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(2009)
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[No.13 No.14 No.15 No.16 No.17 No.18 No.19 No.20 21-22 23-24](#) (2010)
- ✚ [Vol.](#)
[6 No.1 No.2 No.3 No.4 No.5 No.6 No.7 No.8 No.9 No.10 No.11 No.12 No.13 No.14](#)
[No.15 No.16 No.17 No.18 No.19 No.20 No.21 No. 23-24](#) (2011)
- ✚ [Vol. 7 No.1 No.2 No.3 No.4 No.5 No.6 No.7 No.8 No.9 No.10 No.11 No.12](#) (2012)
- ✚ [Vol. 8 No.1](#)
[No.2 No.3 No.4 No.5 No.6 No.7 No.8 No.9 No.10 No.11 No.12 No.13 No.14](#)
[No.15 No.16 No.17 No.18 No.19 No.20](#) (2013)
- ✚ [Vol.9 No.1 No.2 No.3 No.4 No.5 No.6 No.7 No.8 No.9 No.10 No.11 No.12 No.13](#)
[No.14 No.15 No.16 No.17 No.18 No.19 No.20 No.21 No.22 No.23 No.24](#)
[Vol.10 No.1 No.2 No.3 No.4 No.5 No.6 No.7 No.8 No.9 No.10](#)
[No.11 No.12 No.13 No.14 No.15 No.16 No.17 No.18 No.19 No.20 No.21 No.22](#)
[No.23 No.24](#) (2015)
- ✚ [Vol. 11 No.1 No.2 No.3 No.4 No.5 No.6 No.7](#) (2016)
- ✚ [Special Issues](#)
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International Journal of Applied Engineering Research (IJAER)

Volume 11, Number 4 (2016)

CONTENTS

[Comparison evaluation of Particle Swarm Optimization and Genetic algorithm for adaptive beam forming of uniform linear array applications](#)

pp 2157-2160

K. Sridevi and A. Jhansi Rani

[Multiresolution based detection of Macular Degeneration](#)

pp 2161-2164

Lakshmipriya R, Padmapriya N and Hanis S

[A Study and analysis on Web Information Retrieval System for Distributed Environment](#)

pp 2165-2176

S. Meenakshi and R. M. Suresh

[Free Radical Polymerization of Methyl and Ethyl Methacrylates by Green Methodology](#)

pp 2177-2184

M. Meena, S. Nanjundan and M. J. Umapathy

[Shaping of Arts and Crafts Objects Using Computer Graphics](#)

pp 2185-2190

Larisa Vladimirovna Shokorova and Lyubov Nikolaevna Turlyun

[Automated monitoring system for asphaltene-resin-paraffin deposits in main oil pipelines](#)

pp 2191-2198

Alexandra Vladimirovna Kopteva and Vladimir Yurievich Koptev

[Fractional Order Automatic Generation Controller For A Multi Area Interconnected System Using Evolutionary Algorithms](#)

pp 2199-2205

Ravi Kumar. Chekka and P. V. Ramana Rao

[On the Issue of the Innovation Policy at the Road Transport Enterprises](#)

pp 2206-2211

Anna Leonidovna Zaytseva and Tatiana Anatol'yevna Menukhova

[The Effect of Oral Exercise on Oral Health and Subjective Experience of Oral Function among Elderly in Care Hospital](#)

pp 2212-2215

Eun-kyong Kim and Eun Young Park, Dong Fan and Hee-Kyung Lee

[Need of Smart Water Systems In India](#)

pp 2216-2223

Aditya Gupta, Sudhir Mishra, Neeraj Bokde and Kishore Kulat

[Performance Variation of Support Vector Machine and Probabilistic Neural Network in Classification of Cancer Datasets](#)

pp 2224-2234

Kalagotla Satish Kumar and Tummala Sitamahalakshmi

[Classification of PD Defects in Gas Insulated Switchgears under HVDC](#)

pp 2235-2239

Sung-Wook Kim, Jae-Ryong Jung, Guoming Wang, Sun-Jae Kim and Gyung-Suk Kil

[Effect of Carbon Dioxide on Flame Characteristics in Biogas External Premix Combustion](#)

pp 2240-2243

Fandi D. Suprianto, Willyanto Anggono and Michael S C Tanoto

[Biogeography Based Reconfiguration Algorithm for Voltage Stability Enhancement of Distribution Networks](#)

pp 2244-2249

S. Aruul Vizhiy and R. K. Santhi

[Joint Algorithm for Energy-Conservation and Secure Key Generation in Wireless Sensor Network](#)

pp 2250-2257

Roopashree H. R. and Anita Kanavalli

[An Entropy Based Approach for Risk Factor Analysis in a Software Development Project](#)

pp 2258-2262

Pradnya Purandare

[MZDF: An Energy Aware Framework for Multiple-Zone Data Fusion Technique in WSN](#)

pp 2263-2270

S G Shivaprasad Yadavd and A Chitra

[Application of The Hydrocuff Technology For Blood Pressure Evaluation](#)

pp 2271-2274

M. S. Gerashchenko, S. M. Gerashchenko, S. I. Gerashchenko and N. N. Yankina

[Students' Employability Prediction Model through Data Mining](#)

