UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Večfazni sistemi
Course title:	Multiphase Systems
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Procesno strojništvo (smer)	2. letnik	1. semester

Univerzitetna koda predmeta/University course code:	0566928
Koda učne enote na članici/UL Member course code:	6023-M

Predavanja	Seminar	Vaje	Klinične vaje	Druge oblike študija	Samostojno delo	ECTS
30		30			65	5

Nosilec predmeta/Lecturer:	Andrej Bombač, Božidar Šarler
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: - cilji in namen predmeta, - predstavitev učnega programa, - predstavitev učnih pripomočkov, virov in načina dela, - predstavitev obveznosti študentov, - napotki za uspešen študij.	1. Introduction: - objectives and purpose of the course, - presentation of the syllabus, - presentation of teaching aids, resources and working methods, - presentation of student obligations,

2. Večfazni sistemi v tehniki: - motivacija za študij predmeta, - pregled uporabe v klasičnih tehnologijah, - pregled uporabe v modernih tehnologijah. 3. Specifični večfazni sistemi: - plinasto-kapljeviti sistemi, - kapljevito-trdni sistemi, - plinasto-trdni sistemi, - sistemi z alotropnimi fazami, - splošni večfazni sistemi. 4. Vodilne enačbe: - ohranitev mase v večfaznem sistemu, - ohranitev gibalne količine v večfaznem sistemu, - ohranitev vrtilne količine v večfaznem sistemu, - prenos sestavin v večfaznem sistemu, - prenos entropije v večfaznem sistemu. 5. Medfazni pogoji: - medfazni pogoji v primeru brez faznega prehoda, - medfazni pogoji v primeru fazneg prehoda. 6. Povprečevanje vodilnih enačb: - pregled različnih povprečevanj za laminarne in turbulentne sisteme, - volumsko povprečeni homogeni modeli, - volumsko povprečeni več-fluidni modeli. 7. Trdno-kapljevito-plinasti pojavi: - viskoznost, - površinska napetost, - omočjivost in stični koti, - dinamika medfaznih robov. 8. Numerična simulacija I: - problemi s premičnimi in gibajočimi se mejami, - metode s sledenjem diskretizacije medfaznemu robu, - metode na nespremenjivi diskretizaciji. 9. Numerična simulacija II: - metoda celičnih avtomatov, - metoda postavitve nivoja, - metoda faznega polja. 10. Sklopitve pojavov na več merilih: - mikroskopske/mezoskopske sklopitve, - mezoskopske/ makroskopske sklopitve. 11. Tokovni vzorci: - mehurčasti tokovi, - čepasti tokovi, - obročasti tokovi, - ločeni tokovi, - raztrgani tokovi, - kapljičasti tokovi, - tokovi v vertikalnih kanalih, - tokovi v horizontalnih kanalih, - razlike med makro in mikro sistemi. 12. Prhe, tokovi z razpadom, atomizacija: - curki in njihov razpad, - curki visokih hitrosti, - atomizacija.	- directions for successful study. 2. Multiphase systems in engineering: - motivation for study of the course, - overview of applications in classical technologies, - overview of applications in modern technologies. 3. Specific multiphase systems: - gas-liquid systems, - liquid-solid systems, - gas-solid systems, - systems with alotropic phases, - general multiphase systems. 4. Governing equations: - mass conservation in multiphase system, - momentum conservation in multiphase system, - angular momentum conservation in multiphase system, - spicies transfer in multiphase system, - enthropy transfer in multiphase system. 5. Interphase conditions: - interphase conditions without phase change, - inerphase cnditions with phase change. 6. Averaging of governing equations: - overview of different averaging for laminar and turbulent systems, - volume averaged homogenous models, - volume averaged multi-fluid models. 7. Solid-liquid-gas phenomena: - viscosity, - surface tension, - wettability and contanct angles, - dynamics of interphase boundaries. 8. Numerical simulation I: - problems with free and moving boundaries, - front tracking methods, - fixed grid methods. 9. Numerical simulation II: - cellular automata method, - level set method, - phase field method. 10. Coupling of phenomena on different levels: - microscopic/mesoscopic couplings, - mesoscopic/ macroscopic couplings. 11. Flow patterns: - bubbly flows, - slug flows, - annular flows, - stratified flows, - churn flows, - mist flows, - flows in vertical channels, - flow in horizontal channels, - difference betwen macro and micro systems. 12. Showers, flows with breakup, atomization: - jets and their breakup,

