

ISSN 1726-5479

SENSORS & TRANSDUCERS

1 vol. 124
/11



Sensor Instrumentation, DAQ and Virtual Instruments

International Frequency Sensor Association Publishing





Editors-in-Chief: professor Sergey Y. Yurish, tel.: +34 696067716, fax: +34 93 4011989, e-mail: editor@sensorsportal.com

Editors for Western Europe

Meijer, Gerard C.M., Delft University of Technology, The Netherlands
Ferrari, Vittorio, Università di Brescia, Italy

Editor South America

Costa-Felix, Rodrigo, Inmetro, Brazil

Editor for Eastern Europe

Sachenko, Anatoly, Ternopil State Economic University, Ukraine

Editors for North America

Datskos, Panos G., Oak Ridge National Laboratory, USA
Fabien, J. Josse, Marquette University, USA
Katz, Evgeny, Clarkson University, USA

Editor for Asia

Ohyama, Shinji, Tokyo Institute of Technology, Japan

Editor for Asia-Pacific

Mukhopadhyay, Subhas, Massey University, New Zealand

Editorial Advisory Board

- Abdul Rahim, Ruzairi, Universiti Teknologi, Malaysia
Ahmad, Mohd Noor, Northern University of Engineering, Malaysia
Annamalai, Karthikeyan, National Institute of Advanced Industrial Science and Technology, Japan
Arcega, Francisco, University of Zaragoza, Spain
Arguel, Philippe, CNRS, France
Ahn, Jae-Pyoung, Korea Institute of Science and Technology, Korea
Arndt, Michael, Robert Bosch GmbH, Germany
Ascoli, Giorgio, George Mason University, USA
Atalay, Selcuk, Inonu University, Turkey
Atghiaee, Ahmad, University of Tehran, Iran
Augutis, Vyngantas, Kaunas University of Technology, Lithuania
Avachit, Patil Lalchand, North Maharashtra University, India
Ayesha, Aladdin, De Montfort University, UK
Bahreyni, Behraad, University of Manitoba, Canada
Baliga, Shankar, B., General Motors Transnational, USA
Baoxian, Ye, Zhengzhou University, China
Barford, Lee, Agilent Laboratories, USA
Barlingay, Ravindra, RF Arrays Systems, India
Basu, Sukumar, Jadavpur University, India
Beck, Stephen, University of Sheffield, UK
Ben Bouzid, Sihem, Institut National de Recherche Scientifique, Tunisia
Benachaiba, Chellali, Universitaire de Bechar, Algeria
Binnie, T. David, Napier University, UK
Bischoff, Gerlinde, Inst. Analytical Chemistry, Germany
Bodas, Dhananjay, IMTEK, Germany
Borges Carval, Nuno, Universidade de Aveiro, Portugal
Bousbia-Salah, Mounir, University of Annaba, Algeria
Bouvet, Marcel, CNRS – UPMC, France
Brudzewski, Kazimierz, Warsaw University of Technology, Poland
Cai, Chenxin, Nanjing Normal University, China
Cai, Qingyun, Hunan University, China
Campanella, Luigi, University La Sapienza, Italy
Carvalho, Vitor, Minho University, Portugal
Cecelja, Franjo, Brunel University, London, UK
Cerde Belmonte, Judith, Imperial College London, UK
Chakrabarty, Chandan Kumar, Universiti Tenaga Nasional, Malaysia
Chakravorty, Dipankar, Association for the Cultivation of Science, India
Changhai, Ru, Harbin Engineering University, China
Chaudhari, Gajanan, Shri Shivaji Science College, India
Chavali, Murthy, N.I. Center for Higher Education, (N.I. University), India
Chen, Jiming, Zhejiang University, China
Chen, Rongshun, National Tsing Hua University, Taiwan
Cheng, Kuo-Sheng, National Cheng Kung University, Taiwan
Chiang, Jeffrey (Cheng-Ta), Industrial Technol. Research Institute, Taiwan
Chiriac, Horia, National Institute of Research and Development, Romania
Chowdhuri, Arijit, University of Delhi, India
Chung, Wen-Yaw, Chung Yuan Christian University, Taiwan
Corres, Jesus, Universidad Publica de Navarra, Spain
Cortes, Camilo A., Universidad Nacional de Colombia, Colombia
Courtois, Christian, Universite de Valenciennes, France
Cusano, Andrea, University of Sannio, Italy