pp 2275-2282

Tripti Mishra, Dharminder Kumara and Sangeeta Gupta

[A Novel Method of Designing and Implementation of Security Challenges in Data Transmission and Storage in Cloud Computing](#)

pp 2283-2286

Sreedhar Acharya B and M. Siddappa

[Analysis of an Efficient 64-Bit Carry Select Adder with Less Delay and Reduced Area Applications](#)

pp 2287-2290

Krishna Naik Dungavathdd and V. Vijayalakshmi

[A study of environmental factors affecting indKustrial sustainability using ISM and MICMAC Methodology](#)

pp 2291-2297

Archana Singh, Nehajoan Panackal and Adya Sharma

[An Integrated Switching Technique for Minimizing Power Consumption Using MDFSD in Domino Logic System](#)

pp 2298-2304

J. Muralidharan and P. Mamimegalai

[Topic Trend Prediction for Learning Objects Using Kernel Fuzzy C Means Clustering and Autoregressive Integrated Moving Average Model](#)

pp 2305-2313

E. A. Vimal and S. Chandramathi

[Development of a Programmable Mobile Robot](#)

pp 2314-2320

Ademola Abdulkareem, C.O.A. Awosope, S. A. Daramola and E. C. Nnorom

[CAD for Detection of Fetal Electrocardiogram by using Wavelets and Neuro-Fuzzy Systems](#)

pp 2321-2326

Pradeep Kumar, Sudhir Kumar Sharma and Sidheshwar Prasad

[Heuristic Approach for Optimizing the localization of wireless sensor Networks](#)

pp 2327-2331

A. Tamizharasi and A. Kavi Priya

[Methodical Advances in Power Systems aimed at Best Arrangement of Distributed Generation Sources](#)

pp 2332-2339

S. Jayalakshmid and V. Balaji

[Corpus-Based Studies – Some Perspectives](#)

pp 2340-2342

P. Aswini and R. Srinivasan

[Analytical Solution of Vertical Plate in a rotating fluid with variable Temperature, Uniform Mass Diffusion in the Presence of MHD and Thermal Radiation](#)

pp 2343-2348

A. R. Vijayalakshmi and J. Ravikumar

[Multiobjective Optimal Reactive Power Flow Using Chemical Reaction Based Optimization](#)

pp 2349-2353

G. K. Moorthy, R. K. Santhi and Alamelu Nachiappan

[A Review on Electrochemical Machining Processes](#)

pp 2354-2355

K. Raja and R. Ravikumar

[Composition of Capital Inflows Into India During 1991-92 to 2009-2010](#)

pp 2356-2358

G. Raja Rajeswari

[Design and Analysis of An Enhanced SHA-1 Hash Generation Scheme for Android Mobile Computers](#)

pp 2359-2363

bh. Padma and GVS Raj Kumar

[A Comparative Analysis of Flow Boiling in Micro-Gaps with Internal Micro-Fins of Rectangular and Triangular Profiles](#)

pp 2364-2372

Shugata Ahmed, Ahmad Faris Ismail, Erwin Sulaeman and Muhammad Hasibul Hasan

[Improving QoS of TCP/IP Sensor Networks Using Novel Gateway Approach](#)

pp 2373-2378

K. Satya Rajesh and P. Suresh Varma

[Use of Oil Palm Shell as Replacement of Coarse Aggregate For Investigating Properties of Concrete](#)

pp 2379-2383

Khan M. M. H, Guong Wei L, Deepak T. J and Nair S

[Safety Related Services Using Smart Vehicle Connections](#)

pp 2384-2387

R. Thenmozhi and S. Govindarajan

[Speech to Text Synthesis from Video Automated Subtitling using Levinson Durbin Method of Linear Predictive Coding](#)

pp 2388-2395

Sathish Kumar Selvaperumal, Chandrasekharan Nataraj, Vinesh Thiruchelvam and Willy Tong Chen Hung

[Combining Artificial Neural Network with Image Data Partitioning for Personal Iris Recognition System](#)

pp 2396-2401

D. Elantamilan, V. Saishanmuga raja and S. P. Rajagopalan

[New Uniform Order Single Step Hybrid Block Method for Solving Second Order Ordinary Differential Equations](#)

pp 2402-2406

Zurni. Omar and Ra'ft. Abdelrahim

[Solving Two-Point Second Order Boundary Value Problems Using Two-Step Block Method with Starting and Non-Starting Values](#)

pp 2407-2410

Zurni Omar and Oluwaseun Adeyeye

[A Survey on Machine Learning Approaches to Social Media Analytics](#)

pp 2411-2416

Magesh. S and Nimala. K

[Statistical Analysis of Precipitation over Seonath River Basin, Chhattisgarh, India](#)

pp 2417-2423

Mani Kant Verma, M. K. Verma and Sabyasachi Swain

[Image Based Autonomous Navigation for a Lander](#)

pp 2424-2428

V. Bagyaveereswaran, Neeraj Nair Rajagopal and R. Anitha

[Investigation of Concrete Beam Behavior in FRP Composite Layering Under Incremental Loading](#)

pp 2429-2435

Mohammadreza Zarringol and Mohammadehsan Zarringol

[Extended Approach for Self Ordered Feature Reweighting for Relevance Feedback in CBIR Systems](#)

pp 2436-2450

Kranthi Kumar. K and T.Venu Gopal

[Toward Semantic Web Using Personalization Techniques](#)

pp 2451-2453

Sinan Adnan Diwan

[Matrix Graph III: The graphs of the symmetric group ????](#)

pp 2454-2457

S. Peninal Dhanamani and R. Stella Maragatham

[Business Intelligence as a Service in Analysis of Academic Courses](#)

pp 2458-2467

V.S. Akshaya and T. Purusothaman

[An Overview of Performance Evaluation of Inter Vehicular Ad hoc Networks \(VANET's\) Handovers by the Use of Intelligent Metaheuristic Algorithms](#)

pp 2468-2473

Pravin Wararkar, S. S. Dorle, Ankit Dixit, Chhayadevi Bhamre and Pratiksha Meshram

