ilustr. Science et technique du froid. ISBN 978-2-36215-056-2. ISSN 0151-1637. [COBISS.SI-ID [167805699](#)]
5. **KLINAR, Katja**, VOZEL, Katja, PETELIN, Nada, TOMC, Urban, KITANOVSKI, Andrej. Fluidic EWOD thermal switch for magnetocaloric device. V: *Refrigeration science and technology proceedings : 26th IIR International Congress of Refrigeration, Paris, France, August 21-25, 2023*. Paris: Institut international du froid = International Institute of Refrigeration, 2023. Vol. 2, str. 280-289, ilustr. Science et technique du froid. ISBN 978-2-36215-056-2. ISSN 0151-1637. [COBISS.SI-ID [167799043](#)]