D'Amico, Arnaldo, Università di Tor Vergata, Italy
De Stefano, Luca, Institute for Microelectronics and Microsystem, Italy
Deshmukh, Kiran, Shri Shivaji Mahavidyalaya, Barshi, India
Dickert, Franz L., Vienna University, Austria
Dieguez, Angel, University of Barcelona, Spain
Dimitropoulos, Panos, University of Thessaly, Greece
Ding, Jianning, Jiangsu Polytechnic University, China
Djordjevic, Alexandar, City University of Hong Kong, Hong Kong
Donato, Nicola, University of Messina, Italy
Donato, Patricio, Universidad de Mar del Plata, Argentina
Dong, Feng, Tianjin University, China
Driljaca, Predrag, Instersema Sensoric SA, Switzerland
Dubey, Venketesh, Bournemouth University, UK
Enderle, Stefan, Univ. of Ulm and KTB Mechatronics GmbH, Germany
Erdem, Gursan K. Arzum, Ege University, Turkey
Erkmen, Aydan M., Middle East Technical University, Turkey
Estelle, Patrice, Insa Rennes, France
Estrada, Horacio, University of North Carolina, USA
Faiz, Adil, INSA Lyon, France
Fericean, Sorin, Balluff GmbH, Germany
Fernandes, Joana M., University of Porto, Portugal
Francioso, Luca, CNR-IMM Institute for Microelectronics and Microsystems, Italy
Francis, Laurent, University Catholique de Louvain, Belgium
Fu, Weiling, South-Western Hospital, Chongqing, China
Gaura, Elena, Coventry University, UK
Geng, Yanfeng, China University of Petroleum, China
Gole, James, Georgia Institute of Technology, USA
Gong, Hao, National University of Singapore, Singapore
Gonzalez de la Rosa, Juan Jose, University of Cadiz, Spain
Granel, Annette, Goteborg University, Sweden
Graff, Mason, The University of Texas at Arlington, USA
Guan, Shan, Eastman Kodak, USA
Guillet, Bruno, University of Caen, France
Guo, Zhen, New Jersey Institute of Technology, USA
Gupta, Narendra Kumar, Napier University, UK
Hadjiloucas, Sillas, The University of Reading, UK
Haider, Mohammad R., Sonoma State University, USA
Hashsham, Syed, Michigan State University, USA
Hasni, Abdelhafid, Bechar University, Algeria
Hernandez, Alvaro, University of Alcalá, Spain
Hernandez, Wilmar, Universidad Politecnica de Madrid, Spain
Homentcovschi, Dorel, SUNY Binghamton, USA
Horstman, Tom, U.S. Automation Group, LLC, USA
Hsiai, Tzung (John), University of Southern California, USA
Huang, Jeng-Sheng, Chung Yuan Christian University, Taiwan
Huang, Star, National Tsing Hua University, Taiwan
Huang, Wei, PSG Design Center, USA
Hui, David, University of New Orleans, USA
Jaffrezic-Renault, Nicole, Ecole Centrale de Lyon, France
Jaime Calvo-Galleg, Jaime, Universidad de Salamanca, Spain
James, Daniel, Griffith University, Australia
Janting, Jakob, DELTA Danish Electronics, Denmark
Jiang, Liudi, University of Southampton, UK
Jiang, Wei, University of Virginia, USA
Jiao, Zheng, Shanghai University, China
John, Joachim, IMEC, Belgium
Kalach, Andrew, Voronezh Institute of Ministry of Interior, Russia
Kang, Moonho, Sunmoon University, Korea South
Kaniusas, Eugenijus, Vienna University of Technology, Austria
Katake, Anup, Texas A&M University, USA
Kausel, Wilfried, University of Music, Vienna, Austria
Kavasoglu, Nese, Mugla University, Turkey
Ke, Cathy, Tyndall National Institute, Ireland
Khelfaoui, Rachid, Université de Bechar, Algeria
Khan, Asif, Aligarh Muslim University, Aligarh, India
Kim, Min Young, Kyungpook National University, Korea South
Ko, Sang Choon, Electronics. and Telecom. Research Inst., Korea South
Kockar, Hakan, Balikesir University, Turkey
Kotulska, Malgorzata, Wroclaw University of Technology, Poland
Kratz, Henrik, Uppsala University, Sweden
Kumar, Arun, University of South Florida, USA
Kumar, Subodh, National Physical Laboratory, India