[Improvement of the quality of development process of E-learning and M-learning systems](#)

pp 2474-2477

Aissaoui Karima and Azizi Mostafa

[Efficient Breast Cancer Classification Using Improved Fuzzy Cognitive Maps with Csonn](#)

pp 2478-2485

D. Thuthi Sarabai and K. Arthi

[Strategy and Planning Model Village Fishermen Coastal Areas in Surabaya](#)

pp 2486-2493

Wiwik Widyo Widjajanti

[Investigation and assessment of the Project Management Methodology in Iraqi Construction Sector](#)

pp 2494-2507

Faiq Mohammed Sarhan Al-Zwainy, Ibrahim Abed Mohammed, Saja Hadi Raheem

[Analysis of an Almost Periodic Reconfigurable Circuits Using Iterative Method](#)

pp 2508-2512

M. Latifa, L. Latrach and A. Gharsallah

[Rough Exact Sequences of Modules](#)

pp 2513-2517

Arvind Kumar Sinha and Anand Prakash

[Power Quality Improvement in Hybrid Power System: Review](#)

pp 2518-2521

M Vivek, P. K. Srividhya and K. Sujatha

[Developing the Reading Skills in English of Students At College Level – A Task-Based Approach](#)

pp 2522-2524

S. Ameer Anisaa and M. A. Mohamed Sahul Hameed

[Residents' Perception of Housing Quality in an Informal Settlement](#)

pp 2525-2535

Akunnaya P. Opoko and Adedapo A. Oluwatayo

[Optimization of Digitalized Document Verification Using E-Governance Service Delivery Platform \(E-SDP\)](#)

pp 2536-2544

Raghunathan V.S, V. Cyril Raj, Sumathy Eswaran, Ambika A and Sangeetha R.U

[Geographic Mismatch between Emergency Patients and the Service Area](#)

pp 2545-2552

Sung Hyo Hong and Junhong Im

[Analytical Implementation of Web Structure Mining Using Data Analysis in Educational Domain](#)

pp 2553-2557

S. P. Victor and M. Xavier Rex

[A Technical Comprehensive Survey of ETL Tools](#)

pp 2557-2559

Vaishali A. Kherdekar and Pravin S. Metkewar

[Efficient Parallel Implementation of Single Source Shortest Path Algorithm on GPU Using CUDA](#)

pp 2560-2567

Dhirendra Pratap Singh, Nilay Khare and Akhtar Rasool

[VLSI Implementation of Discrete Linear Convolution using Vedic Mathematics \(Real and Complex Numbers\)](#)

pp 2568-2571

R. Anitha and Sarat Kumar Sahoo

[Performance Evaluation of Double Stage Filter Algorithm for Stereo Vision Applications](#)

pp 2572-2578

Teo Chee Huat, Nurulfajar Abd Manap, Abd Majid Darsono

[Review Based on Hybrid Renewable Energy Power System for Underrate Cost and Inflate Power](#)

pp 2579-2586

V. R. Vanajaa, D. Priyadharshini and P. Balaji

[Performance and Thermal Analysis of One Shell Two Tube Pass Heat Exchanger with Ethylene Glycol and SIC Nano Fluid](#)

pp 2587-2594

YogithaSeerapu, M.V.Ramana, D.Sreeramulu and C.J.Rao

[Mobile Colored Overlay Application to Korean WRRT With Detailed Color Control](#)

pp 2595-2600

Y. Jang

[Agile Development Methods for Online Training Courses Web Application Development](#)

pp 2601-2606

M. Wasim Raja and K. Nirmala

[An Efficient Offline Tamil Handwritten Character Recognition System using Zernike Moments and Diagonal-based features](#)

pp 2607-2610

Ashlin Deepa R. N and R. Rajeswara Rao

[Evaluation of Two Different Tubular Daylighting Devices in UAE Climate](#)

pp 2611-2614

Omar Akash, Zaki Iqbal and Mousa Mohsen

[A Study on Mitigation Measures for the Development of Neermahal Palace and Surrounding Rudrasagar Lake Area in Tripura, India using Analytic Hierarchy Process](#)

pp 2615-2619

Joyanta Pal, Manish Pal, Pankaj Kr. Roy and Asis Mazumdar

[Ground Water Quality Assessment of Milli Watershed Area in Zaheerabad](#)

pp 2620-2624

M.A. Kalam and M. Ramesh

[Automated Control System for the Milling Unit of Mineral Powders Plant](#)

pp 2625-2628

Andrey Vladimirovich Ostroukh, Igor Vadimovich Nedoseko, Nataliya Evgenievna Surkova and Bulat Galievich Bulatov

