UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Prenos toplote
Course title:	Heat transfer
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri
Strojništvo - razvojno raziskovalni program, prva stopnja, univerzitetni	Ni členitve (študijski program)	2. letnik	2. semester

Univerzitetna koda predmeta/University course code:	0562758
Koda učne enote na članici/UL Member course code:	2020-U

Predavanja	Seminar	Vaje	Klinične vaje	Druge oblike študija	Samostojno delo	ECTS
45		30			50	5

Nosilec predmeta/Lecturer:	Iztok Golobič
Vrsta predmeta/Course type:	Obvezni splošni predmet /Compulsory general course

Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	Prerequisites:
Izpolnjevanje pogojev za vpis v Univerzitetni študijski program I. stopnje Strojništvo - Razvojno raziskovalni program.	Meeting the enrollment conditions for the Academic study programme of Mechanical Engineering - Research and Development program.

Vsebina:	Content (Syllabus outline):
Uvod v prenos toplote: - Kronološki pregled; - Osnovni mehanizmi prevoda toplote, konvekcije in sevanja; - Zakon o ohranitvi energije in snovi. 2. Uvod v prevod toplote: - Enačba prevoda toplote; - Enačba difuzije toplote; - Enodimenzionalni stacionarni prevod toplote, ravna stena in radialni sistemi, toplotna upornost, toplotna prehodnost, kritični radij izolacije.	. Introduction to heat transfer: - Chronological overview; - Fundamental mechanisms of conduction, convention and radiation; - Laws of conservation of energy and mass. 2. Introduction to heat conduction: - Equation of heat conduction; - Equation of heat diffusion; - One-dimensional steady-state heat conduction, plane walls and radial systems, thermal resistance, critical radius of insulation.

3. Prevod toplote: - Stacionarni prevod toplote ob notranji generaciji toplotnega toka, ravna stena in radialni sistemi; - Prenos toplote iz razširjenih površin, stacionarna temperaturna porazdelitev in preneseni toplotni tok po rebru konstantnega preseka in s konvekcijo na okoliški fluid pri različnih robnih pogojih; - Učinek in učinkovitost rebra, učinkovitost razširjenih površin. 4. Dvodimenzionalni stacionarni prevod toplote: - Stacionarni dvodimenzionalni prevod toplote; - Analiza dvodimenzionalnega prevoda toplote, metoda ločevanja spremenljivk; - Energijske bilance in robni pogoji ter ovrednotenje analiz dvodimenzionalnega stacionarnega prevoda toplote. 5. Uvod v nestacionarni prevod toplote: - Posplošena kapacitivnostna metoda; - Nestacionarni prevod toplote, Fourierovo in Biotovo število, temperatura kontakta; - Nestacionarni prevod toplote ob konstantnem konvektivnem robnem pogoju za polneskončno ploščo, valj in kroglo. 6. Nestacionarni prevod toplote: - Večdimenzionalna analiza nestacionarnega prevoda toplote; - Nestacionarni prevod toplote ob časovno odvisnem konvektivnem robnem pogoju za polneskončno ploščo, valj in kroglo; - Začetni in robni pogoji ter ovrednotenje analiz nestacionarnega prevoda toplote. 7. Uvod v konvekcijo: - Hitrostna, termična in koncentracijska mejna plast, laminarni in turbulentni tok; - Enačbe konvektivnega prenosa toplote in snovi, koeficient toplotne prestopnosti; - Podobnostna teorija, teorem, brezdimenzijska števila. 8. Konvekcija: - Zunanji tokovi, tok vzdolž ravne plošče, laminarni in turbulentni tok, prečni tok okoli valja in krogle, tok preko zaporedne in izmenične namestitve cevi v snopu; - Notranji tokovi, hidrodinamična in termična obravnava notranjega toka v cevi, vzdolžni temperaturni profil toka fluida v cevi, laminarni in turbulenti tok fluida v ceveh; - Prosta konvekcija na vertikalni, nagnjeni in horizontalni plošči, na valju in krogli ter v kanalih. 9. Vrenje in kondenzacija: - Vrenje, vrenje v bazenu, vrelna krivulja, mehurčkasto vrenje; - Kritična gostota toplotnega toka, filmsko vrenje; - Kondenzacija, laminarna in turbulentna filmska kondenzacija na vertikalni površini, filmska kondenzacija	3. Heat conduction: - Steady-state conduction with internal heat generation, plane walls and radial systems; - Heat transfer from extended surfaces, steady-state temperature distribution, transferred heat flux in fins with constant cross section and with convection to the surrounding fluid for different boundary conditions; - Fin efficiency and effectiveness, efficiency of extended surfaces. 4. Two-dimensional steady-state heat conduction: - Steady-state two-dimensional heat conduction; - Analysis of two-dimensional heat conduction, method of separation of variables; - Energy balance and boundary conditions, evaluation of two-dimensional heat conduction analyses. 5. Introduction to transient heat conduction: - Lumped capacity method; - Transient heat conduction, Fourier and Biot number, temperature of the contact; - Transient heat conduction using a constant convective boundary condition for a semi-infinite slab, cylinder and sphere. 6. Transient heat conduction: - Multi-dimensional analysis of transient heat conduction; - Transient heat conduction with a time-dependent convective boundary condition for a semi-infinite slab, cylinder and sphere; - Initial and boundary conditions, evaluation of transient heat conduction analyses. 7. Introduction to convection: - Velocity, thermal and concentration boundary layer, laminar and turbulent flow; - Equations of convective heat and mass transfer, heat transfer coefficient; - Similarity theory, -theorem, dimensionless numbers. 8. Convection: - External flows, flat plate in parallel flow, laminar and turbulent flow, cross flow around cylinders and spheres, flow around aligned and staggered tube bundles; - Internal flows, hydrodynamic and thermal considerations, axial temperature distribution of internal flows in pipes, laminar and turbulent flows in pipes; - Free convection on vertical, inclined and horizontal plates, on cylinders, spheres and in channels. 9. Boiling and condensation: - Boiling, pool boiling, nucleate boiling; - Critical heat flux, film boiling; - Condensation, laminar and turbulent film condensation on vertical surfaces, film condensation on a horizontal tube, dropwise condensation. 10. Heat exchangers: - Heat exchanger types, parallel-flow and counterflow