Kung, Chih-Hsien, Chang-Jung Christian University, Taiwan
Lacnjevac, Caslav, University of Belgrade, Serbia
Lay-Ekuakille, Aime, University of Lecce, Italy
Lee, Jang Myung, Pusan National University, Korea South
Lee, Jun Su, Amkor Technology, Inc. South Korea
Lei, Hua, National Starch and Chemical Company, USA
Li, Genxi, Nanjing University, China
Li, Hui, Shanghai Jiaotong University, China
Li, Xian-Fang, Central South University, China
Liang, Yuanchang, University of Washington, USA
Liawruangrath, Saisunee, Chiang Mai University, Thailand
Liew, Kim Meow, City University of Hong Kong, Hong Kong
Lin, Hermann, National Kaohsiung University, Taiwan
Lin, Paul, Cleveland State University, USA
Linderholm, Pontus, EPFL - Microsystems Laboratory, Switzerland
Liu, Aihua, University of Oklahoma, USA
Liu Changgeng, Louisiana State University, USA
Liu, Cheng-Hsien, National Tsing Hua University, Taiwan
Liu, Songqin, Southeast University, China
Lodeiro, Carlos, University of Vigo, Spain
Lorenzo, Maria Encarnacio, Universidad Autonoma de Madrid, Spain
Lukaszewicz, Jerzy Pawel, Nicholas Copernicus University, Poland
Ma, Zhanfang, Northeast Normal University, China
Majstorovic, Vidosav, University of Belgrade, Serbia
Marquez, Alfredo, Centro de Investigacion en Materiales Avanzados, Mexico
Matay, Ladislav, Slovak Academy of Sciences, Slovakia
Mathur, Prafull, National Physical Laboratory, India
Maurya, D.K., Institute of Materials Research and Engineering, Singapore
Mekid, Samir, University of Manchester, UK
Melnyk, Ivan, Photon Control Inc., Canada
Mendes, Paulo, University of Minho, Portugal
Mennell, Julie, Northumbria University, UK
Mi, Bin, Boston Scientific Corporation, USA
Minas, Graca, University of Minho, Portugal
Moghavvemi, Mahmoud, University of Malaya, Malaysia
Mohammadi, Mohammad-Reza, University of Cambridge, UK
Molina Flores, Esteban, Benemérita Universidad Autónoma de Puebla, Mexico
Moradi, Majid, University of Kerman, Iran
Morello, Rosario, University "Mediterranea" of Reggio Calabria, Italy
Mounir, Ben Ali, University of Sousse, Tunisia
Mulla, Imtiaz Sirajuddin, National Chemical Laboratory, Pune, India
Nabok, Aleksey, Sheffield Hallam University, UK
Neelamegam, Periasamy, Sastra Deemed University, India
Neshkova, Milka, Bulgarian Academy of Sciences, Bulgaria
Oberhammer, Joachim, Royal Institute of Technology, Sweden
Ould Lahoucine, Cherif, University of Guelma, Algeria
Pamidighanta, Sayanu, Bharat Electronics Limited (BEL), India
Pan, Jisheng, Institute of Materials Research & Engineering, Singapore
Park, Joon-Shik, Korea Electronics Technology Institute, Korea South
Penza, Michele, ENEA C.R., Italy
Pereira, Jose Miguel, Instituto Politecnico de Seteбал, Portugal
Petsev, Dimiter, University of New Mexico, USA
Pogacnik, Lea, University of Ljubljana, Slovenia
Post, Michael, National Research Council, Canada
Prance, Robert, University of Sussex, UK
Prasad, Ambika, Gulbarga University, India
Prateepasen, Asa, Kingmoungut's University of Technology, Thailand
Pullini, Daniele, Centro Ricerche FIAT, Italy
Pumera, Martin, National Institute for Materials Science, Japan
Radhakrishnan, S. National Chemical Laboratory, Pune, India
Rajanna, K., Indian Institute of Science, India
Ramadan, Qasem, Institute of Microelectronics, Singapore
Rao, Basuthkar, Tata Inst. of Fundamental Research, India
Raoof, Kosai, Joseph Fourier University of Grenoble, France
Reig, Candid, University of Valencia, Spain
Restivo, Maria Teresa, University of Porto, Portugal
Robert, Michel, University Henri Poincare, France
Rezazadeh, Ghader, Urmia University, Iran
Royo, Santiago, Universitat Politècnica de Catalunya, Spain
Rodriguez, Angel, Universidad Politècnica de Catalunya, Spain
Rothberg, Steve, Loughborough University, UK
Sadana, Ajit, University of Mississippi, USA
Sadeghian Marnani, Hamed, TU Delft, The Netherlands
Sandacci, Serghei, Sensor Technology Ltd., UK
Schneider, John K., Ultra-Scan Corporation, USA
Sengupta, Deepak, Advance Bio-Photonics, India
Shah, Kriyang, La Trobe University, Australia
Sapozhnikova, Ksenia, D.I.Mendeleev Institute for Metrology, Russia