13. Zadevanje kapljic, nalet na površine in brizganje: - zadevanje kapljic, - nalet na kapljevite in trdne površine, - vpliv na površine in depozicija. 14. Izbira primerne formulacije in numerične rešitve za različne večfazne sisteme: - taljenje, topljenje, zmrzovanje, strjevanje, - sublimacija in depozicija, - kondenzacija in izhlapevanje, - vrenje, - dvofazni tok s prenosom toplote. 15. Nano in mikro večfazni sistemi: - specifike nano večfaznih tokov, - specifike mikro večfaznih tokov, - tokovi z nanodelci, - dinamika tekočin na čipu.	- high velocity jets, - atomization. 13. Droplet collision, impact and splashing: - droplet collision, - impact on solid and liquid surfaces, - impact on surfaces and deposition. 14. Selection of proper formulation and numerical solution for different multiphase systems: - melting, disolution, freezing, solidification, - sublimation and deposition, - condensation and evaporation, - boiling, - two-phase flow with heat transfer. 15. Nano and micro multiphase systems: - specifics of nano multiphase systems, - specifics of micro multiphase systems, - flows with nanoparticles, - fuid dynamics on a chip.

Temeljna literatura in viri/Readings:

1. A. Faghri, Y. Zhang, Transport Phenomena in Multiphase Systems, Academic Press, Burlington, 2006.
2. J. A. Dantzig, M. Rappaz, Solidification, 2nd Edition, EPFL Press, Lausanne, 2016.
3. G. Heng, Y. J. Tu, Computational Techniques for Multiphase Flows, 2nd Edition, Elsevier, London, 2019.
4. S. Prakash, J. Yeom, Nanofluidics and Microfluidics, Systems and Applications, 1st Edition, Elsevier, Amsterdam, 2014.
5. E. E. Michaelides, C. T. Crowe, J.D. Schwarzkopf, Multiphase Flow Handbook, 2nd Edition, CRC Press, Boca Raton, 2016.

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Predstaviti osnove in uporabo večfaznih sistemov v tehniki na celovit način, z obravnavanjem vseh agregatnih stanj in alotropskih faz. 2. Predstaviti poglobljen teoretični ter metodološki pristop k obravnavanju in reševanju različnih večfaznih sistemov. 3. Predstaviti praktično uporabo večfaznih sistemov na številnih inženirskih primerih. 4. Navdušiti študente za nadaljni, bolj poglobljeni študij predstavljenih osnov. Kompetence: 1. Biti sposoben razpoznave različnih večfaznih sistemov, njihovega teoretičnege opisa in metodologije obravnave (P1-MAG, P2-MAG). 2. Biti sposoben reševanja širokega spektra večfaznih problemov (P4-MAG). 3. Biti sposoben optimizacije inženirskih večfaznih sistemov glede na učinkovitost, kvaliteto in vpliv	Objectives: 1. To present the fundamentals and application of multiphase systems in engineering in a holistic way, by addressing all states of matter and allotropic phases. 2. To present an in-depth theoretical and methodological approach to considering and solving different multiphase systems. 3. Demonstrate the practical use of multiphase systems on various engineering cases. 4. To inspire students for further, more in-depth study of the presented fundamentals. Competences: 1. Being able to identify different multiphase systems, their theoretical description and approach methodology (P1-MAG, P2-MAG). 2. Being able to solve a wide range of multiphase problems (P4-MAG). 3. Being able to optimize engineering multiphase

na okolje (P6-MAG).	systems in terms of efficiency, quality and environmental impact (P6-MAG).

