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Symposium of Emerging Nuclear Technology and Engineering Novelty (SENTEN 2018)

PREFACE

Following the previous successful of SENTEN-ICoNETS 2015-2017, five research centers under the Deputy of Nuclear Energy Technology – National Nuclear Energy Agency of Indonesia (BATAN) in collaboration with Universitas Sriwijaya organize the First Symposium of Emerging Nuclear Technology and Engineering Novelty (SENTEN) with theme: “Discovering Science and Engineering Novelty for improving human life prosperity”. SENTEN 2018 has been conducted in Horison Ultima Hotel, Palembang, South Sumatra, Indonesia, on 4-5 July 2018. This conference aims at summarizing recent research activities relevant to the nuclear, material, mechanical, electric, chemical, geology, architect and civil engineering, computer science and IT, food and agriculture, and also facilitate communication among relevant experts.

More than 150 people from Indonesia, Malaysia, India, Taiwan, and some other countries have participated in this conference. About 207 presentations including 6 keynote speeches and 1 plenary talk are presented. The presentations are grouped into 9 areas of particular interest: (1) Nuclear Science and Engineering, (2) Material Science and Engineering, (3) Mechanical and Industrial Engineering, (4) Electrical Science and Engineering, (5) Chemical Science and Engineering, (6) Geological Science and Mining Engineering, (7) Architecture and Civil Engineering, (8) Computer Science and Information Technology, and (9) Food and Agricultural Science, Natural Resource Science.

From about 190 full papers submitted, then peer-reviewed by relevant experts, eventually 169 papers were accepted for publication in this proceeding. We are indebted to all of authors for submitting their original papers.

We would like to thank all participants, and express our gratitude to all those who helped the success of this conference.

Syaiful Bakhri

SENTEN 2018 Chairman

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TABLE OF CONTENTS

PART 1

NUCLEAR SCIENCE AND ENGINEERING

SHORT CIRCUIT ANALYSIS ON HPS ELECTRICAL SYSTEM	1
<i>Khairul Handono, Edy Sumarno, Kiswanta, Koes Indrakoesoema</i>	
POWER FLOW ANALYSIS ON RDE FUEL HANDLING SYSTEM USING ETAP	9
<i>Edy Sumarno, Khairul Handono, Kiswanta, Koes Indrakoesoema</i>	
COMPARISON OF GALLIUM-68 PRODUCTION YIELDS FROM (P,2N), (α,2N) AND (P,N) NUCLEAR REACTIONS APPLICABLE FOR CANCER DIAGNOSIS	19
<i>I Kambali, F A Wibowo</i>	
ANALYSIS OF HEAVY METAL LOADING OPTIMIZATION THROUGH CRITICALITY CALCULATION ON RDE	29
<i>Suwoto, H. Adrial, Zuhair, K. Kamajaya, S. Bakhri</i>	
NUCLEAR POWER PLANT MAINTENANCE OPTIMISATION: MODELS, METHODS & STRATEGIES	40
<i>I Wayan Ngarayana, Thi-Mai-Dung Do, Kenta Murakami, Masahide Suzuki</i>	
TECHNOLOGICALLY ENHANCED NATURALLY OCCURRING RADIOACTIVE MATERIALS (TENORM) ANALYSIS OF BANGKA TIN SLAG	63
<i>Onek Gunawan, Eko Pudjadi, Musaddiq Musbach, Wahyudi</i>	
DETERMINATION OF DIFFUSION COEFFICIENT OF ¹³⁷CS AT UNSATURATED ZONE OF DH-2 SITE SOIL UNDER $\delta = 1.41 \text{ G.CM}^{-3}$ CONDITION	70
<i>Budi Setiawan, Nurul Efri Ekaningrum</i>	
CALCUIYIELD: A NOVEL ANDROID-BASED SOFTWARE FOR RADIOACTIVITY YIELD CALCULATIONS	78
<i>F A Wibowo, I Kambali</i>	
WATER EVAPORATION RATE OF RSG-GAS SPENT FUEL STORAGE POOL	86
<i>Titik Sundari, Mukhsimun Hadi Kusuma, Budiyono, M. Joko Puspito, Parjono, Darmawan Aji, Irwan Santoso, Sri Ismarwanti</i>	
IMPROVEMENT OF NUCLEAR SCIENCE STANDARDS (SNI) TO MEET MARKET NEEDS AND HARMONIZATION	101
<i>J. Sutanto, P. Sulisworo</i>	
ANALYSIS FOR DEVELOPING A CLEARING HOUSE OF NUCLEAR TECHNOLOGY USING SWOT-BSC STRATEGIES	107
<i>A. Bayu Purnomo, Jepri Sutanto</i>	
CROSS-SECTIONAL IMAGING OF TREE STEM DENSITY DISTRIBUTION USING GAMMA-RAY TOMOGRAPHY TECHNIQUE	114
<i>Wibisono, Bayu Azmi, Sastra Kusuma Wijaya, Prawito, Firliyani Rahmatia Ningsih</i>	
INFLUENCE ANALYSIS OF NATURAL VENTILATION SYSTEM ON RADON CONCENTRATION IN INTERIM STORAGE FOR RADIOACTIVE WASTE	121
<i>R. Ratiko</i>	
A SELF-EVALUATION TOOLS FOR THE ASSESSMENT OF NUCLEAR FORENSIC CAPABILITY	129
<i>Nurul Ilyani Zaharudin, Phongphaeth Pengvanich</i>	
REVERSE ENGINEERING PROGRAM USING MBSE TO SUPPORT DEVELOPMENT OF I&C SYSTEM EXPERIMENTAL POWER REACTOR FROM PLC TO FPGA.	139
<i>Restu Maerani, Deswandri, Sigit Santoso, Sudarno, Ign. Djoko Irianto</i>	
TRANSIENT ANALYSIS OF CVCS MALFUNCTION IN LARGE PASSIVE PWR	152
<i>Surip Widodo, Andi Sofrany Ekariansyah</i>	
EVALUATION OF FUEL BURN-UP AND RADIOACTIVITY INVENTORY IN THE 2 MW TRIGA-PLATE BANDUNG RESEARCH REACTOR	160
<i>M Budi Setiawan, S Kuntjoro, P M Udiyani, I Husnayani</i>	
APPLICABILTY STUDY OF ULTRASONIC FLAW DETECTOR FOR NUCLEAR GRADE GRAPHITE EXAMINATION	167
<i>Roziq Himawan, Freddy Lie, Prita Dewi Basoeki, Mudi Haryanto</i>	

PRELIMINARY STUDY OF TEMPERATURE HOMOGENISATION IN EXPERIMENTAL POWER REACTOR HOT GAS CHAMBER.....	175
<i>R Andika Putra Dwijayanto, Muhammad Subekti</i>	
A COMPARATIVE STUDY ON SAFETY DESIGN REQUIREMENTS BETWEEN HTGR AND LWR	182
<i>Julwan Hendry Purba, Damianus Toersiw Sany Tjahyani</i>	
INVESTIGATION OF GRAPHITE MATRIX ACTIVATION IN THE FUEL PEBBLE OF REAKTOR DAYA ESKPERIMENTAL.....	190
<i>I Husnayani, P M Udiyani, S Kuntjoro, M B Setiawan</i>	
COMPARATIVE STUDY OF RDE AND CONVENTIONAL PLANT FOR MODERATE SCALE POWER GENERATIONS.....	195
<i>S Sudadiyo, T Taryo, E Saragi, Krismawan</i>	
COMMISSIONING PREPARATION OF A SUBCRITICAL EXPERIMENTAL FACILITY FOR 99MO PRODUCTION	205
<i>Syarip, P I Wahyono, W Susilo, K Donny</i>	
DESIGNING INSTRUMENTATION AND CONTROL SYSTEM FOR POWER CONTROL AND SHUTDOWN SYSTEM OF RDE	213
<i>Agus Cahyono, Demon Handoyo, Kristedjo Kurnianto, Deswandri</i>	
ANALYSIS OF IRRADIATED PEBBLE BED FUEL TRANSFER SYSTEM IN HOT CELL 101 RADIOMETALLURGY INSTALLATION.....	220
<i>Helmi Fauzi Rahmatullah, Rohmad Sigit, Sri Ismarwanti, Erlina Noerpitari, Maman Kartaman Ajiriyanto, Jan Setiawan</i>	
CORRELATION BETWEEN DIFFERENT TYPE OF CAESIUM CARRIER IN THE RADIOCAESIUM INTERCEPTION POTENTIAL MEASUREMENT FOR FOREST SOILS.....	228
<i>Hendra A Pratama, M Yoneda, Y Shimada, F Satoshi, M Ikegami</i>	
REGULATORY ASSESSMENT ON A NEW UTILIZATION OF SAMOP TEST FACILITY: DETERMINATION ON FISSION POWER.....	238
<i>Azizul Khakim</i>	
FUEL BURN-UP AND RADIOACTIVITY INVENTORY ANALYSIS FOR NEW IN-CORE FUEL MANAGEMENT OF THE RSG-GAS RESEARCH REACTOR.....	246
<i>S Kuntjoro, P M Udiyani, M Budi Setiawan</i>	
DESIGN CRITERIA OF INSTRUMENTATION AND CONTROL IN FUEL HANDLING SYSTEM OF RDE	253
<i>Dian Fitri Atmoko, Achmad Suntoro, Deswandri</i>	
TRADE-OFF ANALYSIS BETWEEN PLC AND FGPA FOR THE SYSTEM PLATFORM OF INSTRUMENTATION AND CONTROL SYSTEM EXPERIMENTAL POWER REACTOR: A PRELIMINARY STUDY.....	260
<i>Saharudin, Restu Maerani</i>	
STUDY ON MOX CORE CHARACTERISTICS OF EXPERIMENTAL POWER REACTOR USING MCNP6 CODE	268
<i>Zuhair, Suwoto, H. Adrial, T. Setiadipura</i>	
CONTROL ROD REACTIVITY ANALYSIS OF ONE STUCK ROD CONDITION IN 10 MWTH EXPERIMENTAL REACTOR CONCEPTUAL DESIGN (RDE-10 MWTH) ON FIRST FULL CORE	278
<i>H. Adrial, Suwoto, A. Hamzah, Zuhair</i>	
BENCHMARKING OF EXPERIMENTAL SETUP FOR PRESSURE DROP CALCULATION IN A PACKED PEBBLE BED USING RELAP5.....	289
<i>A S Ekariansyah, S Widodo</i>	
INHERENT SAFETY ANALYSIS OF THE UO₂ FUELED PEBBLE LATTICE AT THE RDE USING SRAC2006 MODULE OF PIJ.....	296
<i>J Susilo, I Husnayani, A A Waskita, Zuhair, S Bakhri</i>	
THE DEVELOPMENT OF TRIAC-BATAN: A TRISO FUEL PERFORMANCE ANALYSIS CODE.....	306
<i>A. A. Waskita, T. Setiadipura</i>	
BURNUP CALCULATION STUDY OF PEBBLE BED EQUILIBRIUM CORE.....	315
<i>L. Suparlina, T. Setiadipura, Suwoto</i>	
ESTIMATION OF RADIOACTIVITY IMPACT FOR RDE BASED ON HTR-10 HYPOTHETICAL ACCIDENT - A CASE STUDY.....	324
<i>P M Udiyani, S Kuntjoro, I Husnayani, M Budi Setiawan, S A Santa</i>	
PRELIMINARY ANALYSIS OF DOSE RATES DISTRIBUTION OF EXPERIMENTAL POWER REACTOR 10 MW USING MCNP	331
<i>Amir Hamzah, Suwoto, Hery Adrial</i>	

