TERMODINAMIKA

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Termodinamika
Course title:	Thermodynamics
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri	Izbirnost
Strojništvo - razvojno raziskovalni program, prva stopnja, univerzitetni (od študijskega leta 2024/2025 dalje)	Ni členitve (študijski program)	1. letnik	2. semester	obvezni

Univerzitetna koda predmeta/University course code:	0562746
Koda učne enote na članici/UL Member course code:	2009-U

Predavanja /Lectures	Seminar /Seminar	Vaje /Tutorials	Klinične vaje /Clinical tutorials	Druge oblike študija /Other forms of study	Samostojno delo /Individual student work	ECTS
45		30			75	6

Nosilec predmeta/Lecturer:	Boštjan Mavrič, Božidar Šarler

Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

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: - cilji in namen predmeta, - uporaba termodinamike v tehniki - predstavitev učnega programa - predstavitev učnih pripomočkov, virov in načina dela, - predstavitev obveznosti študentov in napotki za uspešen študij. 2. Razvrstitev termodinamike: - termodinamika, inženirska termodinamika, klasična in moderna termodinamika, ravnotežna in neravnotežna termodinamika, - nivoji popisa v termodinamiki in njena povezava z mehaniko kontinuuma in s termofluidnimi znanostmi. 3. Termodinamski koncepti: - struktura termodinamike: spremenljivke stanja, procesne spremenljivke, eksperimentalne spremenljivke. 4. Zakoni termodinamike: - Ničti zakon, - Prvi zakon, - Drugi zakon, - Tretji zakon. 5. Termodinamske spremenljivke: - termodinamske spremenjivke in definicije, ki izhajajo iz termodinamskih zakonov, - relacije za koeficiente, Maxwellove relacije,	. Introduction: - objectives and purpose of the course, - application of thermodynamics in engineering, - presentation of the course program, - presentation of teaching tools, references and working methods, - presentation of student obligations and advices for successful study. 2. Classification of thermodynamics: - thermodynamics, engineering thermodynamics, classical and modern thermodynamics, equilibrium and non-equilibrium thermodynamics, - levels of description in thermodynamics and its connection with continuum mechanics and thermofluid sciences. 3. Thermodynamics concepts: - structure of thermodynamics: state variables, process variables, experimental variables. 4. Thermodynamics laws: - Zeroth law, - First law, - Second law, - Third law. 5. Thermodynamics variables: - thermodynamics variables and definitions, stemming from thermodynamics laws, - relations for coefficients, Maxwell

- termodinamsko ravnovesje. 6. Osnove opisa zaprtih in odprtih sistemov: - integralni ohranitveni princip, - diferencialni ohranitveni princip, - primeri. 7. Osnove opisa enosestavinskih enofaznih in večfaznih sistemov: - idealni in realni plin, - led, voda, vodna para, - Clausius-Clapeyronova enačba. 8. Osnove opisa večsestavinskih enofaznih sistemov: - delne molske količine, - mešanica idealnih plinov, - plini v stiku s kapljevinami in trdninami. 9. Osnove opisa večsestavinskih večfaznih sistemov: - Gibbsovo fazno pravilo, - fazni diagrami in njihovo računanje, - primeri. 10. Osnove opisa zapletenih sistemov: - kapilarnost, - vpliv zunanjih polj, - primeri. 11. Statistična termodinamika: - mikrostanja, makrostanja in entropija. - izračun makroskopskih količin iz mikroskopskih količin, - model kristala in model enoatomnega plina. 12. Termodinamska analiza toplotnih strojev: - Carnotov cikel, - Rankinov cikel, - Braytonov cikel, - Ottov cikel, - Dieselov cikel, - dualni cikel, - Stirlingov cikel. 13. Termodinamska analiza hladilnih naprav - stiskanje, - absorbcija, - vzvratni Braytonov cikel. 14. Osnove opisa atmosferskega zraka: - psihrometrija, metode za določanje vlažnosti, pogoji ugodja, - hlajenje in sušenje zraka,	relations, - thermodynamics equilibrium. 6. Fundamentals of description of closed and open systems: - integral conservation principle, - differential conservation principle, - examples. 7. Fundamentals of description of single constituent single phase and multiphase systems: - ideal and real gas, - ice, water, water steam, - Clausius-Clapeyron equation. 8. Fundamentals of description of multi-constituent single-phase systems: - partial molar properties, - mixture of ideal gases, - gases in contact with liquids and solids. 9. Fundamentals of description of multi-constituent multi-phase systems: - Gibbs phase rule, - phase diagrams and their calculation, - examples. 10. Fundamentals of description of complicated systems: - capillarity, - influence of external fields, - examples. 11. Statistical thermodynamics: - microstates, macrostates and entropy, - calculation of macroscopic quantities from microscopic quantities, - model of crystal and model of monoatomic gas. 12. Thermodynamics analysis of heat engines: - Carnot cycle, - Rankin cycle, - Brayton cycle, - Otto cycle, - Diesel cycle, - dual cycle, - Stirling cycle. 13. Thermodynamics analysis of cooling devices: - compression, - absorbtion, - inverse Brayton cycle. 14. Fundamentals of description of