[Integration of Optimized GDI Logic based NOR Gate and Half Adder into PASTA for Low Power & Low Area Applications](#)

pp 2629-2633

M. Sivakumar and S.Omkumar

[Context-aware human-centric 3D visual quality classification model Using Machine Intelligence](#)

pp 2634-2636

P. M. Arun Kumar and S. Chandramathi

[Analysis of Cost and Returns from NHAI – A Case Study of Nh45](#)

pp 2637-2639

Prof. Nilavathy. K and N. P. Hariharan

[Shunt Active Correction System Analysis in Conditions of Industrial Enterprises Networks](#)

pp 2640-2645

Boris N. Abramovich and Yuriy A. Sychev

[Image and Vibration Based Mixed Variable Approach For Machining Performance Estimation](#)

pp 2646-2650

Umamaheswara Raju. R. S, V. Ramachandra Raju and R. Ramesh

[Enhancing TCP Performance by detecting spurious RTO in Wireless Network](#)

pp 2651-2657

S.V. Jansi Rani and P. Narayanasamy

[Performance and Emission Analysis of Gasoline Blended Hydrogen Gas Fuel Engine](#)

pp 2658-2662

R. Koushik Srinivas and R. Murali

[A Set Combine Map Method for Manual Synthesis of Logic Circuits](#)

pp 2663-2670

Sahadev Roy and Chandan Tilak Bhunia

[Image Duplication Copy Move Forgery Detection Using Discrete Cosine Transforms Method](#)

pp 2671-2674

M. Buvana Ranjani and R. Poovendran

[Removal of Dye by Adsorption: A Review](#)

pp 2675-2679

Ta Wee Seow and Chi Kim Lim

[An Overview of Ceramic Wastes Management in Construction](#)

pp 2680-2685

Sh. K. Amin, H. A. Sibak, S. A. El-Sherbiny and M. F. Abadir

[On the open sea propagation of 2004 global tsunami generated by the sea bed deformation](#)

pp 2686-2692

Md. Fazlul Karim, D. S. Sankar and Esa Yunus

[Clustering Uncertain Gene Dataset using KLSE \(Kullback-Leibler & Shannon Entropy\) to improve Cluster Quality](#)

pp 2693-2696

S. Vydehi and M. Punithavalli

[Feature Extraction Based Lung Nodule Detection in CT Images](#)

pp 2697-2700

Veerakumar Kuppusamy and Ravichandran C Gopalakrishnan

[A Four-Step Block Predictor-Block Corrector Method for Solving Third Order Ordinary Differential Equations Directly](#)

pp 2701-2704

Z. Omar, Y. A. Abdullah and J. O. Kuboye

[Service Performance Factors Affecting Customer Satisfaction: E-Grocery in Jeddah, Saudi Arabia](#)

pp 2705-2710

Ahmad Hassan J Thabit, Ahmad Suhaimi Baharudin and Kamal Karkonasasi

[Technology Acceptance Factors Affecting Intention to Adopt Geographical Information System \(GIS\) among the Local Governments in West Aceh, Sumatera, Indonesia](#)

pp 2711-2716

Jamal Mirda, Ahmad Suhaimi Baharudin and Kamal Karkonasasi

[Data Mining Framework for Test Time Optimization in Industrial Electronics Manufacturing Enterprise](#)

pp 2717-2722

Thai Chuan Chee, Ahmad Suhaimi Baharudin and Kamal Karkonasasi

[Image force effects between lattice dislocations and interphase boundaries in bicrystals of FCC materials Pb-X, X: Al, Au, Ag, Cu and Ni](#)

pp 2723-2728

A. Ouchtati and O. Khalfallah

[Radiation effects on MHD non-Newtonian power-law fluid past over a non-linearly stretching surface with viscous dissipation](#)

pp 2729-2736

K. Saritha, M.N. Rajasekhar and B. Shashidar Reddy

[Trust in stored data in EHRs acceptance of medical staff: using UTAUT2](#)

pp 2737-2748

Malik Bader Alazzam, Abd. Samad Hasan Basari, Abdul Samad Sibghatullah, Yousif Monadhil Ibrahim, Mohamad Raziff Ramli and Mohd Hariz Naim

[Small-Swing Cross-Coupled Inverters Based Low-Power Embedded Memory in Logic CMOS Technology](#)

pp 2749-2754

Sivasundar Manisankar and Yeonbae Chung

[Slant Correction for Offline Handwritten Telugu Isolated Characters and Cursive Words](#)

pp 2755-2760

Ch. N. Manisha, Y.K. Sundara Krishna and E. Sreenivasa Reddy

[A Fuzzy Parallel Island Model Multi Objective Genetic Algorithm Gene Feature Selection For Microarray Classification](#)

pp 2761-2770

A. Natarajan and R. Balasubramanian

[Optimization of Machining Parameters for Tool Wear Rate and Material Removal Rate in CNC turning by Grey Relational Analysis](#)

pp 2771-2775

Upinder kumar, Abhinavkumar Singh and Rakesh kumar

[Green Roofs for Energy Conservation and Sustainable Development: A Review](#)