Saxena, Vibha, Bhabha Atomic Research Centre, Mumbai, India
Seif, Selemani, Alabama A & M University, USA
Seifter, Achim, Los Alamos National Laboratory, USA
Silva Girao, Pedro, Technical University of Lisbon, Portugal
Singh, V. R., National Physical Laboratory, India
Slomovitz, Daniel, UTE, Uruguay
Smith, Martin, Open University, UK
Soleymanpour, Ahmad, Damghan Basic Science University, Iran
Somani, Prakash R., Centre for Materials for Electronics Technol., India
Srinivas, Talabattula, Indian Institute of Science, Bangalore, India
Srivastava, Arvind K., NanoSonix Inc., USA
Stefan-van Staden, Raluca-Ioana, University of Pretoria, South Africa
Sumriddetchka, Sarun, National Electronics and Computer Technology Center, Thailand
Sun, Chengliang, Polytechnic University, Hong-Kong
Sun, Dongming, Jilin University, China
Sun, Junhua, Beijing University of Aeronautics and Astronautics, China
Sun, Zhiqiang, Central South University, China
Suri, C. Raman, Institute of Microbial Technology, India
Sysoev, Victor, Saratov State Technical University, Russia
Szewczyk, Roman, Industrial Research Inst. for Automation and Measurement, Poland
Tan, Ooi Kiang, Nanyang Technological University, Singapore
Tang, Dianping, Southwest University, China
Tang, Jaw-Luen, National Chung Cheng University, Taiwan
Teker, Kasif, Frostburg State University, USA
Thirunavukkarasu, I., Manipal University Karnataka, India
Thumbavanam Pad, Kartik, Carnegie Mellon University, USA
Tian, Gui Yun, University of Newcastle, UK
Tsiantos, Vassilios, Technological Educational Institute of Kaval, Greece
Tsigara, Anna, National Hellenic Research Foundation, Greece
Twomey, Karen, University College Cork, Ireland
Valente, Antonio, University, Vila Real, - U.T.A.D., Portugal
Vange, Raghav Rao, Summit Technology Services, Inc., USA
Vaseashta, Ashok, Marshall University, USA
Vazquez, Carmen, Carlos III University in Madrid, Spain
Vieira, Manuela, Instituto Superior de Engenharia de Lisboa, Portugal
Vigna, Benedetto, STMicroelectronics, Italy
Vrba, Radimir, Brno University of Technology, Czech Republic
Wandelt, Barbara, Technical University of Lodz, Poland
Wang, Jiangping, Xi'an Shiyong University, China
Wang, Kedong, Beihang University, China
Wang, Liang, Pacific Northwest National Laboratory, USA
Wang, Mi, University of Leeds, UK
Wang, Shinn-Fwu, Ching Yun University, Taiwan
Wang, Wei-Chih, University of Washington, USA
Wang, Wensheng, University of Pennsylvania, USA
Watson, Steven, Center for NanoSpace Technologies Inc., USA
Weiping, Yan, Dalian University of Technology, China
Wells, Stephen, Southern Company Services, USA
Wolkenberg, Andrzej, Institute of Electron Technology, Poland
Woods, R. Clive, Louisiana State University, USA
Wu, DerHo, National Pingtung Univ. of Science and Technology, Taiwan
Wu, Zhaoyang, Hunan University, China
Xiu Tao, Ge, Chuzhou University, China
Xu, Lisheng, The Chinese University of Hong Kong, Hong Kong
Xu, Sen, Drexel University, USA
Xu, Tao, University of California, Irvine, USA
Yang, Dongfang, National Research Council, Canada
Yang, Shuang-Hua, Loughborough University, UK
Yang, Wuqiang, The University of Manchester, UK
Yang, Xiaoling, University of Georgia, Athens, GA, USA
Yaping Dan, Harvard University, USA
Ymeti, Aurel, University of Twente, Netherland
Yong Zhao, Northeastern University, China
Yu, Haihu, Wuhan University of Technology, China
Yuan, Yong, Massey University, New Zealand
Yufera Garcia, Alberto, Seville University, Spain
Zakaria, Zulkarnay, University Malaysia Perlis, Malaysia
Zagnoni, Michele, University of Southampton, UK
Zamani, Cyrus, Universitat de Barcelona, Spain
Zeni, Luigi, Second University of Naples, Italy
Zhang, Minglong, Shanghai University, China
Zhang, Qintao, University of California at Berkeley, USA
Zhang, Weiping, Shanghai Jiao Tong University, China
Zhang, Wenming, Shanghai Jiao Tong University, China
Zhang, Xueji, World Precision Instruments, Inc., USA
Zhong, Haoxiang, Henan Normal University, China
Zhu, Qing, Fujifilm Dimatix, Inc., USA
Zorzano, Luis, Universidad de La Rioja, Spain
Zourob, Mohammed, University of Cambridge, UK