COMPARISON ON TWO OPTION DESIGN OF THE RDE COGENERATION SYSTEM	338
<i>Sukmanto Diby, Ign.Djoko Irianto, Syaiful Bakhri</i>	
ANALYSIS OF HYDROCYCLONE AS RIVER WATER PRE-TREATMENT FOR TERTIARY COOLANT OF RDE	344
<i>Sriyono, Rahayu Kusmastuti, Sofia L. Butarbutar, Djati Hoesen Salimy, Febrianto, Ign. Djoko Irianto, M. Pancoko, Geni R. Sunaryo</i>	
THE ANALYSIS FOR PREDICTION OF A CENTRAL DISTRIBUTION CRACK FOR RDE PRESSURE VESSEL BY FUZZY NEURAL NETWORK	353
<i>Mike Susmikanti, Roziq Himawan, Jos Sulisty</i>	
TWO DIMENSIONAL PERFORMANCE ANALYSIS OF SMALL HTR RESIDUAL HEAT REMOVAL SYSTEM IN DLOFC CONDITION	363
<i>Hendro Tjahjono, Susyadi, Surip Widodo, Anhar R. Antariksawan, Andi Sofrany, Hadi Kusuma, Rahayu Kusumastuti</i>	
DECOMPOSED FUNCTIONAL BEHAVIOR OF HELIUM PURIFICATION SUPPORT SYSTEM FOR EXPERIMENTAL POWER REACTOR (RDE) TYPE USING SEQUENCE DIAGRAM	372
<i>Kussigit Santosa, Restu Maerani, Sudarno</i>	
EFFECT OF HEAT ON COATING PROCESS OF JOINT TUBE WALL ASCENDING TUBE FUEL HANDLING SYSTEM RDE	377
<i>Andryansyah, Alim Mardhi, Mudi Haryanto, Darlis, Ari Nugroho</i>	
EFFECT OF SUPERHEATED STEAM PRESSURE ON THE PERFORMANCE OF RDE ENERGY CONVERSION SYSTEM	384
<i>Ign. Djoko Irianto, Sriyono, R. Kusumastuti, K. Santoso, H. Subiyah, A. Citra, S. Diby, Zuhair, S. Bakhri, G. R. Sunaryo</i>	
SOFTWARE REQUIREMENT ANALYSIS FOR DIGITAL BASED REACTOR PROTECTION SYSTEM OF RDE DESIGN	394
<i>S. Santoso, Sudarno, R. Maerani, J. Situmorang, A. Cahyono</i>	
ANALYSIS OF AIR DISTRIBUTION AT MOLECULAR SIEVE VESSEL IN RDE SYSTEM BASED ON FAN FLOW RATE VARIATION USING AEROSOL DENSITY TESTING FACILITY	402
<i>Ainur Rosidi, G. Bambang Heru, Dedy Haryanto</i>	
STUDY OF STRUCTURE SYSTEMS AND COMPONENTS CLASSIFICATION OF REAKTOR DAYA EKSPERIMENTAL - RDE BASED ON LIFE CYCLE MANAGEMENT	408
<i>Endiah Puji Hastuti, Sri Sudadiyo, Syaiful Bakhri</i>	
SENSITIVITY OF HEAT TRANSFER PARAMETERS ON THE REAKTOR DAYA EKSPERIMENTAL - RDE CORE	419
<i>Sudarmono, Suwoto, Syaiful Bakhri</i>	
CALCULATION OF DOMESTIC RAW MATERIALS USING DOMESTIC RESOURCE COST METHOD	427
<i>Arief Tris Yuliyanto, Dharu Dewi, Ewitha Nurulhuda, Nurlaila, Moch. Djoko Birmano, Utomo, Muhammad Subhan, Putut Hery Setiawan, Krismawan, Edi Siswanto, Citra Candranurani, Sufiana Solihat, Rustama</i>	
RECENT STATUS OF PUBLIC RESPONSE TO RDE DEVELOPMENT & UTILIZATION	435
<i>Dimas Irawan, Theresia Erni Wijayanti, Mudjiono, Muhammad Busthomi</i>	
SOCIAL ENGINEERING TO THE DEVELOPMENT PLAN OF EXPERIMENTAL POWER REACTOR (RDE)	441
<i>Mudjiono, Siti Alimah, Dimas Irawan, M. Busthomi, Heni Susiati</i>	
CHAIN AND SPROCKET ANALYSIS OF CONTROL ROD DRIVE MECHANISM OF HTGR EXPERIMENTAL POWER REACTOR	448
<i>M. Awwaluddin, Sri Hastuty, Z. Petrus, H. S. Putut, Krismawan, S. Edi, E. Byan W. R, A. Nugroho</i>	
THE METHODS OF CONDITION MONITORING FOR CIRCULATOR OF HTGR	455
<i>S. Bakhri, N. Ertugrul, Wen. L. Soong</i>	
PRELIMINARY EXPERIMENT OF U-SHAPED HEAT PIPE AS PASSIVE COOLING SYSTEM IN HIGH TEMPERATURE GAS-COOLED REACTOR COOLING TANK	466
<i>Mukhsinun Hadi Kusuma, Anhar Riza Antariksawan, Giarno, Sri Ismarwanti, Mulya Juarsa, Dedy Haryanto, Surip Widodo, Tanti Ardiyati</i>	
CONCEPTUAL DESIGN OF INDONESIA EXPERIMENTAL POWER REACTOR COUPLED WITH DESALINATION UNIT	475
<i>Erlan Dewita, Teguh Ariyanto, Heni Susiati, Marliyadi Pancoko</i>	
DESIGN OF REINFORCED CONCRETE SHEAR WALL OF REACTOR BUILDING, EXPERIMENTAL POWER REACTOR	483
<i>Hadi Suntoko, Eko Rudi Iswanto, Ary Marwanto, Antonius Mahatma Puteraka</i>	
PERCEPTION STUDY OF SAFETY INDICATORS IN NUCLEAR INSTALLATIONS USING MANN WITHNEY NONPARAMETRIC STATISTIC TECHNIQUE	493
<i>J. Situmorang, S. Santoso</i>	