- segrevanje in vlaženje zraka - hladilni stolpi. 15. Zgorevanje: - kemijske reakcije, opis zgorevanja, - določanje reaktantov iz produktov, - toplota in entropija pri zgorevanju.	atmospheric air: - psychometry, methods for determination of humidity, conditions of comfort, - cooling and heating of air, - heating and humidifying air, - cooling towers. 15. Combustion: - chemical reactions, description of combustion, - determination of reactants from the products, - heat and entropy in combustion.

Temeljna literatura in viri/Readings:

1. R. Reisel, Principles of Engineering Thermodynamics, Cengage Learning, Boston, 2016. ISBN - 978-0-357-11179-6, [COBISS.SI-ID 67180803]
2. J.A. Cengel, M.A. Boles, Therodynamics: An Engineering Approach, Ms-Graw Hill, New York, 2011. ISBN - 978-0-07-339817-4; 0-07-339817-9, [COBISS.SI-ID 10421844]
3. R. DeHoff, Thermodynamics in Materials Science, Second Edition CRC Press, Boca Raton, 2006. ISBN - 0-07-016313-8; 0-07-112596-5, [COBISS.SI-ID 761115]

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Predstaviti osnove in uporabo termodinamike. 2. Predstaviti strukturo termodinamike in teoretični ter metodološki pristop k reševanju različnih termodinamskih sistemov. 3. Predstaviti praktično uporabo termodinamike na številnih inženirskih primerih. 4. Navdušiti študente za nadaljni, bolj poglobljeni študij predstavljenih osnov. Kompetence: 1. P1-RRP, P2-RRP: Biti sposoben razpoznave različnih termodinamskih sistemov, njihovega teoretičnege opisa in metodologije obravnave. 2. P4-RRP: Biti sposoben reševanja širokega spektra termodinamskih problemov. 3. P6-RRP: Biti sposoben	Objectives: 1. To present the fundamentals and application of thermodynamics. 2. To present the structure of thermodynamics and theoretical and methodological approach for solving different thermodynamic systems. 3. Demonstrate the practical use of thermodynamics on various engineering cases. 4. To inspire the students for further, more in-depth study of the presented fundamentals. Competences: 1. P1-RRP, P2-RRP: Being able to identify different thermodynamic systems, their theoretical description and approach methodology. 2. P4-RRP: Being able to solve a wide range of themodynamic problems. 3. P6-RRP: Being able to make a thermodynamic optimization of

termodinamske optimizacije inženirskih sistemov glede na učinkovitost, kvaliteto in vpliva na okolje.	engineering systems in terms of efficiency, quality and environmental impact.