Contents

Volume 124
Issue 1
January 2011

www.sensorsportal.com

ISSN 1726-5479

Research Articles

Investigation of Magnetic-field-induced Temperature Error of Pt- 500 <i>Rajinikumar Ramalingam and Michael Schwarz</i>	1
Classification of Unknown Thermocouple Types Using Similarity Factor Measurement <i>Seshu K. Damarla and Palash Kundu</i>	11
The Design of a Novel Flexible Tactile Sensor Based on Pressure-conductive Rubber <i>Fei Xu, Yunjian Ge, Yong Yu, Junxiang Ding, Tao Ju, Shanhong Li</i>	19
Study on the Relative Difference of the Force Transducer Constants in Tensile and Compressive Modes Calibration Equations <i>Ebtisam H. Hasan and Seif. M. Osman</i>	30
Design of a Large-scale Three-dimensional Flexible Arrayed Tactile Sensor <i>Junxiang Ding, Yunjian Ge, Shanhong Li, Fei Xu, Feng Shuang</i>	37
The Activity Airflow Detection of Vehicle Intake System Using Hot-film Anemometry Sensors Instrument <i>Rong-Hua Ma and Chi-Kuen Sung</i>	48
Hardware Developments of an Ultrasonic Tomography Measurement System <i>Hudabiyah Arshad Amari, Ruzairi Abdul Rahim, Mohd Hafiz Fazalul Rahiman, Herlina Abdul Rahim, Muhammad Jaysuman Puspanathan</i>	56
Design and Development of Microcontroller Based Fluoride Meter <i>Bhaskar Reddy S., V. V. Ramana C. H. and Malakondaiah K.</i>	64
Effect of Magnetic Flux Density and Applied Current on Temperature, Velocity and Entropy Generation Distributions in MHD Pumps <i>M. Kiyasatfar, N. Pourmahmoud, M. M. Golzan, M. Eskandarzade</i>	72
Design of a DCS Based Model for Continuous Leakage Monitoring System of Rotary Air Preheater of a Thermal Power Plant <i>Madan Bhowmick and Satish Chandra Bera</i>	83
The Design of a Wireless Monitoring System for Unattended Environmental Applications <i>Ibrahim Al-Bahadly and Victor Mtetwa</i>	101
Performance Measures of Ultra-Wideband Communication System <i>Mrutyunjaya Panda, Sarat Kumar Patra</i>	120
Unspecified Low-Frequency Noise in Chopper Op-Amps <i>Charles Gilbert</i>	127

Authors are encouraged to submit article in MS Word (doc) and Acrobat (pdf) formats by e-mail: editor@sensorsportal.com
Please visit journal's webpage with preparation instructions: <http://www.sensorsportal.com/HTML/DIGEST/Submission.htm>



The Third International Conference
on Bioinformatics, Biocomputational Systems and Biotechnologies

BIOTECHNO 2011

May 22-27, 2011 - Venice, Italy



Tracks:

A. Bioinformatics, chemoinformatics, neuroinformatics and applications

- Bioinformatics
- Advanced biocomputation technologies
- Chemoinformatics
- Bioimaging
- Neuroinformatics

B. Computational systems

- Bio-ontologies and semantics
- Biocomputing
- Genetics
- Molecular and Cellular Biology
- Microbiology

C. Biotechnologies and biomanufacturing

- Fundamentals in biotechnologies
- Biodevices
- Biomedical technologies
- Biological technologies
- Biomanufacturing

Important deadlines:

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

<http://www.aria.org/conferences2011/BIOTECHNO11.html>



The Seventh International Conference
on Networking and Services

ICNS 2011

May 22-27, 2011 - Venice, Italy



Important deadlines:

Submission (full paper)	January 10, 2011
Notification	February 20, 2011
Registration	March 5, 2011
Camera ready	March 20, 2011

<http://www.aria.org/conferences2011/ICNS11.html>

Tracks:

- ENCOT: Emerging Network Communications and Technologies
- COMAN: Network Control and Management
- SERVI: Multi-technology service deployment and assurance
- NGNUS: Next Generation Networks and Ubiquitous Services
- MPQSI: Multi Provider QoS/SLA Internetworking
- GRIDNS: Grid Networks and Services
- EDNA: Emergency Services and Disaster Recovery of Networks and Applications
- IPv6DFI: Deploying the Future Infrastructure
- IPDy: Internet Packet Dynamics
- GOBS: GRID over Optical Burst Switching Networks



The Sixth International Conference on Systems

ICONS 2011

January 23-28, 2011 - St. Maarten,
The Netherlands Antilles



Important deadlines:

Submission (full paper)	September 25, 2010
Notification	October 20, 2010
Registration	November 5, 2010
Camera ready	November 5, 2010

<http://www.aria.org/conferences2011/ICONS11.html>

Tracks:

- Systems' theory and practice
- System engineering
- System instrumentation
- Embedded systems and systems-on-the-chip
- Target-oriented systems [emulation, simulation, prediction, etc.]
- Specialized systems [sensor-based, mobile, multimedia, biometrics, etc.]
- Validation systems
- Security and protection systems
- Advanced systems [expert, tutoring, self-adapting, interactive, etc.]
- Application-oriented systems [content, eHealth, radar, financial, vehicular, etc.]
- Safety in industrial systems
- Complex Systems

Design of a DCS Based Model for Continuous Leakage Monitoring System of Rotary Air Preheater of a Thermal Power Plant

Madan BHOWMICK and Satish Chandra BERA

Department of Instrumentation & Measurement, Applied Physics

Calcutta University, 92, APC Road, Kolkata – 700009, India

Tel.: +91-9477373269

E-mail: msbhowmick776@rediffmail.com, scb152@indiatimes.com

Received: 17 November 2010 /Accepted: 24 January 2011 /Published: 28 January 2011

Abstract: The leakage in rotary air preheater makes a considerable contribution to the reduced overall efficiency of fossil-fuel-fired thermal power plants and increase the effect on environment. Since it is normal phenomenon, continuous monitoring of leakage is generally omitted in most power plants. But for accurate analysis of the operation of the thermal power plant, this leakage monitoring plays a vital role. In the present paper, design of a DCS based model for continuous leakages monitoring of rotary air preheater has been described. In the proposed model, the existing DCS based instrumentation system has been modified and online leakage monitoring system has been developed. This model has been installed in a captive power plant with high capacity boilers and very much satisfactory operation of this system has been observed. The observed online data along with their analysis results are presented in this paper. *Copyright © 2011 IFSA.*

Keywords: Rotary air preheater, Regenerators, Continuous leakage monitoring, Combustion.

1. Introduction

Combustion refers to the rapid oxidation of fuel accompanied by the production of heat, or heat & light and flue gas. The heat recovery from the exhaust flue gas is in most cases, the largest benefit for investment in energy conservation equipment. There are a considerable number of applications, where the waste heat of flue gas is utilized, and these depend to a large extent on the temperature and

condition of the exhaust gases or air, the heat recovery equipment used, and the economic assessment of the overall system performance. High efficiency is the key feature in the operation of any energy conversion device, and this includes large fossil fuel fired steam boilers, furnaces or turbines. It is therefore very important to recover as much energy as possible from that available in the fuel. Air preheaters have proved to have an important influence on the efficiency of the entire steam boiler, furnace or turbine. Their primary task is to return considerable amounts of waste heat, carried by the flue gas, back to the combustion process.

There are generally two major techniques for waste heat recovery, which are recuperators and regenerators. The recuperator functions in such a way that the heat flows steadily and continuously from one fluid to another through a separating wall. In a regenerator, however, the flow of heat is intermittent, and is typified by rotary systems such as the heat wheel, rotary air preheater, Muntz wheel etc. Rotary air preheater has been exclusively used in waste heat recovery applications for many years due to its compactness and preferable performance. The internal structure of the rotary air preheater is shown in Fig. 1. The heat transfer surface or elements are usually referred to as a matrix.