pp 2776-2780

Vinod Kumar V and A.M. Mahalle

[Optimum allocation of Renewable DG sources and Synchronous capacitor simultaneously using PSO](#)

pp 2781-2785

R.Sivasangari and N. Kamaraj

[Computational Model for Infill Walls under Cyclic Loads](#)

pp 2786-2790

T. Nelson Ponnu Durai, J. Arunachalam, L. Avinash Karthich, D.C. Haran Pragalath, D. Iswarya and Robert Singh

[Study and Investigation of Complementary Split Ring Resonators \(CSRR\)Metamaterials and Its Application in Microstrip Antenna Design](#)

pp 2791-2795

Hassan M. Elkamchouchi, Ahmed A. Sheshtawy and Ayman I. Almahallawy

[Unconstrained Handwriting Recognition into Text using Parser](#)

pp 2796-2800

Pinagadi. Venkateswararao and S. Murugavalli

[Data Visualization: Enhancing Big Data More Adaptable and Valuable](#)

pp 2801-2804

A. S. Syed Fiaz, N. Asha, D. Sumathi and A.S. Syed Navaz

[Feasibility Study of Minute Flaw Detection Using Ultrasonic Waves](#)

pp 2805-2809

Tony George, Elizabeth Rufus and Zachariah C Alex

[Interline Dynamic Voltage Restorer Employing Wind Generator and Fuel Cell](#)

pp 2810-2815

S. Leela and S. S. Dash

[Semantic processing and morphosyntactic analysis of Kazakh text](#)

pp 2816-2819

Begimtay Ulykbek Hosmanuly and Karimzhan Bernur

[Combinations of Conditions Affecting the Successful Transfer of Korean Saemaul \(New Community\) Movement Policy to Developing Countries](#)

pp 2820-2828

Young-Chool Choi and Ji-Hyun Jang

[A Comparative study of various approaches used for the classification of Hyperspectral Satellite Imagery](#)

pp 2829-2832

R. Venkatesan and S. Prabu

[A Survey of Trust Management in Mobile Ad hoc Networks](#)

pp 2833-2838

Vijayan R and Jeyanthi N

[Cooperative Random Walk for Pipe Network Layout Optimization](#)

pp 2839-2847

Stefan Ivić, Luka Grbčić and Siniša Družeta

[Review on IOT Technologies](#)

pp 2848-2853

Govinda K and Saravanaguru R.A.K

[Experimental Study on the Strength and Durability of Nano Concrete](#)

pp 2854-2858

Rajkumar R, Akkineni Surya Teja and Ramya Sajeevan

[Soft Skills-The Need of the Hour for Professional Competence: A Review on Interpersonal Skills and Intrapersonal Skills Theories](#)

pp 2859-2864

V. Vijayalakshmi

[Humidity-controlling and deodorizing effects of yellow loess plastering as finishing materials](#)

pp 2865-2871

Hongseok Jang, Hyeseon Kang and Seungyoung So

[Mathematical and Software of the Distributed Computing System Work Planning on the Multiagent Approach Basis](#)

pp 2872-2878

Svetlana A. Oleinikova, Oleg Ya. Kravets, Elena B. Zolotukhina, Dmitry V. Shkurkin, Iskandar S. Kobersy and Valentina V. Shadrina

[Model for Optimization Elements System for Screening of Cylindrical Hydroacoustic Aerials](#)

pp 2879-2884

Vitaly E. Bolnokin, Valery I. Storozhev, Sergey V. Vasilenko, Iskandar S. Kobersy, Dmitry V. Shkurkin and Valentin Yu. Evtushenko

[Functional Modeling of Engineering and Technical Personnel](#)

pp 2885-2889

Marina Nikolaevna Vrazhnova, Aleksandr Vyacheslavovich Akhterov, Andrey Vladimirovich Ostroukh, Ekaterina Igorevna Makarenko, Olga Vladimirovna Lezina and Nataliya Evgenievna Surkova

[Rotor Structural Design of A Hydrokinetic Turbine](#)

pp 2890-2897

Chica E, Pérez F and Rubio-Clemente A

[A Survey on Screening of Cancer Subtypes using Microarray Data](#)

pp 2898-2901

Vishnu Priya J. P, Jegatheeswari S and Devaki P

[Impact of Implementation of Human Resource Management Practices And Its Consequences In Fireworks](#)

pp 2902-2906

Bijeesh Pushpa and S. Nadarajan

[Experimental Investigation on Heat Transfer Impinging Liquid Jet Characteristics of the Vapor Chambers](#)

pp 2907-2912

Songkran Wiriyasart and Paisarn Naphon

[Instructional Model Based Sharable Content Objects for E-Learning](#)

pp 2913-2916

C. S. Nithya and K Nirmala

[Cloud Service for Data Analysis in Medical Information Systems Using Artificial Neural Networks](#)

pp 2917-2920

Alexander A. Zakharov, Evgeni A. Olennikov, Tatyana I. Payusova and Dmitry Sergeevich Silnov