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja: Z1: Poglobljeno strokovno teoretično in praktično znanje termodinamike, podprto s primerno široko teoretično in metodološko osnovo. Spretnosti: S1.1 Hitra prilagoditev reševanju različnih termodinamskih sistemov. S1.2 Samostojna uporaba znanja pri snovanju inženirskih termodinamskih sistemov. - Reševanje problemov glede na učinkovitost, kvaliteto in vpliv na okolje. - Biti sposoben nadaljnjega, poglobljenega samostojnega študija.	Knowledge: Z1: Thorough professional theoretical and practical knowledge of thermodynamics that is supported with a broad theoretical and methodological basis. Skills: S1.1 Rapid adaptation to solving of various thermodynamic systems. S1.2 Independent use of knowledge in the design of thermodynamic systems. - Solving problems in terms of efficiency, quality and environmental impact. - To be able to further independently in-depth study.

Metode poučevanja in učenja:	**Learning and teaching methods:**
P1: Avditorni način predavanja. 2. P14: Občasna uporaba računalniške animacije. 3. P5: Uporaba študijskega gradiva v obliki skripta predavanj. 4. P14: Virtualni eksperimenti. 5. P15: Uporaba video vsebin kot priprava na predavanja in vaje. 6. P3: Avditorialne vaje - teoretično znanje podkrepljeno s praktičnimi računskimi primeri. 7. P5: Uporaba študijskega gradiva v obliki učbenika za vaje. 8. P4: Laboratorijske vaje: določanje specifične toplote trdne snovi, fazne spremembe, določanje krivulje kapljevina-plin za vodo v P-T diagramu, določanje termodinamskih stanj pri ekspanziji in kompresiji idealnega plina.	. P1: Auditorial lectures. 2. P14: Occasional use of computer animation. 3. P5: Use of study materials in the form of a lecture script. 4. P14: Virtual experiments. 5. P15: Using video contents as a preparation for lectures and exercises. 6. P3: Auditorial exercises - theroetical knowledge supported by calculations of practical examples. 7. P5: Use of study materials in the form of an excercise textbook. 8. P4: Laboratory work: determination of the specific heat of the solid, phase changes, determination of the liquid-gas curve for water in P-T diagram, determination of the thermodynamic states at the expansion and compression of the ideal gas.

Načini ocenjevanja:	**Delež/ Weight**	**Assessment:**
Pisni izpit	50,00 %	Written exam
Naloge	50,00 %	Exercises

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:

Božidar Šarler:

1. VUGA, Gašper, MAVRIČ, Boštjan, **ŠARLER, Božidar**. An improved local radial basis function method for solving small-strain elasto-plasticity. *Computer methods in applied mechanics and engineering*. [Print ed.]. Jan. 2024, vol. 418, pt. a, str. 1-28, ilustr. ISSN 0045-7825. https://www.sciencedirect.com/science/article/pii/S0045782523006254, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=151689, DOI: 10.1016/j.cma.2023.116501. [COBISS.SI-ID 168587267]
2. KOVAČIČ, Miha, STOPAR, Klemen, VERTNIK, Robert, **ŠARLER, Božidar**. Comprehensive electric arc furnace electric energy consumption modeling: a pilot study. Energies. Jun. 2019, vol. 12, iss. 11, f. 1-13, ilustr. ISSN 1996-1073. https://www.mdpi.com/1996-1073/12/11/2142, DOI: 10.3390/en1211214 [COBISS.SI-ID 16647451]
3. HANOGLU, Umut, **ŠARLER, Božidar**. Multi-pass hot-rolling simulation using a meshless method. Computers & Structures. [Print ed.]. Jan. 2018, vol. 194, str. 1-14, ilustr. ISSN 0045-7949. http://ac.els-cdn.com/S004579491730038X/1-s2.0-S004579491730038X-main.pdf?_tid=d90e0950-9397-11e7-b016-00000aab0f26&acdnat=1504766785_f7050a8813a3d32e98f6a93afb8e7f30, DOI: 10.1016/j.compstruc.2017.08.012. [COBISS.SI-ID 15624731]
4. MRAMOR, Katarina, VERTNIK, Robert, **ŠARLER, Božidar**. Application of the local RBF collocation method to natural convection in a 3D cavity influenced by a magnetic field. *Engineering analysis with boundary elements*. 2020, vol. 116, str. 1-13, ilustr. ISSN 0955-7997. https://www.sciencedirect.com/science/article/abs/pii/S0955799720300977, DOI: 10.1016/j.enganabound.2020.03.025. [COBISS.SI-ID 17163547]
5. HATIĆ, Vanja, MAVRIČ, Boštjan, **ŠARLER, Božidar**. Meshless simulation of a lid-driven cavity problem with a non-Newtonian fluid. *Engineering analysis with boundary elements*. Oct. 2021, vol. 131, str. 86-99, ilustr. ISSN 0955-7997. https://www.sciencedirect.com/science/article/pii/S0955799721001715, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=138693, DOI: 10.1016/j.enganabound.2021.06.015. [COBISS.SI-ID 69191939]