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja: Poglobljeno teoretično, metodološko in analitično znanje z elementi raziskovanja, ki je osnova za zelo zahtevno strokovno delo, Z2. Spretnosti: Hitra prilagoditev reševanju različnih večfaznih sistemov, S2.1 Samostojna uporaba znanja pri snovanju inženirskih večfaznih sistemov, S2.2 Reševanje večfaznih problemov glede na učinkovitost, kvaliteto in vpliv na okolje, S2.3 Biti sposoben nadaljnjega, samostojnega študija predstavljenih osnov, S2.4	Knowledge: Thorough theoretical, methodological and analyitical knowledge with elements of a research work that form a basis for very demanding professional work, Z2. Skills: Rapid adaptation to solving of various multiphase systems, S2.1 Independent use of knowledge in the design of engineering multiphase systems, S2.2 Solving multiphase problems in terms of efficiency, quality and environmental impact, S2.3 Beeing able to further, independently study the presented fundmentals, S2.4

Metode poučevanja in učenja:	**Learning and teaching methods:**
P1: Avditorna predavanja z reševanjem izbranih - za področje značilnih - teoretičnih in praktično uporabnih primerov. P14: Občasna uporaba računalniške animacije. P5: Uporaba študijskega gradiva v obliki (učbenik predavanj). P14: Virtualni eksperimenti. P15: Uporaba video vsebin kot priprava na predavanja in vaje. P3: Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. P5: Uporaba študijskega gradiva v obliki (učbenik za vaje). P4: Laboratorijske vaje z namenskimi didaktičnimi pripomočki: Lastnosti dvofaznega toka plin-kapljevina (Tenziometer in namenski sistem kapilarnih cevk z optičnim zaznavanjem), karakteristike stičnih struktur toka plina in kapljevine (namenska testna sekcija s hitrotekočim video sistemom), torni padec tlaka v toku plina in kapljevine (namenska testna sekcija z vgrajenimi zaznavali za merjenje tlaka in sistemom za hitro zajemanje podatkov), porazdelitev lokalnega deleža plinaste faze v vertikalnem toku plina in	P1: Auditorial lectures with solving selected field-specific theoretical and applied use cases. P14: Occasional use of computer animation. P5: Application of study material (textbook for lectures). P14: Virtual experiments. P15: Application of videos for preparations to the lectures and exercises. P3: Auditorial exrecises, in which theoretical content from the lectures is supplemented with practical examples. P5: Application of study material (textbook for exercises). P4: Laboratory exercises with special-purpose didactic devices: Properties of gas-liquid two-phase flow (Tensiometer and purpuse built capillary tubes system with optical detection), characteristics of interfacial structures in gas-liquid two-phase flow (purpose built test section with high-speed video system), frictional pressure drop in gas-liquid flow (purpose built test section with bult-in pressure sensors and high speed data acquisition system), distribution of local void fraction in vertical flow of

kapljevine (namenska testna sekcija z uporovnim zaznavalom za lokalno zaznavanje faze in sistemom za hitro zajemanje podatkov), lastnosti dvofaznega toka plin trdi delci (Wursterjeva komora s sistemom za merjenje padca tlaka in določitev deleža trde faze). P4: Ekskurzija.	gas and liquid (purpose built test section with resistivity probe for local phase detection), properties of gas-solid two phase flow (Wurster chamber with system for measuring solid fraction and pressure drop). P4: Excursion.

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

Reference nosilca/Lecturer's references:

Božidar Šarler:

1. TALAT, Nazia, MAVRIČ, Boštjan, HATIĆ, Vanja, BAJT, Saša, ŠARLER, Božidar. Phase field simulation of Rayleigh-Taylor instability with a meshless method. Engineering analysis with boundary elements. [Print ed.]. Feb. 2018, vol. 87, str. 78-89, ilustr. ISSN 0955-7997. https://www.sciencedirect.com/science/article/pii/S0955799717304009, DOI: 10.1016/j.enganabound.2017.11.015. [COBISS.SI-ID 1376682]
2. ZAHOOR, Rizwan, BAJT, Saša, ŠARLER, Božidar. Influence of gas dynamic virtual nozzle geometry on micro-jet characteristics. International journal of multiphase flow. [Print ed.]. 2018, vol. 104, str. 152-165, ilustr. ISSN 0301-9322. DOI: 10.1016/j.ijmultiphaseflow.2018.03.003. [COBISS.SI-ID 5124347]
3. KOSEC, Gregor, ŠARLER, Božidar. Solution of phase change problems by collocation with local pressure correction. Computer modeling in engineering & sciences : CMES. Tiskana izd. 2009, vol. 47, no. 2, str. 191-216, ilustr. ISSN 1526-1492. [COBISS.SI-ID 1246203]
4. DOBRAVEC, Tadej, MAVRIČ, Boštjan, ŠARLER, Božidar. A cellular automaton - finite volume method for the simulation of dendritic and eutectic growth in binary alloys using an adaptive mesh refinement. Journal of computational physics. Nov. 2017, vol. 349, str. 351-375, ilustr. ISSN 0021-9991. http://ac.els-cdn.com/S002199911730582X/1-s2.0-S002199911730582X-main.pdf?_tid=c3cfccb4-8f13-11e7-acb0-00000aacb35f&acdnat=1504270251_7b2431d97e82010a9ab8b78f7d0f0c9e, DOI: 10.1016/j.jcp.2017.08.011. [COBISS.SI-ID 15618075]
5. HON, Yiu-Chung, ŠARLER, Božidar, YUN, Dong-fang. Local radial basis function collocation method for solving thermo-driven fluid-flow problems with free surface. Engineering analysis with boundary elements. [Print ed.]. Aug. 2015, vol. 57, str. 2-8, ilustr. ISSN 0955-7997. DOI: 10.1016/j.enganabound.2014.11.006. [COBISS.SI-ID 3715835]

Andrej Bombač:

1. BOMBAČ, Andrej, REK, Zlatko, LEVEC, Janez. Void fraction distribution in a bisectional bubble column reactor. AIChE journal, ISSN 1547-5905. [Online ed.], Apr. 2019, vol. 65, iss. 4, str. 1186-1197, ilustr. https://onlinelibrary.wiley.com/doi/epdf/10.1002/aic.16534, doi: 10.1002/aic.16534. [COBISS.SI-ID 16463387]
2. BOMBAČ, Andrej, PIRNAR, Jernej. Numerical and experimental analyses of a stirred vessel for a large volumetric flow rate of sparged air. Chinese journal of chemical engineering, ISSN 1004-9541, 2019, str. 1-34, ilustr. https://www.sciencedirect.com/science/article/pii/-S1004954118314204?via%3Dihub, doi: 10.1016/j.cjche.2019.03.009. [COBISS.SI-ID 16556827]
3. BOMBAČ, Andrej. Asymmetric blade disc turbine for high aeration rates. Strojniški vestnik, ISSN 0039-2480, Sep. 2018, vol. 64, no. 9, str. 513-524, ilustr. https://www.sv-jme.eu/?ns_articles_pdf=/ns_articles/files/ojs/5149/public/5149-30018-1-PB.pdf&id=6119, doi: 10.5545/sv-jme.2017.5149. [COBISS.SI-ID 16191515]
4. PIRNAR, Jernej, ŠIROK, Brane, BOMBAČ, Andrej. Effect of airway surface liquid on the forces on the

pharyngeal wall : experimental fluid-structure interaction study. Journal of biomechanics, ISSN 0021-9290. [Print ed.], Oct. 2017, vol. 63, str. 117-124, ilustr. https://ac.els-cdn.com/S0021929017304256/1-s2.0-S0021929017304256-main. pdf?_tid=5675a9e4-ace7-11e7-bd92-00000aacb362&acdnat=1507549705_3545784e854ed245a0807ee62d15b40d, doi: 10.1016/j.jbiomech.2017.08.014. [COBISS.SI-ID 15693339]

5. BOMBAČ, Andrej, BEADER, Dečan, ŽUN, Iztok. Mixing times in a stirred vessel with a modified turbine. Acta chimica slovenica, ISSN 1318-0207. [Tiskana izd.], 2012, vol. 59, no. 4, str. 707-721, ilustr. [COBISS.SI-ID 12578075]