na radialni horizontalni površini, kapljičasta kondenzacija. 10. Prenosniki toplote: - Vrste prenosnikov toplote, istosmerni in protismerni prenosnik toplote; - Metoda srednje logaritmične temperaturne razlike za analizo prenosnika toplote; - Učinkovitost prenosnika toplote in število prenosnih enot, - NTU metoda za analizo prenosnika toplote. 11. Uvod v sevanje: - Osnovni koncept analize sevanja; - Sevanje črnega telesa, Planckova porazdelitev spektralne emisijske moči, Wienov zakon, Štefan - Boltzmanov zakon; - Površinska absorptivnost, reflektivnost in transmisivnost, Kirchhoffov zakon, sončno sevanje. 12. Sevanje: - Vidni faktor, sumacijsko pravilo, recipročnost; - Sevalna izmenjava med površinami črnih teles; - Sevalna izmenjava med difuznimi, sivimi površinami v omejenem zaprtem prostoru. 13. Termografija in prenos toplote: - Infrardeča termografija, primeri sočasne uporabe hitrotekoče video in infrardeče kamere; - Schlieren metoda za vizualizacijo konvektivnega gibanja fluida; - Termografija s tekočimi kristali, termografija s temperaturno občutljivimi barvnimi nanosi, termografija s fluorescenčno mikrospektroskopijo. 14. Fenomeni prenosa toplote na mikro in nano skali: - Prenos toplote v trdno kapljevito plinasti mejni plasti; - Prenos toplote na superhidrofilnih, superhidrofobnih in bifilnih površinah, mikro in nanostrukturiranih površinah; - Prenos toplote in nanofluidi. 15. Pregled izbranih vsebin iz prenosa toplote: - Analiza, možnosti, koncepti, izvedba, rešitve, uporaba. Primer; - Predstavitev in diskusija.	heat exchangers; - Log mean temperature difference method for heat exchanger analysis; - Effectiveness of heat exchangers and the number of transfer units, - NTU methods for heat exchanger analysis. 11. Introduction to radiation: - Fundamental concepts of thermal radiation analysis; - Blackbody radiation, Planck distribution of spectral-energy distribution, Wien's displacement law, Stefan-Boltzmann law; - Absorption, reflection, and transmission by real surfaces, Kirchhoff's law, solar radiation. 12. Radiation: - The view factor, summation rule, reciprocity rule; - Radiation exchange between surfaces of black bodies; - Radiation exchange between diffuse and grey surfaces in an enclosure. 13. Thermography and heat transfer: - Infrared thermography, examples of simultaneous use of a high-speed and infrared camera; - Schlieren methods for convective fluid motion visualization; - Liquid crystal thermography, temperature sensitive paint thermography, fluorescence microscpectrometry thermography. 14. Micro- and nanoscale heat transfer phenomena: - Heat transfer in solid-liquid-gaseous boundary layer; - Heat transfer on superhydrophilic, superhydrophobic and biphilic surfaces and on micro- and nanostructured surfaces; - Heat transfer and nanofluids. 15. Review of selected heat transfer topics: - Analysis, possibilities, concepts, realization, execution, solutions, utilization including an example; Presentation and discussion.