SENSITIVITY OF REFLECTOR ON NEUTRONIC PARAMETER FOR CONVERSION CORE DESIGN OF THE TRIGA RESEARCH REACTOR	501
<i>S. Tukiran, Pinem Surian, Bakhri Syaiful</i>	
AN IMPROVEMENT OF THE DECISION MAKING GRID MODEL IN FAILURE- BASED MAINTENANCE ON RSG-GAS SYSTEM/COMPONENTS.....	511
<i>Entin Hartini, Muhammad Subekti</i>	
STUDY ON PITTING CORROSION OF ALMG₂ IN SOLUTION CONTAINING CHLORIDE.....	522
<i>Febrianto, Sriyono, Endiah Puji Hastuti, Geni Rina Sunaryo</i>	
THE DEVELOPMENT OF HTGR-TRISO COATED FUELS IN THE GLOBE: CHALLENGING OF INDONESIA TO BE AN HTGR FUEL PRODUCER.....	529
<i>T Taryo, I Husnayani, RM Subekti, S Sudadiyo, E Saragi, Rokhmedi</i>	
ASSESSMENT OF RELAP5 CODE MODEL TO SIMULATE U-SHAPED HEAT PIPE PERFORMANCE FOR HEAT SINK.....	545
<i>Anhar R. Antariksawan, Mukhsinun Hadi Kusuma, Surip Widodo, Giarno, Mulya Juarsa, Hendro Tjahyono, Dedy Haryanto</i>	
OVERVIEW OF THE APPLICATION OF THE SPECIFIC SAFETY REQUIREMENTS TO BATAN RESEARCH REACTORS	551
<i>Iman Kuntoro, Sriyono, M. Subekti, G.R. Sunaryo, Agus Rokhim, Taxwim, Jaja Sukmana</i>	
PWR FUEL MACROSCOPIC CROSS SECTION ANALYSIS FOR CALCULATION CORE FUEL MANAGEMENT BENCHMARK	558
<i>S. Pinem, T.M. Sembiring, Tukiran Surbakti</i>	
HEAT REMOVAL ANALYSIS IN THE AP1000 REACTOR'S REFUELLING PROCESS.....	574
<i>Muh. Darwis Isnaini, M. Subekti</i>	
FAST DEFECT DETECTION ON PRIMARY PUMP PIPE FOR RSG-GAS REACTOR USING ACOUSTICS EMISSION TECHNIQUES.....	582
<i>Rokhmedi, M. Yahya, Santosa Pujiarta, Syaiful Bakhri, R. Muhammad Subekti</i>	
A REVIEW ON PNEUMATIC TRANSPORTATION IN THE DESIGN OF FUEL HANDLING SYSTEM IN RDE-HTGR	590
<i>K Widiyati, Sukmanto Dibyo</i>	
UTILIZATION OF HTGR FOR PHOSPHATE FERTILIZER PRODUCTION AND URANIUM RECOVERY	597
<i>Djati H Salimy, Abdul Hafid, Sriyono</i>	
PROBABILISTIC SAFETY ANALYSIS FOR ASSESSING THE FAILURE OF HEAT REMOVAL CONTROL OF AP1000	605
<i>D T Sony Tjahyani, J H Purba</i>	
SUSTAINING THE OPERABILITY AND SAFETY OF MALAYSIAN RESEARCH REACTOR TO SUPPORT NATIONAL NUCLEAR RESEARCH AND EDUCATION	615
<i>M.F. Abd Farid, N. Ramli, M. F. Zakaria, A. N. Ab Rahim, A. S. Ligam</i>	
SIMPLE SIMULATION USING COUPLING BETWEEN FLOWNEX AND LABVIEW SIMULTANEOUSLY IN CASE OF INDONESIAN EXPERIMENTAL POWER REACTOR	622
<i>A. S. Muksin, B. Syaiful</i>	
PRELIMINARY INVESTIGATION ON NATURAL CIRCULATION FLOW USING CFD AND CALCULATION BASE ON EXPERIMENTAL DATA PRE-FASSIP-02.....	627
<i>Mulya Juarsa, Anhar R. Antariksawan, Mukhsinun Hadi Kusuma, Nandy Putra, Pryawrata Putera Moniaga</i>	
PRELIMINARY STUDY ON FLUID DYNAMICS IN MANIFOLDS OF THE REACTOR CAVITY COOLING SYSTEM – THE EXPERIMENTAL POWER REACTOR TEST FACILITY	634
<i>Arif Adtyas Budiman, Dedy Haryanto, Muhammad Subekti, Mukhsinun Hadi Kusuma</i>	
ROLE OF SENSORS (NANO) IN NUCLEAR TECHNOLOGY	645
<i>Murthy Chavali Yadav</i>	
EQUILIBRIUM CORE DESIGN OF REAKTOR DAYA EKSPERIMENTAL	650
<i>T Setiadipura, Suwoto, Zuhair</i>	
3D MODELLING AND STATIC STRUCTURAL ANALYSIS OF BOTTOM REFLECTOR EXPERIMENTAL POWER REACTOR (RDE) USING SOLIDWORKS SOFTWARE.....	658
<i>Farisy Yogatama Sulisty, Ari Nugroho, Syaiful Bakhri</i>	
CRITICALITY AND BURNUP STUDY ON DIFFERENT TRISO MODELLING OF HTR PEBBLE	665
<i>L Wahid, T Setiadipura, Zuhair, Suwoto, S Bakhri</i>	
THE SELECTION OF GEOMETRY AND FLOW RATE ON THE FLUIDIZED BED REACTOR FOR COATING PARTICLE	681
<i>R Sukarsono, S Riyadi, D Husnurrofiq, Sri Rinanti</i>	
APPLICABLE STANDARD DOCUMENT REFERENCES FOR AGEING MANAGEMENT ISSUES RELATED TO INDONESIAN RESEARCH REACTORS	695
<i>Restu Maerani, Eric Yee</i>	

MATERIAL SCIENCE AND ENGINEERING

EXTRACTION OF NEODYMIUM (III) FROM NEODYMIUM CONCENTRATE USING SYNERGISTIC SOLVENT D2EHPA, TOPO AND TBP.....	702
<i>Moch Setyadji, Suyanti</i>	

PART 2

LOW CYCLE FATIGUE PROPERTIES OF EXTRUDED 6061-T6 ALUMINUM ALLOY.....	710
<i>M Badaruddin, Zulhanif, H Supriadi</i>	
SEPARATION OF CE, LA AND ND IN RARE EARTH HYDROXIDE (REOH) BY OXIDATION WITH POTASSIUM PERMANGANATE AND PRECIPITATION.....	716
<i>M V Purwani, K Trinopiawan, H Poernomo, Suyanti, N D Pusporini, R A Amiliana</i>	
ANALYSIS OF COMPOSITION, DENSITY, AND THERMAL PROPERTIES OF U-ZR-NB ALLOY POWDER FOR NUCLEAR FUEL.....	729
<i>Masrukan, Yanlinastuti, M.H Alhasa, Arif Sasongko</i>	
INFLUENCE OF HOOKED-ENDSTEEL FIBERS ON FRESH AND HARDENED PROPERTIES OF STEEL FIBER REINFORCEMENT SELF-COMPACTING CONCRETE (SFRSCC).....	737
<i>Faiz Sulthan, Saloma</i>	
ANALYSIS OF FATIGUE LIFE AND CRACK PROPAGATION CHARACTERIZATION OF GRAY CAST IRON UNDER NORMALIZING PROCESS.....	748
<i>Hendri Chandra, Nukman, Baoadi Sianturi</i>	
FINITE ELEMENT FAILURE ANALYSIS ON 34CRNIMO6 FIRING PIN IN FATIGUE FRACTURE.....	757
<i>A Yusup, A Mataram, I Yani, M Zahir</i>	
EVALUATION PAVEMENT DETERIORATING CONDITION ON SURFACE DISTRESS INDEX (SDI) DATA USING RADIAL BASIS FUNCTION NEURAL NETWORKS (RBFNN).....	763
<i>Amrina Rosada, Joni Arliansyah, Erika Buchari</i>	
STUDY ON THE MECHANISM OF CO₂ ADSORPTION PROCESS ON ZEOLITE 5A AS A MOLECULAR SIEVE IN RDE SYSTEM: AN INFRARED INVESTIGATION.....	770
<i>R. Kusumastuti, Sriyono, M. Pancoko, S.L. Butar-Butar, Guntur Eko Putra, Hendro Tjahjono</i>	
CONSIDERATIONS OF MATERIAL SELECTION FOR CONTROL ROD DRIVE MECHANISM OF REAKTOR DAYA EKSPERIMENTAL.....	778
<i>Sri Hastuty, Petrus Zacharias, M Awwaluddin, Krismawan, Putut Hery Setiawan, Edy Siswanto, Budi Santoso, Ari Nugroho, Ahmad Majdi Abdul-Rani</i>	
ANALYSIS OF RPV STRENGTH IN CURRENT RDE BASED ON TEMPERATURE.....	786
<i>E. Saragi, S. Sudadiyo, T. Taryo</i>	
PREPARING THE CARBON-BASED MATERIAL WITH DIFFERENT MILLING SETTINGS TO CHANGE THE MORPHOLOGY AND CRYSTALLINE STRUCTURE.....	793
<i>Barlin, WC Chang</i>	
EFFECTS OF SIC PARTICULATE-REINFORCED ON THE FLUIDITY AND MECHANICAL PROPERTIES OF ALUMINIUM MATRIX COMPOSITE THROUGH STIR CASTING ROUTE.....	801
<i>Gunawan, Amir Arifin, Yani Irsyadi, Bembi Aris Munandar</i>	
THE INFLUENCES OF CATALYST COMBINATION ON THE HIGH TEMPERATURE PROTON EXCHANGE MEMBRANE FUEL CELL.....	808
<i>K Sasiwimonrit, W-C Chang</i>	

MECHANICAL AND INDUSTRIAL ENGINEERING

MICRO HYDRO ELECTRIC POWER PLANT (MHEP) PROTOTYPE A STUDY OF THE EFFECT OF BLADE NUMBERS TOWARD TURBINE ROTATIONAL VELOCITY.....	815
<i>Ibnu Asrafi, M. Yerizam, Sairul Effendi, Agung Mataram</i>	
THE EFFECT OF MAGNETIC FIELD AND HEATER IN BIODIESEL FUEL LINE TOWARD TORQUE, POWER, AND FUELD CONSUMPTION OF ONE CYLINDER FOUR STROKE DIESEL ENGINE AT MAXIMUM LOAD.....	826
<i>Muhamad Sirajudin, A Husaini, Tri Widagdo, Agung Mataram</i>	
PV PANEL COOLER TO ENHANCE OUTPUT PERFORMANCE USING PERFORATED ALUMINIUM PLATE.....	832
<i>I Bizzy, L Mustafizal</i>	

