

# TERMODINAMIKA

## UČNI NAČRT PREDMETA/COURSE SYLLABUS

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

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

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

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

<b>Nosilec predmeta/Lecturer:</b>	Boštjan Mavrič, Božidar Šarler
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<b>Izvajalci predavanj:</b>	
<b>Izvajalci seminarjev:</b>	
<b>Izvajalci vaj:</b>	
<b>Izvajalci kliničnih vaj:</b>	
<b>Izvajalci drugih oblik:</b>	
<b>Izvajalci praktičnega usposabljanja:</b>	

**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:**

Izpolnjevanje pogojev za vpis v Univerzitetni študijski program I. stopnje Strojništvo - Razvojno raziskovalni program.

**Prerequisites:**

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

**Vsebina:**

- . 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 spremenljivke in definicije, ki izhajajo iz termodinamskih zakonov,
  - relacije za koeficiente, Maxwellove relacije,

**Content (Syllabus outline):**

- . 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

<ul style="list-style-type: none"> <li>- termodinamsko ravnovesje.</li> </ul> <p>6. Osnove opisa zaprtih in odprtih sistemov:</p> <ul style="list-style-type: none"> <li>- integralni ohranitveni princip,</li> <li>- diferencialni ohranitveni princip,</li> <li>- primeri.</li> </ul> <p>7. Osnove opisa enosestavinskih enofaznih in večfaznih sistemov:</p> <ul style="list-style-type: none"> <li>- idealni in realni plin,</li> <li>- led, voda, vodna para,</li> <li>- Clausius-Clapeyronova enačba.</li> </ul> <p>8. Osnove opisa večsestavinskih enofaznih sistemov:</p> <ul style="list-style-type: none"> <li>- delne molske količine,</li> <li>- mešanica idealnih plinov,</li> <li>- plini v stiku s kapljevimi in trdninami.</li> </ul> <p>9. Osnove opisa večsestavinskih večfaznih sistemov:</p> <ul style="list-style-type: none"> <li>- Gibbsovo fazno pravilo,</li> <li>- fazni diagrami in njihovo računanje,</li> <li>- primeri.</li> </ul> <p>10. Osnove opisa zapletenih sistemov:</p> <ul style="list-style-type: none"> <li>- kapilarnost,</li> <li>- vpliv zunanjih polj,</li> <li>- primeri.</li> </ul> <p>11. Statistična termodinamika:</p> <ul style="list-style-type: none"> <li>- mikrostanja, makrostanja in entropija.</li> <li>- izračun makroskopskih količin iz mikroskopskih količin,</li> <li>- model kristala in model enoatomnega plina.</li> </ul> <p>12. Termodinamska analiza toplotnih strojev:</p> <ul style="list-style-type: none"> <li>- Carnotov cikel,</li> <li>- Rankinov cikel,</li> <li>- Braytonov cikel,</li> <li>- Ottov cikel,</li> <li>- Dieslov cikel,</li> <li>- dualni cikel,</li> <li>- Stirlingov cikel.</li> </ul> <p>13. Termodinamska analiza hladilnih naprav</p> <ul style="list-style-type: none"> <li>- stiskanje,</li> <li>- absorbcija,</li> <li>- vzratni Braytonov cikel.</li> </ul> <p>14. Osnove opisa atmosferskega zraka:</p> <ul style="list-style-type: none"> <li>- psihrometrija, metode za določanje vlažnosti, pogoji ugodja,</li> <li>- hlajenje in sušenje zraka,</li> </ul>	<p>relations,</p> <ul style="list-style-type: none"> <li>- thermodynamics equilibrium.</li> </ul> <p>6. Fundamentals of description of closed and open systems:</p> <ul style="list-style-type: none"> <li>- integral conservation principle,</li> <li>- differential conservation principle,</li> <li>- examples.</li> </ul> <p>7. Fundamentals of description of single constituent single phase and multiphase systems:</p> <ul style="list-style-type: none"> <li>- ideal and real gas,</li> <li>- ice, water, water steam,</li> <li>- Clausius-Clapeyron equation.</li> </ul> <p>8. Fundamentals of description of multi-constituent single-phase systems:</p> <ul style="list-style-type: none"> <li>- partial molar properties,</li> <li>- mixture of ideal gases,</li> <li>- gases in contact with liquids and solids.</li> </ul> <p>9. Fundamentals of description of multi-constituent multi-phase systems:</p> <ul style="list-style-type: none"> <li>- Gibbs phase rule,</li> <li>- phase diagrams and their calculation,</li> <li>- examples.</li> </ul> <p>10. Fundamentals of description of complicated systems:</p> <ul style="list-style-type: none"> <li>- capillarity,</li> <li>- influence of external fields,</li> <li>- examples.</li> </ul> <p>11. Statistical thermodynamics:</p> <ul style="list-style-type: none"> <li>- microstates, macrostates and entropy,</li> <li>- calculation of macroscopic quantities from microscopic quantities,</li> <li>- model of crystal and model of monoatomic gas.</li> </ul> <p>12. Thermodynamics analysis of heat engines:</p> <ul style="list-style-type: none"> <li>- Carnot cycle,</li> <li>- Rankin cycle,</li> <li>- Brayton cycle,</li> <li>- Otto cycle,</li> <li>- Diesel cycle,</li> <li>- dual cycle,</li> <li>- Stirling cycle.</li> </ul> <p>13. Thermodynamics analysis of cooling devices:</p> <ul style="list-style-type: none"> <li>- compression,</li> <li>- absorption,</li> <li>- inverse Brayton cycle.</li> </ul> <p>14. Fundamentals of description of</p>
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<ul style="list-style-type: none"> <li>- segrevanje in vlaženje zraka</li> <li>- hladilni stolpi.</li> </ul> <p>15. Zgorevanje:</p> <ul style="list-style-type: none"> <li>- kemijske reakcije, opis zgorevanja,</li> <li>- določanje reaktantov iz produktov,</li> <li>- toplota in entropija pri zgorevanju.</li> </ul>	<p>atmospheric air:</p> <ul style="list-style-type: none"> <li>- psychometry, methods for determination of humidity, conditions of comfort,</li> <li>- cooling and heating of air,</li> <li>- heating and humidifying air,</li> <li>- cooling towers.</li> </ul> <p>15. Combustion:</p> <ul style="list-style-type: none"> <li>- chemical reactions, description of combustion,</li> <li>- determination of reactants from the products,</li> <li>- heat and entropy in combustion.</li> </ul>
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### 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, Thermodynamics: 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:

<p>Cilji:</p> <ol style="list-style-type: none"> <li>1. Predstaviti osnove in uporabo termodinamike.</li> <li>2. Predstaviti strukturo termodinamike in teoretični ter metodološki pristop k reševanju različnih termodinamskih sistemov.</li> <li>3. Predstaviti praktično uporabo termodinamike na številnih inženirskih primerih.</li> <li>4. Navdušiti študente za nadaljni, bolj poglobljeni študij predstavljenih osnov.</li> </ol> <p>Kompetence:</p> <ol style="list-style-type: none"> <li>1. P1-RRP, P2-RRP: Biti sposoben razpoznave različnih termodinamskih sistemov, njihovega teoretičnega opisa in metodologije obravnave.</li> <li>2. P4-RRP: Biti sposoben reševanja širokega spektra termodinamskih problemov.</li> <li>3. P6-RRP: Biti sposoben</li> </ol>	
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### Objectives and competences:

<p>Objectives:</p> <ol style="list-style-type: none"> <li>1. To present the fundamentals and application of thermodynamics.</li> <li>2. To present the structure of thermodynamics and theoretical and methodological approach for solving different thermodynamic systems.</li> <li>3. Demonstrate the practical use of thermodynamics on various engineering cases.</li> <li>4. To inspire the students for further, more in-depth study of the presented fundamentals.</li> </ol> <p>Competences:</p> <ol style="list-style-type: none"> <li>1. P1-RRP, P2-RRP: Being able to identify different thermodynamic systems, their theoretical description and approach methodology.</li> <li>2. P4-RRP: Being able to solve a wide range of thermodynamic problems.</li> <li>3. P6-RRP: Being able to make a thermodynamic optimization of</li> </ol>	
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termodinamske optimizacije inženirskih sistemov glede na učinkovitost, kvaliteto in vpliva na okolje.	engineering systems in terms of efficiency, quality and environmental impact.
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### **Predvideni študijski rezultati:**

<p>Znanja:</p> <p>Z1: Poglobljeno strokovno teoretično in praktično znanje termodinamike, podprto s primerno široko teoretično in metodološko osnovo.</p> <p>Spretnosti:</p> <p>S1.1 Hitra prilagoditev reševanju različnih termodinamskih sistemov.</p> <p>S1.2 Samostojna uporaba znanja pri snovanju inženirskih termodinamskih sistemov.</p> <ul style="list-style-type: none"> <li>- Reševanje problemov glede na učinkovitost, kvaliteto in vpliv na okolje.</li> <li>- Biti sposoben nadaljnjega, poglobljenega samostojnega študija.</li> </ul>
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### **Intended learning outcomes:**

<p>Knowledge:</p> <p>Z1: Thorough professional theoretical and practical knowledge of thermodynamics that is supported with a broad theoretical and methodological basis.</p> <p>Skills:</p> <p>S1.1 Rapid adaptation to solving of various thermodynamic systems.</p> <p>S1.2 Independent use of knowledge in the design of thermodynamic systems.</p> <ul style="list-style-type: none"> <li>- Solving problems in terms of efficiency, quality and environmental impact.</li> <li>- To be able to further independently in-depth study.</li> </ul>
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### **Metode poučevanja in učenja:**

<p>P1: Avditorni način predavanja.</p> <p>2. P14: Občasna uporaba računalniške animacije.</p> <p>3. P5: Uporaba študijskega gradiva v obliki skripta predavanj.</p> <p>4. P14: Virtualni eksperimenti.</p> <p>5. P15: Uporaba video vsebin kot priprava na predavanja in vaje.</p> <p>6. P3: Avditorialne vaje - teoretično znanje podkrepljeno s praktičnimi računskimi primeri.</p> <p>7. P5: Uporaba študijskega gradiva v obliki učbenika za vaje.</p> <p>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.</p>
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### **Learning and teaching methods:**

<p>. P1: Auditorial lectures.</p> <p>2. P14: Occasional use of computer animation.</p> <p>3. P5: Use of study materials in the form of a lecture script.</p> <p>4. P14: Virtual experiments.</p> <p>5. P15: Using video contents as a preparation for lectures and exercises.</p> <p>6. P3: Auditorial exercises - theoretical knowledge supported by calculations of practical examples.</p> <p>7. P5: Use of study materials in the form of an exercise textbook.</p> <p>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.</p>
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**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
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**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](https://doi.org/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-b016-00000aabb0f26&acdnat=1504766785\\_f7050a8813a3d32e98f6a93afb8e7f30](http://ac.els-cdn.com/S004579491730038X/1-s2.0-S004579491730038X-main.pdf?_tid=d90e0950-9397-11e7-b016-00000aabb0f26&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](https://doi.org/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](https://doi.org/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](https://doi.org/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](https://doi.org/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](https://doi.org/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]