Temeljna literatura in viri/Readings:

Bergman, T.L, Lavine, A.S., Incropera F.P., DeWitt P.D., Fundamentals of Heat and Mass Transfer, 8th Edition, John Wiley and Sons, New York, 2018.

Gašperšič B., Prenos toplote, Univerza v Ljubljani, Fakulteta za strojništvo, Ljubljana, 2001.

Baehr H.D., Stephan K., Wärme und Stoffübertragung, Springer Verlag, Berlin, Heidelberg, 2004.

Lienhard IV J.H., Lienhard V J.H., A Heat Transfer Textbook, 5th Edition, Phlogison Press, Cambridge, Massachusetts, 2019.

Cilji in kompetence:	**Objectives and competences:**
Cilji:	Objectives:

1. Usposobiti študenta za uporabo inženirskih orodij za reševanje problemov iz prenosa toplote in utrjevanje inženirskega pristopa k njihovemu reševanju. 2. Pridobiti temeljna znanja in spoznati mehanizme in popis stacionarnega in nestacionarnega prevoda toplote, naravne in prisilne konvekcije brez in s fazno spremembo, prenosnike toplote ter mehanizme in popis sevanja. 3. Razvijati usposobljenost določitve prenosa toplote in temperaturnih stanj pri osnovnih inženirskih procesih. 4. Razvijati kreativnost in profesionalno inženirsko rast, timsko delo in interdisciplinarno povezovanje na področju strojništva. Kompetence: 1. Razvijanje sposobnosti za opredelitev, razumevanje in ustvarjalno reševanje inženirskih nalog iz področja prenosa toplote. Obvladovanje temeljnih teoretičnih znanj prevoda toplote, konvekcije in sevanja, ki so bistvena za obvladovanje tehničnega področja strojništva (S1-RRP, P1-RRP). 2. Usposobljenost za uporabo pridobljenih znanj pri samostojnem reševanju tehničnih problemov na področju prenosa toplote v inženirstvu. Sposobnost osnovnega fizikalnega, matematičnega in numeričnega modeliranja prenosa toplote pri različnih inženirskih problemih z razvito sposobnostjo kritične analize rezultatov. (S6-RRP, P4-RRP) 3. Usposobljenost za timsko delo in sposobnost samostojnega kreativnega reševanja posameznih dobro definiranih nalog iz prenosa toplote na področju strojništva. (S8-RRP, P6-RRP)	1. Educate the student on the use of engineering tools for heat tranfer problem solving and consolidation of an engineering approach in problem solving. 2. Obtaining basic knowledge and becoming acquainted with mechanisms and description of steady-state and transient heat conduction, free and forced convection with and without phase change, heat exchangers and thermal radiation. 3. Develop informed decisions in determining the heat transfer and temperature conditions of basic engineering processes. 4. Develop creativity and professional growth as an engineer, develop team work and interdisciplinary connections within engineering. Competences: 1. The ability to define, understand and creatively solve professional challenges in the field of heat transfer. Mastery of basic theoretic skills regarding heat conduction, convection and thermal radiation, fundamental to the technical aspect of mechanical engineering (S1-RRP, P1-RRP). 2. The ability to use the acquired knowledge to solve professional engineering problems in the field of heat transfer independently. The ability of basic physical, mathematical and numerical modelling of heat transfer problems with the ability of critically analysing the results. (S6-RRP, P4-RRP) 3. The ability for teamwork and for interdisciplinary networking in the field of heat transfer. Ability to perform easier development, engineering and professional organisational tasks as well as to solve individual well-defined engineering tasks in the filed fo heat transfer (S8-RRP, P6-RRP).

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanje in razumevanje: Poglobljeno strokovno teoretično in praktično znanje na področju prenosa toplote. (Z1) 1. Izvajanje kompleksnih izračunov prenosa toplote in določitve temperaturne porazdelitve v elementih prenosnikov toplote, ki vključujejo tudi uporabo metodoloških orodij v zahtevnejših programskih okoljih (S1). 2. Obvladovanje zahtevnih, kompleksnih in interdisciplinarnih inženirskih procesov gretja in hlajenja ob samostojni uporabi znanja iz prenosa toplote. (S1.2) 3. Diagnosticiranje in reševanje problemov delovanja sistemov zaradi generiranja toplote in	Knowledge: Z1: Thorough professional theoretical and practical knowledge in the field of heat transfer that is supported with a broad theoretical and methodological basis. Skills: 1. Executing complex heat transfer calculations and determining temperature distributions in the components of heat exchangers, which incorporates usage of methodological tools in advanced software environments (S1). 2. Mastering demanding, complex and interdisciplinary work processes of heating and cooling by independent usage of heat transfer

neučinkovitega prenosa toplote v inženirskem industrijskem okolju ter prenašanje znanj in usposabljanja v timskem projektnem okolju. (S1.3)	knowledge (S1.2). 3. Problem diagnostics and solving due to heat generation and inefficient heat transfer in an industrial engineering environment and transferring knowledge including training in project teamwork (S1.3).