OPTIMALIZATION PHYSICAL ENVIRONMENT EFFECTS ON WORK PRODUCTIVITY FOR ASSEMBLY OPERATOR WITH RESPONSE SURFACE METHODOLOGY	837
<i>M. Rosyidah, D. Oktarini, Madagaskar, Azhari</i>	
SUSTAINABLE DEVELOPMENT OF LUBRICATOR TO OPTIMIZATION PROCESS OF LUBRICATION IN WIRE ROPE SLING	847
<i>Mgs Halim, H Chandra, D K Pratiwi, M Zahir</i>	
THERMODYNAMICS PERFORMANCE EVALUATION IN COMBINED CYCLE POWER PLANT BY USING COMBINED PINCH AND EXERGY ANALYSIS	854
<i>M I Riady, D Santoso, M D Bustan</i>	
DEVELOPMENT OF IMAGE ACQUISITION SOFTWARE FOR DIGITAL RADIOGRAPH AND X-RAY CT	864
<i>Fitri Suryaningsih, Demon Handoyo, Andeka Tris Susanto</i>	
DESIGN OPTIMIZATION IN STRESS DISTRIBUTION OF FIRING PIN RIFLE BY IMPACT FORCE USING FINITE ELEMENT MODELLING	872
<i>E P Riyanto, I Yani, A Arifin, M Zahir</i>	
CHALLENGES IN TURBINE FLOW METERING SYSTEM: AN OVERVIEW	878
<i>Bunyamin, Nyayu Latifah Husni, Hasan Basri, Irsyadi Yani</i>	
MECHANICAL FRACTURE CHARACTERIZATION OF RICE KERNEL UNDER MILLING PROCESS	889
<i>H Chandra'</i>	
THE ANALYSIS OF DIMPLE GEOMETRY ON ARTIFICIAL HIP JOINT TO THE PERFORMANCE OF LUBRICATION	894
<i>Hasan Basri, A. Syahrom, A. T. Prakoso, D. Wicaksono, M. I. Amarullah, T. S. Ramadhoni, R. D. Nugraha</i>	
THE EFFECT OF THE WELDING DIRECTION ON FATIGUE CRACK PROPAGATION RATE OF WELDED SHELL KILN	904
<i>Akbar Teguh Prakoso, Irsyadi Yani, Agung Mataram, Gunawan, Hasan Basri</i>	
ANALYTICAL DESIGN OF HELICAL COIL STEAM GENERATOR FOR HOT TEMPERATURE GAS REACTOR	910
<i>B W Riyandwita, M Awwaludin, Krismawan, P Zacharias, E Siswanto, P H Setiawan, A Nugroho</i>	
FATIGUE EVALUATION OF PRESSURE VESSEL USING FINITE ELEMENT ANALYSIS BASED ON ASME BPVC SEC. VIII DIVISION 2	917
<i>P. Kadarno, D. S. Park, N. Mahardika, I. D. Irianto, A. Nugroho</i>	
APPLICATION OF RSM AND ANN IN PREDICTING SURFACE ROUGHNESS FOR SIDE MILLING PROCESS UNDER ENVIRONMENTALLY FRIENDLY CUTTING FLUID	929
<i>M Yanis, A S Mohruni, S Sharif, I Yani, A Arifin, B Khona'ah</i>	
PROCESSING OF STAINLESS STEEL (SS316L)-HYDROXYAPATITE (HA) POWDER COMPOSITE THROUGH POWDER INJECTION MOLDING	937
<i>Mohd Ikram Ramli, Abu Bakar Sulong, Norhamidi Muhamad, Andanastuti Mughtar, Amir Arifin, Seong Jin Park</i>	
MACHINABILITY ANALYSIS OF DRILLED BAMBOO FIBRE REINFORCED POLYMER (BFRP) COMPOSITE	943
<i>M F A Zaharuddin, P A A Yunos, Y Jiyounng, A S Mohruni, I Yani, M Yanis</i>	
DETECTING SKIN DEFECTS OF STAR APPLE BY USING HYPERSPECTRAL IMAGES	952
<i>Quoc Thien Pham, Nai-Shang Liou</i>	
THE FABRICATION POROUS HYDROXYAPATITE SCAFFOLD USING SWEET POTATO STARCH AS A NATURAL SPACE HOLDER	958
<i>Gunawan, Amir Arifin, Irsyadi Yani, Sufran Danar Arian</i>	
SELF-IGNITION TEMPERATURE OF PEAT	965
<i>A Taufik Arief, Nukman, Elda Elwita</i>	

ELECTRICAL SCIENCE AND ENGINEERING

ELECTRICAL DESIGN FOR HELIUM PURIFICATION AND SUPPLY SYSTEM OF RDE	973
<i>Kiswanta, E. Sumarno, K. Santosa, K. Indrakoesoema, K. Handono</i>	
ROBOT POSITION CONTROL USING ANDROID	983
<i>A S Handayani, N L Husni, A B Insani, E Prihatini, C R Sitompul, S Nurmaini, I Yani</i>	
ANALYSIS OF DIELECTRIC STRENGTH OF VIRGIN COCONUT OIL AS AN ALTERNATIVE TRANSFORMER LIQUID INSULATION	990
<i>Ansyori, Zainuddin Nawawi, M. Abubakar Siddik, Indra Verdana</i>	
ELECTRICITY LOAD SATURATION ANALYSIS FOR MAKASSAR CITY	999
<i>Yusri Syam Akil, Hendra Pachri, Saiful Mangnggenre, Yusran, Muhammad Azwal, and Jumardin</i>	

EMERGENCY POWER SUPPLY OF CONTROL ROD FOR RDE	1006
<i>Koes Indrakoesoema, Khairul Handono, Edy Sumarno, Kiswanta, Adin Sudirman</i>	
HYDROTHERMAL ECONOMIC DISPATCH USING HYBRID BIG BANG-BIG CRUNCH (HBB-BC) ALGORITHM	1014
<i>Sokun Teng, Yusri Syam Akil, Indar Chaerah Gunadin</i>	
ASSESSMENT OF INPUT PARAMETERS AND ARCHITECTURE OF RDE REACTOR PROTECTION SYSTEM	1020
<i>Sudarno, Sigit Santoso, Kussigit Santosa, Restu Maerani, Deswandri</i>	

CHEMICAL SCIENCE AND ENGINEERING

PRODUCTION OF BIODIESEL FROM WASTE COOKING OIL WITH ULTRASONIC IRRADIATION METHOD AS RENEWABLE ENERGY SOURCE	1028
<i>Agus Lukman Hakim, Martha Aznury, Jaksen M Amin</i>	
SYNTHESIS BIODIESEL FROM WASTE COOKING OIL WITH MICROWAVE IRRADIATION METHOD AS ALTERNATIVE RENEWABLE ENERGY SOURCE	1035
<i>I. Gunawan, M. Aznury, A. Husaini</i>	
1,2-PROPANEDIOL - BETAINE AS GREEN SOLVENT FOR EXTRACTING α-MANGOSTIN FROM THE RIND OF MANGOSTEEN FRUIT: SOLVENT RECOVERY AND PHYSICAL CHARACTERISTICS	1042
<i>K Mulia, Y Yoksandi, N Kurniawan, I F Pane, E A Krisanti</i>	
HYDROGEN RECOVERY FROM CH₄ – H₂ GAS MIXTURE BY ADSORPTION USING COCONUT SHELL-BASED ACTIVATED CARBON	1049
<i>M Sudibandriyo, N A Madiadipura</i>	
THE COMBINED PROCESS OF PYROLYSIS AND CATALYTIC CRACKING OF RICE STRAW USING ZSM-5 AND γ-AL₂O₃ CATALYST PREPARED BY PHYSICALLY MIXING	1056
<i>Aji S Nugraha, RM Ivan Pratama, Setiadi, T S Utami</i>	
EFFECT OF HIGH SPEED HOMOGENIZER SPEED ON PARTICLE SIZE OF POLYLACTIC ACID	1065
<i>K Mulia, A Safiera, I F Pane, E A Krisanti</i>	
TREATMENT OF TOFU INDUSTRY'S WASTEWATER USING COMBINATION OF OZONATION AND HYDRODYNAMIC CAVITATIONS METHOD WITH VENTURI INJECTOR	1070
<i>E F Karamah, A R Primasto, R R Najeges, S Bismo</i>	
FORMULATION, CHARACTERIZATION, AND RELEASE PROPERTY OF ANTIOXIDANT SUPPLEMENT CAPSULE WITH RED GINGER OLEORESIN EXTRACT-LOADED CHITOSAN MICROPARTICLES	1080
<i>K Mulia, U Y Risqi, I F Pane, E A Krisanti</i>	

GEOLOGICAL SCIENCE AND MINING ENGINEERING

IDENTIFICATION OF SANDSTONE LAYER BENEATH THE DEMONSTRATION DISPOSAL SITE AT NUCLEAR SERPONG AREA USING RESISTIVITY GEO-ELECTRICAL METHOD	1090
<i>Sucipta, Bella Septian Lestari, Risdiana Setiawan, Sutrisno</i>	
THE EFFECT OF HEAT TREATMENT ON FATIGUE TESTING OF ALUMINUM CANS	1100
<i>MS Firdaus, Nukman, Irsyadi Yani, Amir Arifin, Prana Arifita, Indra Surya</i>	

ARCHITECTURE AND CIVIL ENGINEERING

EFFECTS OF THE DESIGN PARAMETERS AGAINST SLAB ON GRADE VOLUME USING CORPS OF ENGINEERING DESIGN METHOD	1106
<i>Muhamad Taufik Costarico, Maulid Muhammad Iqbal, Joni Arliansyah</i>	
ANALYZE OF TANJUNG API-API FERRY PORT SERVICE PERFORMANCE SOUTH SUMATERA, INDONESIA	1116
<i>Yossy Marissa, Maulid Muhammad Iqbal, Ika Juliantina</i>	
STRUCTURING OF SLUM SETTLEMENT INFRASTRUCTURE KERTAPATI VILLAGE, PALEMBANG CITY, SOUTH SUMATRA	1126
<i>Ariezki Yuliani, Maulid Muhammad Iqbal, Heni Fitriani</i>	