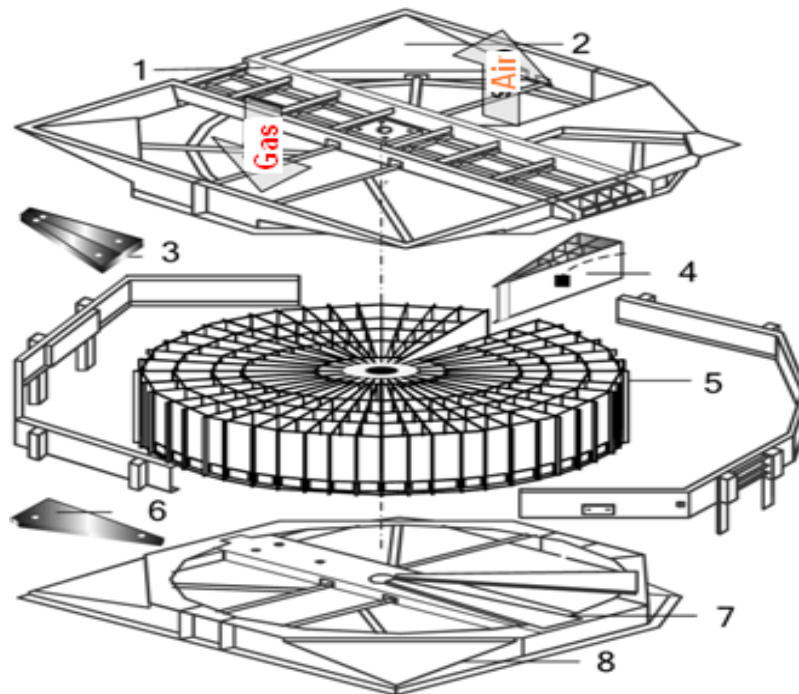


Fig. 1. The internal structure of the rotating air preheater.

- | | |
|-------------------------|--------------------------|
| 1. Upper beam | 5. Rotor |
| 2. Upper Air channels | 6. Cold end sector seals |
| 3. Hot end sector seals | 7. Bottom beam |
| 4. Segmental plate | 8. Bottom gas channels |

They consist of a rotor usually made of corrugated materials which rotates at very low speeds with a constant fraction of the core facing partially for the hot fluid (gas) and cold fluid (air). The heat transfer surface area or flow passages are generally made of metals with cellular structure. When the hot gas flows over the heat transfer surface (through flow passages), the thermal energy is stored in the matrix wall. During the cold gas flow through the same passages later, the matrix wall delivers the thermal energy to the cold fluid. Thus, the specific operating principle of the rotary air preheater is the heat transfer from the hot gas to the cold gas by means of rotating matrix [1-6]. High effectiveness as well as compactness (high ratio of heat transfer surface area to matrix volume) of rotary regenerators is

the most important characteristics of these heat exchangers. A significant weakness of this type of heat exchanger is the unavoidable leakages between both streams caused by the pressure difference between the streams and by the rotation of the matrix. There have been many efforts for energy recovery in different applications including using rotary regenerators [5, 9]. So various works [7 - 17] are still being reported to minimize these problems and increase the efficiency of a thermal power plant. A lot of research was carried out by Skiepko, who studied the influence of leakage on a heat exchanger's performance [14]. He also presented methods for calculating the mass flows of gas through the seals [13], a method of measuring and adjusting the seal clearances in radial seals [15], and the irreversibilities caused by leakage [16]. Many numerical models [6, 10] are a combination of fluid-flow simulation and heat-transfer simulation in a three-dimensional geometrical model of a rotary regenerative heat exchanger was studied by several authors. MacDuff and Clark, for example, present an overview of radial sealing systems [11]. The general conclusion is that the sealing system is an important part of a rotary heat exchanger. Janez Oman et al. and Sepehr Sanaye et al. explained the constant monitoring of the seals' settings in order to ensure their optimum operation under various working conditions [6, 8]. Although the leakages in the air preheater do not significantly affect the boiler's overall thermal efficiency [3], but excessive leakages can reduce the effectiveness of the air preheater itself by over 10 % [14]. Nair et al. solved heat conservation equations using a finite difference approach and estimated the effectiveness and the effect of axial heat dispersion on the exchanger performance [12]. That is, heat is not transferred continuously through the wall as in a direct transfer type exchanger (recuperator), but is alternately stored and rejected by the matrix wall. Since the rotary air preheater operates high temperature the matrix will be expanded in the hot gas stream and be shrinking in the cold fluid stream. At the same time, the inlet gas temperature, gas flow rate and properties are varied momentarily; a mushroom deformation is inevitable [10]. The result is not only the leakage but also mechanical friction which seriously affects the efficiency and security of the system. Therefore, a significant weakness of this type of heat exchanger is the unavoidable flow leakage from the clearance of the rotation matrix due to its thermal stress deformation.