[Scientific Approaches to the Assessment of Intellectual Capital of Technology Park Structures](#)

pp 2921-2926

A. Maltseva

[A Genetic Algorithm-Based Heterogeneous Random Subspace Ensemble Model for Bankruptcy Prediction](#)

pp 2927-2931

Sung-Hwan Min

[Determination of the Existence of Rock Cavities Method Based on Geoelectric Method \(2D\) in the Karangputih Hill Indarung West Sumatra Indonesia](#)

pp 2932-2937

Agus Santoso, Sismanto, Ary Setiawan, Subagyo Pramumijoyo and Indriati Retno Palupi

[Effective Pretending of Encroacher in A Cloud Networks Using Software Defined Networks](#)

pp 2938-2941

Chinthagunta Mukundha, I. Surya Prabha and P. Gayathri

[A Literature Survey on Finite State Testing of Graphical User Interface](#)

pp 2942-2954

Sumit Kumar and Nitin

[Design of Low complexity Fault Tolerant Parallel FFTs Using Partial Summation](#)

pp 2955-2960

S. Shanthi and S. Kamalraj

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Effect of Carbon Dioxide on Flame Characteristics in Biogas External Premix Combustion

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Abstract

Biogas is a renewable and environmentally friendly alternative fuels. Biogas is produced from the fermentation process which consists of mostly CH₄ (50-75%) and CO₂ (up to 50%) and a smaller amount of H₂, N₂, O₂, and H₂S, in which it varies from source. There are several related studies about the characteristics of biogas combustion and external combustion. This research focus on effects of CO₂ as the most abundant inhibitors in biogas towards its effects on external combustion process. This research was conducted by burning a stoichiometric mixture of fuel (CH₄ and CO₂% range 0-50%) and oxygen in the external test equipment premixed methane combustion with a 5 mm nozzle diameter. The results showed that the level of CO₂ affects the formation of flame angle and flame height. The increase in CO₂ content within the fuel mixture will decrease the flame height and moreover, more CO₂ content also creates larger flame angle.

Keywords: carbon dioxide, premixed combustion, external combustion.

Introduction

In combustion engineering, combustion success as is shown in the theoretical calculation in accordance with aspects of thermodynamics combustion is influenced directly by how the combustion process ongoing. In the process of gas fuel combustion, the flame properties and the flame propagation characteristics are the fundamental information, and the flammability limits of a compound or mixture of gases can be used to determine whether a compound gas mixture is flammable. The success of the practical utilization of a combustion system influenced directly by the combustion process that occurs and the characteristics of the flame.

In the field of combustion engineering, there are various categories of flame, and some of them have not been fully defined. But basically the flame can be grouped into two major categories based on the mixing method of the reactants, namely premixed flame and diffusion flame. In the premixed

combustion, fuel gas and oxygen are perfectly mixed before the ignition. Ignition is required to give a certain amount of energy in the appropriate form, so as to trigger a combustion process. Furthermore, the reaction will be spreading to the mixture as a flame or which is known as deflagration. In the non-premixed combustion, the fuel and air are often initially not mixed. The fuel and oxidizer are kept on either side of the reaction zone and moved to the reaction zone. The resultant flame is termed as the diffusion or non-premixed flame. In some cases, the gas and air are injected in a coaxial parallel tube and ignited. The flow behavior of the non-premixed flame is laminar type. Molecular or turbulent diffusion is responsible for the mixing of the gases in non-premixed flames. The turbulent pre-mixed flame plays an important role in the various practical applications because it increases the ignition of fuel with the reduction in the emission of gases. Both the laminar premixed or laminar non-premixed flames (diffusion flame) are slow processes and not economic but however, the laminar flame characteristics are fundamental to the analysis of turbulent flames.

Biogas is a renewable alternative fuel that is derived from the secretion of living things such as plants, animals, and even humans. The composition of biogas varies from source in which the biogas is derived. Mainly, biogas is composed of methane (50-75%) and carbon dioxide (up to 50%) Biogas obtained by reaction of anaerobic bacteria within manure which produced Methane and Carbon dioxide. Methane (CH₄) is combustible organic compound belonging to the group of paraffin. Carbon dioxide (CO₂) is an inert substance that is difficult to react. In addition, there are several other impurities within biogas composition such as, Hydrogen sulfide, Hydrogen, Nitrogen, Oxygen, and some other substances depend on the biogas sources. The calorific value of biogas is highly dependent on the content of methane within. Biogas containing 60% Methane has a calorific value of 30 MJ / kg and several previous related studies conducted biogas combustion fundamental characteristics, those are laminar burning velocities and flammability limit (Anggono et al. and Ullman) [1-6]. One study conducted on the effect of carbon

dioxide (CO₂) in methane (CH₄) combustion by utilizing a burner comprises of a stainless mesh to stabilize the flame and the perforated plate to create turbulence in the flow of premixed. The experiment used nozzle burner to generate a combustion reaction, in which later the flame characteristic is analyzed with a formula closer to the laminar burning velocity [7-9]. This is a good discovery, given that turbulent premixed flames exhibit an area that is challenging to study.

Several studies have been conducted regarding of combustion properties of alternative fuels [10-12]. In addition, there are several other studies that examine the effect of Air Fuel Ratio on combustion characteristics of both on LPG and in some studies on Methane/ Natural Gas [10,13]. These previous studies of gas fuel biogas focus mainly on Carbon dioxide as a compound "impurity" of the main flame instability burning a mixture of biogas which includes various characteristics, structure, properties and mechanisms in the combustion process. These studies aimed to understand the characteristic of Carbon dioxide on combustion process better as research on Carbon dioxide influence on combustion has not been widely studied.