AN ANALYSIS OF AIR QUALITY THROUGH THE BASIS OF TRAFFIC PERFORMANCE OF SIGNALIZED INTERSECTIONS.....	1140
<i>Emelda Raudhati, Joni Arliansyah, Erika Buchari</i>	
ANALYSIS OF THE INFLUENCE OF TRAFFIC FLOW ON AIR POLLUTION AT SIMPANG ANGKATAN 66 OF PALEMBANG CITY.....	1149
<i>Mei Lisa Adha, Joni Arliansyah, Erika Buchari</i>	
IDENTIFICATION OF DAMAGED INFRASTRUCTURE ON SHEET PILE MUSI AT PALEMBANG CITY.....	1157
<i>Ratih Baniva, Maulid M. Iqbal, Heni Fitriani</i>	
CHANGE OF ELEMENT SETTLEMENT IN MUSI RIVERSIDE PALEMBANG.....	1162
<i>Bambang Wicaksono, Ari Siswanto, Susilo Kusdiwanggo, Widya Fransiska Febriati Anwar</i>	
RELIABILITY ANALYSIS OF SAFETY SYSTEM ON FIRE HAZARD FACTORY BUILDING (STUDY CASE AT PT. SEMEN BATURAJA).....	1170
<i>Dewi Marlina, Heni Fitriani, Ika Juliantina</i>	
DEVELOPMENT OF MAINTENANCE SYSTEM PROCEDURE GOVERNOR OFFICE BUILDING SOUTH SUMATERA PROVINCE.....	1176
<i>Andriansyah, Maulid Iqbal, Mona Foralisa</i>	
STUDY ON DEVELOPMENT OF WATER SUPPLY SYSTEM IN PENUKAL ABAB LEMATANG ILIR REGENCY.....	1188
<i>Rina Anggraini, Maulid Muhammad Iqbal, Sarino</i>	
DETERMINING RENT PRICE OF KASNARIANSYAH FLAT USING ABILITY TO PAY ANALISYS.....	1196
<i>F H Putri, M M Iqbal, I Juliantina</i>	
THE SPATIAL DECISION-MAKING SYSTEM IN MITIGATION OF THE SOUTHERN RING ROAD OF INUNDATION SUB WATERSHEDS.....	1206
<i>Tezar Rizky Abdullah, Dinar DA Putranto, Sarino</i>	
ANALYSIS OF OPEN GREEN SPACE IN THE AREA OF SRIWIJAYA UNIVERSITY INDRALAYA.....	1218
<i>Aries Sandratama, Dinar Dwi Anugerah Putranto, Sarino, Ari Siswanto</i>	
THE INFLUENCE OF OPERATION AND MAINTENANCE ACTIVITIES ON WATER MANAGEMENT OF TINONDO SWAMPS IRRIGATION AREA AT EAST KOLAKA REGENCY, SOUTHEAST SULAWESI PROVINCE, INDONESIA.....	1229
<i>Hesti Wahyu Lestari, Dinar Dwi Anugerah Putranto, Sarino</i>	
THE FINANCIAL FEASIBILITY ON DEVELOPING TERMINAL BUILDING OF SULTAN MAHMUD BADARUDDIN II INTERNATIONAL AIRPORT.....	1236
<i>M Oktari, M M Iqbal, M Agustien</i>	
ANALYSIS OF FLOOD HYDROGRAPH TO THE LAND USE CHANGE ON FLOOD PEAK DISCHARGE IN THE SEKANAK WATERSHED.....	1244
<i>Soraya Ayu Lestari, Dinar Dwi Anugerah, Sarino</i>	
HEALTH AND SAFETY ANALYSIS OF LIGHT RAIL TRANSIT PROJECTS IN PALEMBANG.....	1254
<i>Gafo Rudy Hendrik Aji, Dinar DA Putranto, Ika Juliantina</i>	
MECHANICAL PROPERTIES OF FOAMED CONCRETE WITH ADDITIONAL PINEAPPLE FIBER AND POLYPROPYLENE FIBER.....	1260
<i>T Irawan, Saloma, Y Idris</i>	
AN ANALYSIS OF THE DAMAGE AND ESTIMATED MAINTENANCE COSTS A. ROZAK STREET CITY OF PALEMBANG.....	1267
<i>Bayumi Oktorine, Dinar Da Putranto, Ika Juliantina</i>	
CHARACTERISTICS FOAM CONCRETE WITH POLYPROPYLENE FIBER AND STYROFOAM.....	1275
<i>Falfuady, Saloma, Y Idris</i>	
MECHANICAL PROPERTIES OF FLY ASH-BASED GEOPOLYMER WITH NATURAL FIBER.....	1282
<i>R Zulfiati, Saloma, Y Idris</i>	
EVALUATION OF DESIGN PLANNING WATER DISTRIBUTION SYSTEM WITH WATERCAD V.7.0 SIMULATION PROGRAM FOR TOWNSITE BASECAMP SETTLEMENT RELOCATION IN TANJUNG ENIM, SOUTH SUMATRA.....	1289
<i>Eka Septiawati, Edy Sutriyono, Ika Juliantina, Ari Siswanto</i>	
THE ANALYSIS OF ABILITY TO PAY (ATP) AND WILLINGNESS TO PAY (WTP) ON LIGHT RAIL TRANSIT (LRT) TARIFF IN PALEMBANG.....	1299
<i>M. H. A. Sarwandy, Joni Arliansyah, Heni Fitriani</i>	
EXPERIMENTAL STUDY OF MODEL IN FOLDED PLATE SOFT CLAY.....	1308
<i>Evin Oktavina, Maulid Iqbal, Ratna Dewi</i>	

ANALYSIS OF TRIP ATTRACTION AS LAND USE DEVELOPMENT EFFECT IN PALEMBANG: CASE STUDY ON CINDE TRADITIONAL MARKET	1315
<i>Marice Agustini, Erika Buchari, Melawaty Agustien</i>	
EFFICIENCY ANALYSIS OF SUBAN IRRIGATION SYSTEM, WEST TANJUNG JABUNG, JAMBI PROVINCE	1321
<i>Achmad Rezhani Fitra, Dinar DA Putranto, Sarino</i>	
WATER MANAGEMENT PLANNING FOR SWAMP BUFFALO IN SUB-DISTRICT RAMBUTAN, BANYUASIN REGENCY	1326
<i>Andre Wibowo, Dinar Dwi Anugerah Putranto, Sarino</i>	
ROLE ANALYSIS AND MANDOR FUNCTIONS ON BRIDGE AND BUILDING CONSTRUCTION PROJECTS IN DISTRICT OGAN KOMERING ULU.....	1333
<i>R Vrayudha, M Iqbal, M Foralisa</i>	
THE BUILDING PERFORMANCE OF LIMAS HOUSE; DEALING WITH CURRENT CONTEXT	1346
<i>Widya Fransiska F Anwar</i>	
ANALYSIS OF AIR POLLUTION DUE TO VEHICLE EXHAUST EMISSIONS ON THE ROAD NETWORKS OF BERINGIN JANGGUT AREA.....	1354
<i>Achmad Rizki Pratama, Joni Arliansyah, Melawaty Agustien</i>	
ANALYSIS AND DESIGN OF CRANE BEAM OF EXPERIMENTAL POWER PLANT TURBINE BUILDING	1368
<i>Abdul Hafid, Djati Salimi, Ewitha, Sitti Hijraini Nur</i>	

COMPUTER SCIENCE AND INFORMATION TECHNOLOGY

RICE FARMING AGE DETECTION USE DRONE BASED ON SVM HISTOGRAM IMAGE CLASSIFICATION.....	1376
<i>Marsujitullah, Zahir Zainuddin, Salama Manjang, Aksan Surya Wijaya</i>	
A COMPARATIVE STUDY OF THE ALGORITHMS FOR PATH FINDING TO DETERMINE THE ADVERSARY PATH IN PHYSICAL PROTECTION SYSTEM OF NUCLEAR FACILITIES	1383
<i>D. Andiwijayakusuma, A. Mardhi, I. Savitri, T. Asmoro</i>	
AN APPROACH IN AUTO VALUING FOR OPTIMAL THRESHOLD OF VIOLA JONES	1388
<i>Indrabayu, Nurzaenab, Ingrid Nurtanio</i>	
STUDY IN DEVELOPMENT OF CANS WASTE CLASSIFICATION SYSTEM BASED ON STATISTICAL APPROACHES	1397
<i>Y Resti, A.S. Mohruni, T. Rodiana, D.A. Zayanti</i>	
PERSONAL IDENTIFICATION USING VOICE RECOGNITION WITH NEURO FUZZY METHOD	1402
<i>Ariyawan Sunardi, Rezky Mahardika, Sunarko, Heri Suherkiman</i>	

FOOD AND AGRICULTURAL SCIENCE, NATURAL RESOURCE SCIENCE

IDENTIFICATION OF SETTLEMENT IN THE AREA SITE RDE AND IT'S SURROUNDING FOR SOCIAL ENGINEERING EVALUATION	1412
<i>Heni Susiati, Habib Subagio, Mudjiono, Siti Alimah, Dimas Irawan</i>	
Author Index	

Challenges in Turbine Flow Metering System: An Overview

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Abstract. This paper presents an overview of turbine flow meter (TFM). State of the art, the basic concept of TFM, and some parameters that influence the robustness of TFM are described. In addition, some challenges that occurred in TFM that can affect the accuracies of the measurement are also analysed. The different meter reading between the manual metering or turbine stand meter and Electronic Volume Corrector (EVC) that occurs in turbine flow meter in oil and gas industries is one of TFM challenges. This difference leads to losses in customers or in industries themselves. A notification system is proposed in this paper. An intelligent system that can determine the occurrence of the error will be embedded to the system. It is hoped that by having the earlier notification, the losses can be decreased.