Metode poučevanja in učenja:	**Learning and teaching methods:**
P2 Obravnava snovi po urejeni in vnaprej razloženi sistematiki s priazom inženirskih problemov iz področja prenosa toplote. P3 Avditorne vaje, kjer se teoretično znanje iz predavanj podkrepi z računskimi primeri obravnavanih področij prenosa toplote. P4 Laboratorijske vaje z namenskimi eksperimentalnimi progami in didaktičnimi pripomočki za prikaz stacionarnega in nestacionarnega prenosa toplote, določanja koeficienta toplotne prestopnosti pri vrenju, učinkovitosti prenosnikov toplote in sevalnega prenosa toplote. P8 Izdelava in predstavitev aplikativnih seminarskih nalog iz področja prenosa toplote. P9 Timsko razvojno raziskovalno projektbno delo s predstavitvijo in razpravo P12 Individualizirane domače naloge v spletni učilnici. P14 Virtualni eksperimenti iz področja prenosa toplote ob uporabi infrardeče in fluorescenčne termografije, optične pincete in Schlieren metode	P2 Presenting the content according to the explained system including showcases of problems in heat transfer engineering. P3 Auditorial exercises, in which theoretical content from the lectures is supplemented with practical examples of heat transfer processes. P4 Laboratory exercises with special-purpose didactic devices to showcase steady-state and transient heat transfer, determination of the heat transfer coefficient in boiling heat transfer, calculation of heat exchanger efficiency and radiative heat transfer. P8 Making and presenting applied seminar exercises in the field of heat transfer. P9 Team work (discussion pro and contra, discussion of the studied content, snow ball, structured discussion, brainstorming, project work, etc.). P12 Individualised homework in a web classroom. P14 Virtual experiments in the field of heat transfer using infrared and fluorescence thermography, optical tweezers and Schlieren thermography.

Načini ocenjevanja:	**Delež/Weight**	**Assessment:**
Teoretična vsebine (predavanja, računske naloge).	60,00 %	Theoretical content (lectures, calculation problems).
Samostojno/skupinsko delo na vajah.	20,00 %	Individual/group work during auditorial exercises.
Seminar.	20,00 %	Seminar.

Reference nosilca/Lecturer's references:

Iztok Golobič:

1. MOŽE, Matic, ZUPANČIČ, Matevž, **GOLOBIČ, Iztok**. Investigation of the scatter in reported pool boiling CHF measurements including analysis of heat flux and measurement uncertainty evaluation methodology. *Applied thermal engineering*. 2020, vol. 169, str. 1-18. [COBISS.SI-ID 17016091].
2. **GOLOBIČ, Iztok,** PETKOVŠEK, Jure, KENNING, D.B.R. Bubble growth and horizontal coalescence in saturated pool boiling on a titanium foil, investigated by high-speed IR thermography. *International journal of heat and mass transfer*. 2012, vol. 55, str. 1385-140 [COBISS.SI-ID 12107291].
3. SEDMAK, Ivan, URBANČIČ, Iztok, PODLIPEC, Rok, ŠTRANCAR, Janez, MOR
4. IER, Michel, **GOLOBIČ, Iztok**. Submicron thermal imaging of a nucleate boiling process using fluorescence

microscopy. *Energy*. 2016, vol. 109, str. 436-445, [COBISS.SI-ID 14672155].
5. **GOLOBIČ, Iztok**, PETKOVŠEK, Jure, GJERKEŠ, Henrik, KENNING, D.B.R. Horizontal chain coalescence of bubbles in saturated pool boiling on a thin foil. *International journal of heat and mass transfer*. 2011, vol. 54, str. 5517-5526. [COBISS.SI-ID 11996187].
6. **GOLOBIČ, Iztok**, HAFNER, Jože. *Heat insulating filling for a vacuum insulating panel : European Patent No. EP1762662 : date of publication 14.03.2007 : application No. 06468004.4*. HV Rijswijk, Niederlande: European Patent Office (EPO), 2007. [COBISS.SI-ID 9994011]