There are also other previous studies involving different burner, with a wide variety of burner and the results obtained [13-17]. One of the studies [16] was using porous radiant burners commonly used on LPG burner to observe flame characteristics, emissions released, and thermal efficiency. In the case of McKenna burner, the flame produced by the burner is a flat flame with a more uniform temperature distribution than other burner [15]. Aside from the variation of the burner, there is also research on the effect of test equipment used. Studied the influence is on the length and width of the flame nozzle size variations are used, which ultimately affects the resulting flame heights [17].

The focus of the present study is on the effects of CO₂ as the most abundant inhibitor in biogas towards its effects on external premixed combustion process, and the main goal of the present study is to investigate the influence of CO₂ level on the formation of flame angles and flame heights.

Experimental Apparatus and Procedure

The research is conducted at the Thermofluid Laboratory of Mechanical Engineering Department, Petra Christian University. The variables of this experiment are percentage of CO₂ mixture at 0, 10, 20, 30, 40 and 50%. Fuel mixture consists of CH₄ and CO₂ was initially mixed in accordance with the desired ratio. Once the desired composition of fuel mixture is achieved, whether pure CH₄ or CH₄-CO₂ mixture with varying percentages, it is then supplied into the experimental apparatus along with the supply of O₂. The experiment apparatus are used with output of 5 mm in diameter. Details of experiment and test equipment used can be seen as follows:

The experiment was first done by preparing all the necessary modules and arranging them in accordance with the planned experimental scheme. The corresponding modules were then installed in accordance to Fig. 1. The next step was to set the Camera on a Tripod. Once the camera had been ready, the igniter was prepared. After all equipment was installed correctly, let the O₂ flow through the flowmeter and into the

experimental apparatus. The flowmeter was checked accordingly. The procedure used to flow O₂ into the mixing chamber was also applied to flow CH₄/CH₄-CO₂ into the mixing chamber. Once the flowrates of both streams were set to stoichiometric ratio, the burner tip is ignited. To ensure a steady combustion, then a delay is introduced for about 10 to 15 seconds between the moment of ignition and when the flame is recorded. After the desired images are captured, the burner was turned off. The same steps were repeated for various compositions of CH₄-CO₂ mixtures.

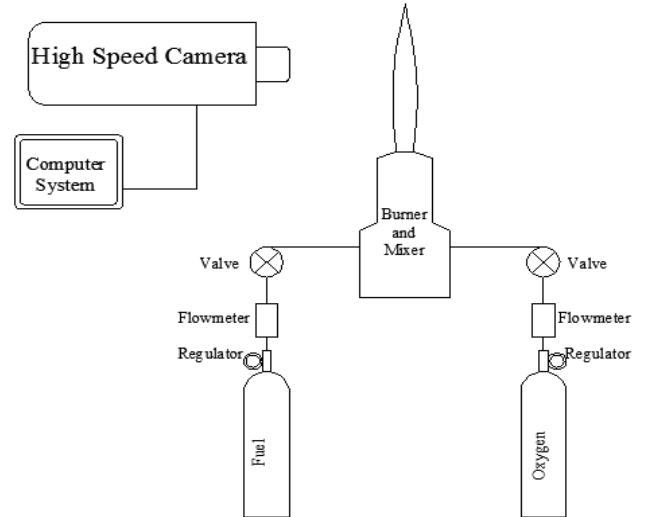


Figure 1: Experimental apparatus scheme

Results and Discussion

Data are obtained from experiment at RTP (Room Temperature Pressure) condition with various CO₂% content. Images of CH₄-CO₂ premixed flames with varying CO₂ content (0-50%) were captured using a high speed camera. These images were analyzed with the help of image processing software. Flame angle is the magnitude of the flame tip angle, and flame height is the distance from the base to the tip of the flame. Figure 2 shows how both parameters are measured.



Figure 2: Measurement of Flame angle (θ) and flame height

Flame angles and flame heights for each composition were measured by uploading pictures of the flame onto computer and using image processing software to measure the angle and the height. Dimensionless flame height is obtained by dividing flame height (H) to the diameter of nozzle (d = 5 mm). Dimensionless flame height is a parameter that shows flame height which are unaffected by nozzle diameter. The measurement results are given below:

Table 1: Experimental Results

CO ₂ content (%)	Flame Angle (deg)	Flame Height (mm)	Dimensionless Flame Height (H/d)
0	2.81	102.016	20.403
10	3.27	87.557	17.511
20	3.73	76.835	15.367
30	4.71	60.820	12.164
40	6.50	44.053	8.811
50	7.96	35.911	7.182

Flame angle increases as the CO₂ level increases while flame Height decreases as the CO₂ level increases. This means that CO₂ affects the physical properties of flame, which in this case, flame angle and flame height. The differences in flame height for each CO₂ contents can be observed in Fig. 3. The flame image shows gradual decrease of flame height and gradual increase in flame angle with the gradual increase in CO₂ content. From experimental observations, no sudden changes of flame properties are present.