Keyword: Artificial Intelligence, Electronic Volume Corrector, Meter Bouncing, Notification, Turbine Flow Meter

1. Introduction

Measuring fluid flow rate (gas or liquid) in real-time becomes one of the most important things in many applications, such as in industry, oil and gas trade, health [1], and other applications [2]. The characteristic of the fluid that is able to change easily in different ways made it become not always remain stable. To overcome this problem, a flow meter with high precision and fast response is of significant need. There were a lot of flow meter types that have been invented by previous researchers; some of them are coriolis [3], venturi [4], orifice [5], ultrasonic [6], and turbine [7] flow meter.

Turbine flow meter has been investigated for a decade due to the economy of installation, low maintenance costs [8], compact (with small size), high stability, precision [7], direct volume readout and wide measurement range [9]. It has succeeded to measure not only the liquid but also the gas. It can be used to measure the billing meter for water and gas flow in private house, office, hotels, apartment complexes, and other commercial buildings. It can also be applied to measure the oil in upstream and downstream of refineries or process liquid in industrial and pharmaceutical chemicals [10]. In conducting the measuring tasks, the turbine flow meter should offer a good performance. It should provide a correct measurement. However, the flow condition in the pipelines usually shows its consistency. The fluid supply and demand fluctuated every time [11]. It could decrease the performance of the turbine flow meter. Therefore, a robust turbine flow meter is really needed.

The accuracy of the flow meter can be obtained using accurate calibration. Turbine flow meter must be properly and periodically calibrated [12]. Unfortunately, even with a well installed and calibrated, turbine flow meters sometimes showed bad performances [13]. Error deviation that is



disadvantageous always occurs as its effects. This paper has an objective to analyze the challenges that cause incorrect measurements of turbine flow meter.

2. Turbine Flow Meter Technology

Previous researchers introduced some flow meters that can handle the measurement of the fluid. In general, the flow meters can be categorized into 2 groups, i.e. inferential and positive displacements [5]. In other researches, they were divided into many classifications, such as: (i) proposed by Furio [9] that divided the flow meter into 3 groups, i.e. inferential, differential pressure and positive displacements; (ii) introduced by Richard [14] that classified the meters into 3 groups, i.e. pressure differential meter, insertion volume, and mass; (iii) presented by Frenzel [15] that grouped the flow meters into 2 main classes (Figure 1). In Frenzel's classification, the division of the groups is based on 2 criteria, namely 1) in closed pipe lines and 2) open channel and free surface pipe lines.

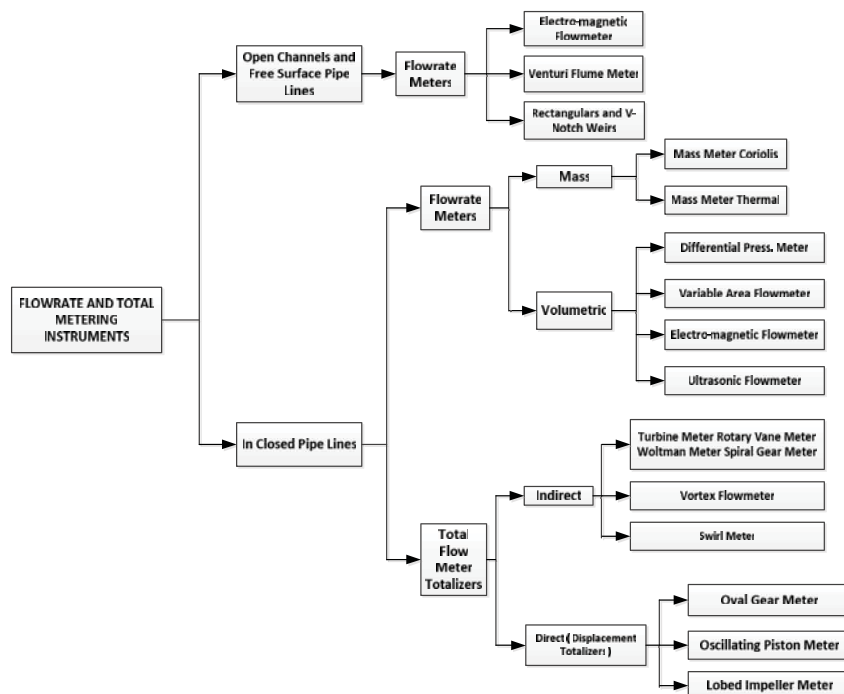


Figure 1. Classification of Flow Meter

The inferential flow meter usually does not measure the volume, velocity or mass directly, but measures flow by inferring its value from other measured parameters, in other word this metering measures the rate of the flow [5]. That is why some references categorize the inferential flow meter as indirect flow meter that measures gas flow volumes by counting the revolutions of the rotor [16]. Flow meters that included as inferential flow meters are: orifice, ventury, flow nozzle, pitot, dall tube.

Differential pressure meters are devices that derive the volumetric flow rate through the measurement of a difference of static pressure between two suitable pressure taps. They work based on the pressure differences that depends on the Bernoulli's theorem and the continuity equation. Some examples of differential pressure meters are orifice plates, nozzles, rotameter, etc.

Positive Displacement meters are actually counter meters. It separates the incoming gas into a series of known discrete volumes and then totalizes the number of volumes. This meter directly measures the volume of the fluid that passed through a pipe. Some examples of positive displacement meters are rotary piston, gear, helical, weir, sluice gate, open channel flow meter, and diaphragm flow meter.

2.1. State of The Art Turbine Flow Meter

The history of turbine flow meter started when the first turbine flow meter was invented by Reinhard Woltman in 1790 [10] [12]. Most of the researchers in that time focused on analyzing the turbine flow meter in steady flow [17]. In 1960, the topic of the researches was shifted to the design the blade shape of the turbine flow meter. Some of the researchers also established some mathematical model of the rotation of the impeller in order to analyze the torque on different part of blade. By having numerical method, the development cycle of new products could be shortened and the cost of the development could be reduced [1]. However, the model still could not describe the internal flow field and the velocity distribution [12]. Moreover, during rotation process of the blade, its precision calculation was also affected by many phenomena, such as separation, whirlpool and reflux [12]. Recently, most of the researches were interested in two research scopes, including the numerical simulation technology and turbine flow meter calibration and measurement (see Table 1). Most usable simulation software in flow meter was computational Fluid Dynamic (CFD). It is a tool for simulating many applications with high accuracy and flexibility.

Table 1. Recent Turbine Flow Meter Researches

Year	Author	Technique/method	Results/Advantages	Type	Ref
2013	Suna Guo	CFD simulation	viscosity and linearity error increased; average meter factor of turbine flow meter decrease	Experiment/Simulation	[2]
2014	Z. Saboohi	Finite difference calculation and CFD simulation	Accurate Result	Simulation	[18]
	Y. Z. Huang	Cavitation modeling	Could predict the cavitation	Simulation	[8]
	Paul W. Tang	Describe some factors that affected the error occurred in the measurement	Offered an accuracy measurement by using optimization	Experiment/Simulation	[16]
	Xin Jin	Mathematical modeling using AMESim	Could manage the high frequency oscillation	Simulation	[19]
2015	Pedišius Nerijus	Comparing the measurement and rotary vane and turbine flow meter	Forecast measurement accuracy	Experiment/Simulation	[20]
	LI Dong-hui	Drift-flux model	Could manage the error	Simulation	[21]
	Furio Cascetta	Addition new original formulae	on-off cycles influenced the extra rotation	Experiment/Simulation	[9]
	Carl L. Tegtmeier	CFD modelling	Steady state rotor speed	Simulation	[12]
2016	Mohammed Liaket Ali	Design and build TFM using Arduino	precise result with 3% error	Experiment	[22]
	Guo Suna	CFD	Showed the optimal flow meter performance	Simulation	[23]
2017	Y. Yuang	workbench	adaptive measurement	Modelling/Simulation	[7]
2018	Z. Džemić	High Frequency Signal	Suggest a good dynamic response	Experiment/Simulation	[24]

Many researchers tried to make new design and optimization of turbine flow meter. Tegtmeier in [12] analyzed the calibration of gas turbine using CFD. A model was established to imitate the real experiment of turbine flow meter. A variation of the flow rate, viscosity, and density was set up in order to reach a stable rotor speed. The model gave some results that can be used to improve the turbine flow meter in the future [12]. Some other researchers that used CFD in their researches can be seen in Table 1.

For the real design, it can be seen in research proposed by Ali in [22]. The research showed a design of turbine flow meter that could record the flow rate and the temperature of fluid. The design

managed to measure the flow of the fluid by utilizing the opto-sensor that grabbed the rotation of turbine and transmitted the pulse signal to the microprocessor. The error produced by the design was really small (3%).

2.2. Turbine Flow Meter Basic Concept and Equation

The turbine meters can be used to measure various flow rates, operating pressures up to 10,000 pounds per square inch, temperature range of -450° to 1000°F [8]. Turbine flow meter in basic concept utilizes the spin of the rotor. The rotor spins when fluid passes through them. The force of the fluid current makes the rotor to spin. Therefore, the rotor in general rotates proportionally to the flow rate. For detecting the rotational speed of the rotor, a pick off sensor is needed. Typically, the pick off sensor is equipped with a magnet and rotating conductor. This magnet has a chance to count the rotation of the rotor of the turbine [10]. When plate blades cut through the flow helically, the value of velocity v and frequency f , can be generated using equation (1) and (2) [25]. In its application, turbine flow meter consisted of many types, as shown in Table 2 [10].

$$v_a = \frac{v}{\tan \beta} \quad (1)$$

$$f = \frac{N \tan \beta v_a}{2\pi r} \quad (2)$$

where v_a is the axial velocity, v is the blade velocity, β is the blade angle, N is the number of the blade, and r is the radius of the blades.