Boštjan Mavrič:

1. DOBRAVEC, Tadej, **MAVRIČ, Boštjan**, ŠARLER, Božidar. Acceleration of RBF-FD meshless phase-field modelling of dendritic solidification by space-time

adaptive approach. *Computers & mathematics with applications*. Nov. 2022, vol. 126, str. 77-99, ilustr. ISSN 1873-7668. https://www.sciencedirect.com/science/article/pii/S0898122122003881, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.camwa.2022.09.008. [COBISS.SI-ID 122502403]

2. VUGA, Gašper, **MAVRIČ, Boštjan**, HANOGLU, Umut, ŠARLER, Božidar. A hybrid radial basis function-finite difference method for modelling two-dimensional thermo-elasto-plasticity. Part 2, Application to cooling of hot-rolled steel bars on a cooling bed. *Engineering analysis with boundary elements*. Feb. 2024, vol. 159, str. 331-341, ilustr. ISSN 0955-7997. https://www.sciencedirect.com/science/article/pii/S0955799723005714, Repozitorij Univerze v Ljubljani – RUL, DiRROS - Digitalni repozitorij raziskovalnih organizacij Slovenije, DOI: 10.1016/j.enganabound.2023.12.001. [COBISS.SI-ID 179241219], [Odprti dostop, JCR, SNIP, WoS, Scopus]
3. ŠARLER, Božidar, **MAVRIČ, Boštjan**, DOBRAVEC, Tadej, VERTNIK, Robert. A comprehensive slice model for continuous casting of steel. V: *Proceedings : 10th European Conference on Continuous Casting, Bari, Italy, 20-22 October 2021*. 10th European Conference on Continuous Casting, Bari, Italy, 20-22 October 2021. [S. l.: s. n., 2021]. Str. [1-10], ilustr. [COBISS.SI-ID 82573827]
4. DOBRAVEC, Tadej, **MAVRIČ, Boštjan**, ŠARLER, Božidar. Phase field modelling of dendritic solidification by using an adaptive meshless solution procedure. V: *MCWASP XV : International Conference on Modelling of Casting, Welding and Advanced Solidification Processes : 22-23 June 2020, Jönköping, Sweden*. Bristol: IOP Publishing, 2020. Vol. 861, str. 1-7, ilustr. IOP conference series, Materials science and engineering, Vol. 861, 2020. ISSN 1757-8981. https://iopscience.iop.org/article/10.1088/1757-899X/861/1/012060, DOI: 10.1088/1757-899X/861/1/012060. [COBISS.SI-ID 20710147]
5. MRAMOR, Katarina, HATIĆ, Vanja, **MAVRIČ, Boštjan**, ŠARLER, Božidar. Modelling of macrosegregation with mesosegregates in a binary metallic cast by the diffuse approximate meshless method. V: *2018 International conference on metal material processes and manufacturing (ICMMPM2018)*. Jeju Island: [s. n.], 2018. [7] str., graf. prikazi, ilustr. http://www.icmmpm.org/ICMMPM2018%20Schedule.pdf. [COBISS.SI-ID 1415850], [Scopus]