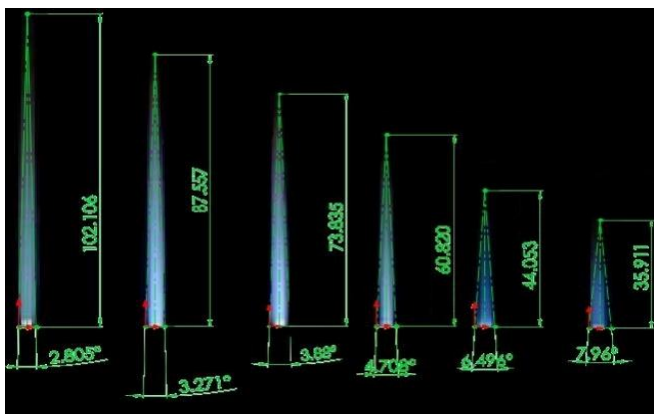


Figure 3: Differences in flame angle and height with varying CO₂ content (0-50%)

In order to ease the observation and to find the tendency of the magnitude of flame height and flame angle at various levels of CO₂, then the data above is presented in the form of simple charts. Fig. 4(a) shows the relationship between various CO₂ contents to the magnitude of flame angle, and Fig. 4(b) & 4(c) show the relation between various CO₂ contents to the flame height and the dimensionless flame height respectively. Below, there are graphs representing the Effect of CO₂ content on flame angle flame height, and dimensionless flame height.

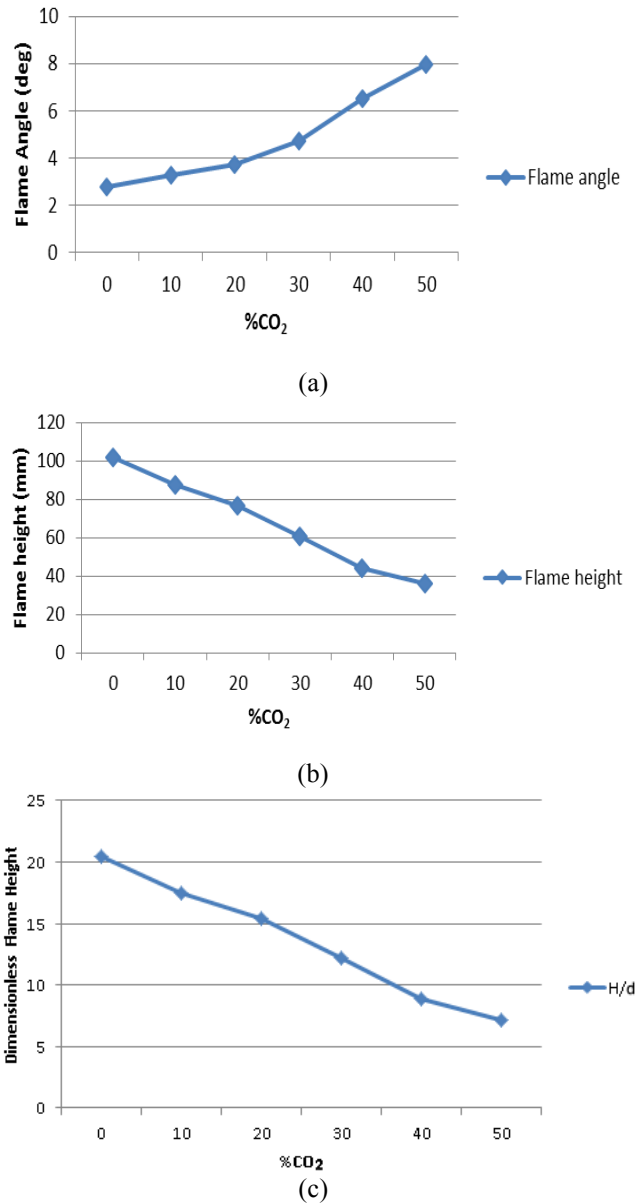


Figure 4: (a) Effects of CO₂ content on flame angle development; (b) Effects of CO₂ content on flame height development; (c) Effects of CO₂ content on dimensionless flame height development

Data obtained from the graphs indicates gradual decrease of flame height and gradual increase of flame angle with the gradual increase in CO₂ content. Based on the data obtained, there are no sudden changes in flame properties. Moreover, it can be concluded from this study that carbon dioxide acts as an inhibitor in the combustion process. Inhibitory effect of Carbon dioxide increased with increasing levels of CO₂ in methane that caused changes in the characteristics of the fire burning. Flame angle appears to increase with increasing CO₂ levels while the flame height decreases nearly in linear manner. This can be seen in the formation of flame angle which tends to be wider at high CO₂ concentrations, but lower the flame height obtained.

Conclusion

The experimental apparatus consists of a burner with a mixing chamber and a high speed camera is adequate to capture the flame produced by an external premixed combustion. Flame height and flame angle can be obtained with the help of an image processing software.

From the data analysis that has been discussed above, it can be concluded that carbon dioxide acts as an inhibitor at combustion process. The study has successfully shown the effect of various CO₂ content on the formation of flame angle and flame height in biogas premixed combustion.

Fuels with 0% content of carbon dioxide results in a narrow flame angle. Increasing levels of CO₂ will increase the flame angle. Decrease in flame height is proportional to the increase of CO₂ levels. The greater the concentration of CO₂ in biogas, the lower the flame height is achieved.

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