Table 2. Flow meter Turbine Types [10].

No.	Type	Principles	Application
1	Axial	The rotor of this type revolves around the axis of flow	industrial liquid, oil or gases measurement
2	Single Jet/ Multi Jet	It has orifices that lead the fluid into blades so that it turns.	municipal, commercial, and industrial water measurement
3.	Paddlewheel	The paddlewheel is light and the blades are flat. The blade spins to flow rate proportionally	to measure low-speed flows
4.	Pelton wheel	It is almost the same with paddlewheel, but it has a single size rotor and the blade is straight	to measure low flow rates of low-viscosity
5.	Propeller	The blade is helical-shaped. This type has longer and fewer blades than the other type	to measure dirty fluid
6.	Woltman	The axis of the turbine is in line with the flow direction	to measure larger volume

2.3. Parameters in Turbine Flow Meter

2.3.1. Viscosity

Viscosity is one of important factors in turbine flow meter performance. When the viscosity is low (1 cSt (centistokes) or below, as in water), the response of the flow meter depends on the flow rate linearly [12]. However, when the viscosity is high (20 to 100 cSt, as in hydraulic fluid), the response of the flow meter is really non-linear [12]. Tegtmeier [12] analysed the effect of viscosity to the turbine flow meter measurement. The result of the research could be very useful for calibrating and designing turbine flow meters.

The viscosity exists not only in liquid but also in gases. The values are appreciably smaller than for liquids and increase with temperature [15]. It is contradictive with liquids where its viscosity reduces with increasing temperature [15]. The viscosity has a tight relation with pressure and temperature. The increasing of viscosity affected the decreasing of the pressure. Therefore, an additional energy is needed to increase the pressure, so that the fluid can manage its rate of flow [26]. Meanwhile, the increasing of the temperature will decrease the absolute viscosity. Thus, the turbine flow meter performance will also be affected by the temperature [26].

Turbine flow meters that are usually used to measure high flow rate are needed to be calibrated for atmospheric pressure. The kinematic viscosity will decrease as the effects of the gas density growth due to the increasing of pressure. This condition leads to the difficulty of extrapolating the laboratory calibration result to operating conditions [20]. The ratio for absolute viscosity to density in equation (3) is called Kinematic Viscosity (ν) [26].

$$\nu = \frac{\mu}{\rho} \quad (3)$$

where, ν is kinematic viscosity; μ is absolute viscosity; and ρ is density

2.3.2. Reynold Number

According to Paul [16], Reynolds number (Re) is a dimensionless ratio that related to the gas flow rate, the meter run diameter, and the properties of the gas. For low Re (below 2000) where the viscous forces are dominant, the flow laminar will take place. In contrast, when the Re is high (above 4000), the turbulent flow will occur due to the domination of inertial forces. For Re between 2000 and 4000, a transitional state will dominate. In this condition, the system shows its instability.

The Re can be calculated using the equation (4):

$$Re = \frac{\rho v D}{\mu} \quad (4)$$

where, ρ is density; v is velocity; D is diameter; and μ is dynamic viscosity.

To reach the dynamic similarity of fluid flow, many researchers took into account a Reynolds number [24], [16]. When the same Re was exposed to an object, the characteristics of that object would be the same. For instance: with the same Re, the rotation of the rotor in a turbine meter would have same angular velocity [24].

2.3.3. Cavitation

Cavitation in a turbine flow meter refers to an empty space that occur due to the decreasing of local pressures near or below the vapor pressure [8]. It can cause the rotor to speed up at the high flow rate due to the increased flow volume and causes the accuracy curve of the turbine flow meter to be adversely affected [8]. Navier-Stokes equations in equation (5)–(8) are the most common formulas used in describing the cavitation models. Equations (5), (6), (7), and (8) are mass conservation, momentum equation, transport equation for cavitation dynamics of vapor volume fraction, and mass transfer.

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_j} (\rho u_j) = 0 \quad (5)$$

$$\frac{\partial (\rho u_i)}{\partial t} + \frac{\partial}{\partial x_j} (\rho u_j u_i) = \rho g_i - \frac{\partial \rho}{\partial x_i} + \frac{\partial \tau_{ji}}{\partial x_i} \quad (6)$$

$$\frac{\partial \alpha_v \rho_g}{\partial t} + \frac{\partial}{\partial x_j} (\alpha_v \rho_g u_j) = S \quad (7)$$

$$S = \dot{m}^+ + \dot{m}^- \quad (8)$$

Where:

$$\dot{m} = \dot{m}^+ + \dot{m}^- = \left(\frac{2\xi}{2-\xi} \right) \left(\frac{M}{2\pi R} \right)^{\frac{1}{2}} \left(\frac{P_v}{\sqrt{T}} - \frac{P}{\sqrt{T}} \right) A \quad (9)$$

2.3.4. Calibration

Calibration means improving the reading of meters by comparing the measurement of the device with the standard one [27]. Some settings that are trained to the device are really needed to enhance the calibration result. Calibration techniques that are frequently used are presented in Table 3.

Table 3. Calibration Techniques

No.	Calibration Techniques	Drawbacks	Ref
1.	Hydrocarbon flow meter calibrations, the standard Stoddard solvent	volatile and poses an environmental and health risk to those performing the calibrations.	[12]
2.	A mixture of propylene glycol and water	the density of the propylene glycol and water mixture is 15% higher than that of the volatile fluid.	[12]
3.	Physical models for the turbine meter calibration curve based on momentum and airfoil approaches	should be supplemented with experimental correction factors to improve accuracy.	[12]
4.	UVC (Universal Viscosity Calibration)	– only for the linear range. – it does not compensate for other temperature and pressure effects such as flowmeter body expansion	[26]
5.	Adaptive Calibration of Turbine Flow Measurement using ANN	A simulation experimental only, not the real one	[28]

3. Challenges in Turbine Flow Meter

Common troubles that always occur in turbine flow meter are usually caused by the cavitation, viscosity, debris on rotor stator, mechanical vibration, and faulty pick up [29]. Cavitation can make the turbine flow meter misread the actual flow rate; the value becomes higher or lower than the real one. The lower reading of the flow meter indicates that there is higher viscosity that occurs in the flow, while the lower one shows that there may be gas which presents in the flow. To overcome those problems, the meter should be cleaned or recalibrated [29]. General detail troubles, causes, and how to resolve the problems in turbine flow meter are presented in Table 4.

Table 4. Troubles, cause and remedy [29]

Trouble	Possible Cause	Remedy
Meter indicates higher than actual flow rate	– Cavitation	– Increase back pressure
	– Debris on rotor support	– Clean meter
	– Build-up of foreign material on meter bore	– Clean meter
	– Gas in liquid	– Install gas eliminator ahead of meter
Meter indicates lower than actual flow rate	– Debris on rotor	– Clean meter and add filter
	– Worn bearing	– Clean meter and add filter
	– Viscosity higher than calibrated	– Recalibrate monitor
Erratic system indication, meter alone works well (remote monitor application only)	Ground loop in shielding	Ground shield one place only. Look for internal electronic instrument ground. Reroute cables away from electrical noise
Indicator shows flow when shut off	Mechanical vibration causes rotor to oscillate without turning	Isolate meter
No flow indication. Full or partial open position	Fluid shock, full flow into dry meter or impact caused bearing separation or broken rotor shaft	Rebuild meter with repair kit and recalibrate monitor. Move to location where meter is full on start-up or add downstream flow control valve
Erratic indication at low flow, good indication at high flow	Rotor has foreign material wrapped around it	Clean meter and add filter
No flow indication	Faulty pick-up	Replace pick-up
System works perfect, except indicates lower flow over entire range	By-pass flow, leak	Repair or replace by-pass valves, or faulty solenoid valves
Meter indicating high flow, upstream piping at meter smaller than meter bore	Fluid jet impingement on rotor	Change piping
Opposite effects of above	Viscosity lower than calibrated	Change temperature, change fluid or recalibrate meter

Troubles that occur in the turbine flow meter will affect its accuracies. The accuracies that are affected by real world implementation become one of challenges in turbine flow meter. According to Mark [13], some errors in measurement occur due to 3 factors, namely: 1. environmental temperature, 2. low static pressures, and 3. calibration before every tests. Some suppliers of the flow meter provide a standard spreadsheet to calculate the flow meter error using Microsoft Excel as shown in Figure 2.

The calculation using AGA 7 standard (in Figure 2) can be established by reading the screenshot data in stand meter (Figure 3). The gas parameters, such as volume, pressure, and temperature were then counted using the equation: $\frac{dV_m}{0.3048^3 \rho_{flow}} : 1000$, to get the dV_b value of AGA7. The value of the dV_b of AGA 7 was then compared to the dV_b of Flowcom measurement. The Flowcom used the gas volume data of stand meter from the Gas chromatograph (GC), where the value of volume, pressure and temperature were based on the high frequency (HF) and low frequency (LF) that were read in real time in online system.

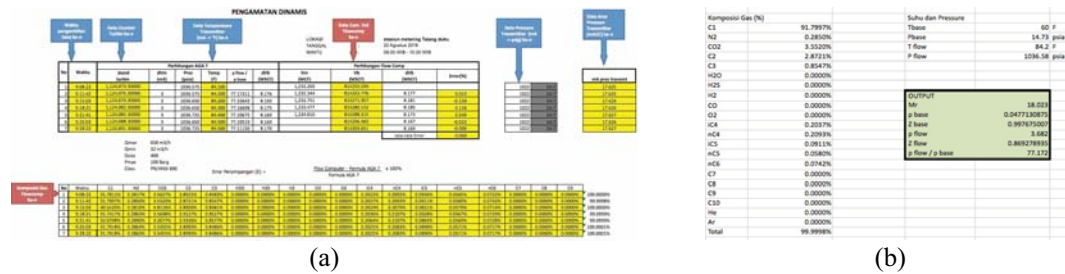


Figure 2. Spreadsheet for calculating the flow meter error

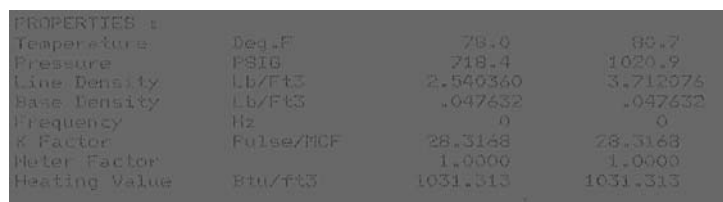


Figure 3. Screenshot data from flow computer

In this research, the gas volume measurement was done using two mechanisms, i.e. 1. using mechanic counter, 2. using electronic. In mechanic counter, the measurement was based on the mechanical gear. When the flow of the fluid passed through the gear, the rotation of the gear was then connected to a pulse counter (stand meter). This meter was read every week. In electronic, there are two ways of reading the pulse counter, namely high frequency (HF) and low frequency (LF). In LF, a reed switch with a magnetic principal mechanism was used as the pulse counter. Its principal works was similar to the contactors that generates the ON and OFF. In HF, a special sensor was used. The value of < 6.65 , indicates that $k = 0.1 m^3$, the value of $6.65 - 6.100$, indicates that $k = 1 m^3$, and the value of > 6100 , indicates that $k = 10 m^3$. The measurement of LF and HF were done using EVC using online system by EVC and sent to the control center using Automatic Meter Reading (AMR). The dynamic test using LF is used due to it has less error than HF (figure 4). However, using LF can cause different reading between stand meter and flow com. The quality of the magnet determines the difference occurred in them. In some applications, some industries prefer HF to LF.

In oil and gas industries, the different meter reading between the manual metering or turbine stand meter and Electronic Volume Corrector (EVC) that occurs in turbine flow meter is called as meter bouncing. In general, they usually show different calculation. Manual metering usually used to display the output of the turbine flow meter. It measures the volume of gas flowing through them without considering its variation. In its application, to compensate the variation of volume that occurs due to the pressure and temperature changing of gas flow, the natural gas industries use EVC. By having EVC, true volume of natural gas that flows through the turbine flow meter can be calculated

correctly. In general, the EVC calculates the electronic signal output obtained from the turbine flow meter and makes the correction of the volume based on AGA7 and AGA8 [30]. One of the examples of meter bouncing can be seen in Table 5 while the meter reading of system can be seen in Figure 5.

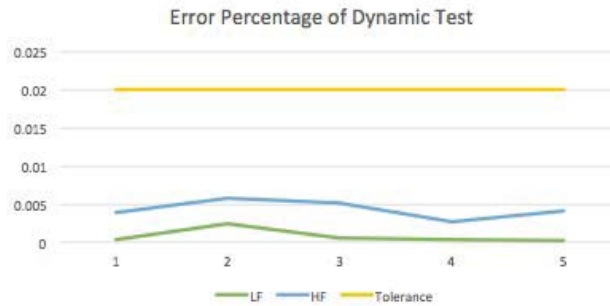


Figure 4. LF and HF error measurement percentage

Table 5. Meter Bouncing example (reprinted with permission of PT. PGN)

No.	Time	Turbine Stand Meter (m ³)	Pressure (BarA)	Temperature (°C)	Meter Reading	
					Manual (AGA 7)	EVC (m ³)
1.	12.14	465246	4.41325	30.03	8.71	8.56
2.	12.19	465247	4.21325	30.01	4.16	4.30
3.	12.24	465249	4.21325	30.01	8.31	8.62
4.	12.29	465250	4.31325	30.01	4.26	4.28
5.	12.34	465252	4.31325	29.99	8.51	8.42
6.	12.39	465253	4.31325	29.99	4.24	4.17
Average/Total			4.3133	30.02	38.02	38.35

From Table 5, the reading meter difference can be calculated using equation (6)

$$\text{Difference} = \frac{\text{EVC} - \text{Manual}}{\text{Manual}} \times 100\%$$

The difference was found 0,4 %.

The correction of meter misreading was then done as shown in Figure 5. It shows the meter reading of manual and EVC. Figure 5 (a) shows the condition of turbine stand mater. In that correction, the stand mater turbine showed the value 465253.0 m³, with pressure 3.3 BarG and temperature 30 °C (Figure 5. (b) and 5 (c)), while the EVC showed the base volume 38.35 m³, with primary volume 465253.0 m³, pressure 4.2419 BarA, and temperature 29.98 °C. Number of bouncing accidents in 2016 and 2017 can be seen in Figure 6 (a) and (b).

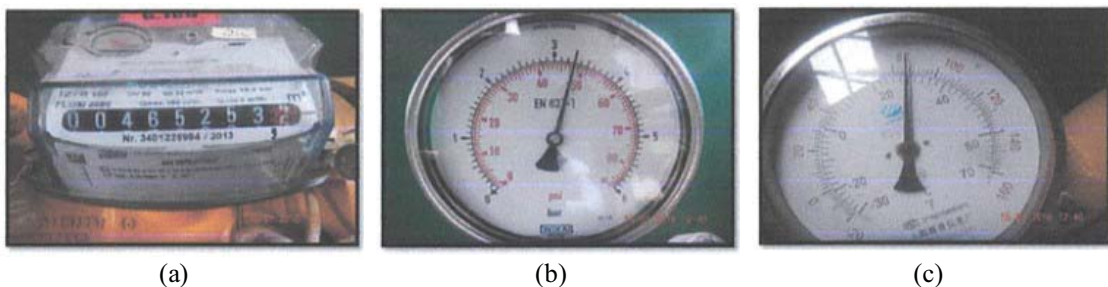


Figure 5. The display of meter reading (a) turbine stand meter; (b) pressure; (c) Temperature (reprinted with permission of PT. PGN)

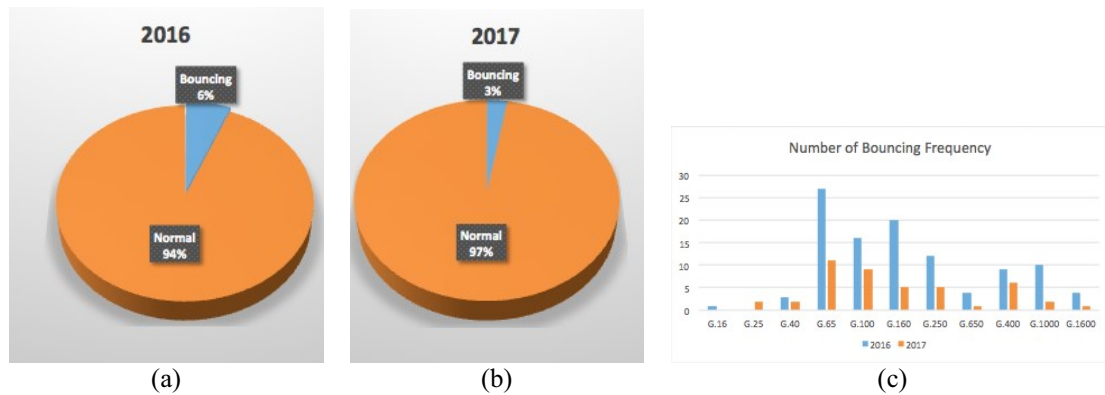


Figure 6. Bouncing percentage (a) 2016, (b) 2017, (c) Bouncing frequency

4. Proposed Research

To overcome the problem of meter bouncing, the author proposed a system that can minimize the error by making a system that has an ability to notify its occurrence. An Intelligent system will be added to the system. The signal from the flow meter, the pressure, and the temperature of the systems will be inputted to the fuzzy logic controller. Fuzzy will determine and decide whether the error reading between the stand meter and the EVC has occurred and send the output to the server. Fuzzy logic controllers has been widely used in various applications, such as for reaching a target [31], [32], navigating [33], [34], controlling robots [35], localizing odor [36], maintaining formation [37]. However, only little researchers who are interesting in using artificial intelligence in flow meter research.

The notification will be very useful to make correction to the error in meter reading. The faster the notification, the faster the error correction will be. When the notification has warned the system that the error has occurred, a correction factor to the EVC can be done by re-inputting the value to the system.

5. Conclusion

Some challenges occurred in TFM still become complicated problems. Although it seems only as a little problem, however, its occurrence has affected the losses in customers and industries. Thus, some strategies should be built. A notification system is proposed in this paper. An intelligent system that can determine the occurrence of the error will be embedded to the system. By having this notification, a correction can be done earlier. It is hope that the earlier the correction, the more minimum losses would be.

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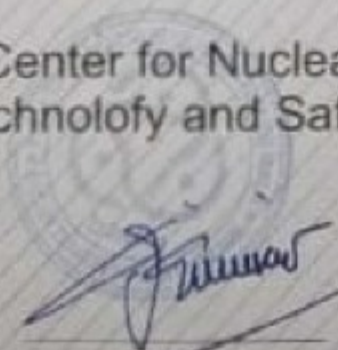
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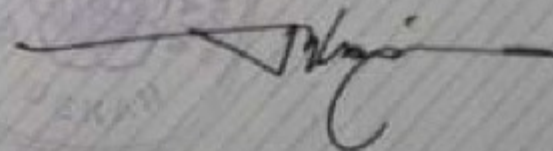
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