It is very much important in every industry to pay special attention to measure the air leakage through rotary air preheater and adjust the sealing clearance. But it is very difficult task to identify the leakage amount for industry and also there are no simple methods or calculations available to estimate the losses in big industry. In the present paper, a DCS based instrumentation model has been described. This model is so designed that online monitoring of air leakage in rotary air preheaters is possible and accordingly preheater's seal tightness can be adjusted. The method is based on the results of numerical simulations. A numerical method has been developed that makes it possible to simulate the leakages in the rotary air preheater and implemented in DCS based steam generation unit.

In DCS system, all these functions are performed on the basis of digital calculations along with proper supervision of the operations of the whole system. This ensures more accurate and faster operation of the plant compared to the earlier manual system by checking excess O₂% in plant laboratory, which is discussed in later parts. The manual conventional system found more erratic and totally non reliable to identify the amount of leakage through rotary air preheaters. This may sometimes misguide the plant persons. These problems may lead to loss of energy, decrease in efficiency, increase in maintenance cost, life time degradation of rotary air preheaters, and environmental effect etc. Hence the aim of this paper is to introduce a new approach for measuring the leakages on continuous basis to the boiler or furnace operation to minimize all foreseen problems. This continuous monitoring system has been designed in DCS based instrumentation blocks. The function of this new approached continuous monitoring system block has been analyzed and the corresponding mathematical equations have been developed.

2. Heat Recovery Process

The air/gas system can be considered a heart of the furnace, in which combustion of gas takes place. In furnace large quantity of heat is generated. It depends upon the calorific value and quantity of fuel. About 5 to 8 % of excess air is added in furnace with help forced draught (FD) fan, for complete combustion of fuel. If more air is added it cools the furnace and consumes more fuel, in the result increases the production cost of steam. Part of heat is transferred through boiler tubes which are directly used to produce steam. Boiler efficiency is increased by recovering heat from flue gas in superheater coil, high temperature economizer, low temperature economizer and air preheater. Required quantity of air for combustion in boiler is supplied with help of forced draught fan.

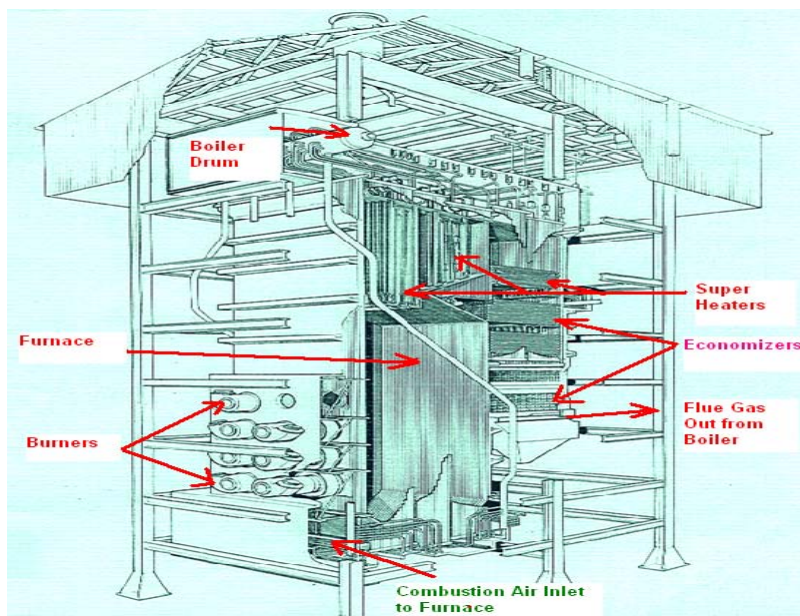


Fig. 2. Overview of high capacity boiler.

The schematic view of rotary air preheater is shown in Fig. 3. In this schematic, four K-type thermocouple sensors are used to measure the temperatures of hot flue gases, cold flue gases, hot combustion air and cold combustion air. One oxygen analyzer is used to measure excess oxygen percentage in flue gas placed at the exit point of boiler and before rotary air preheater.

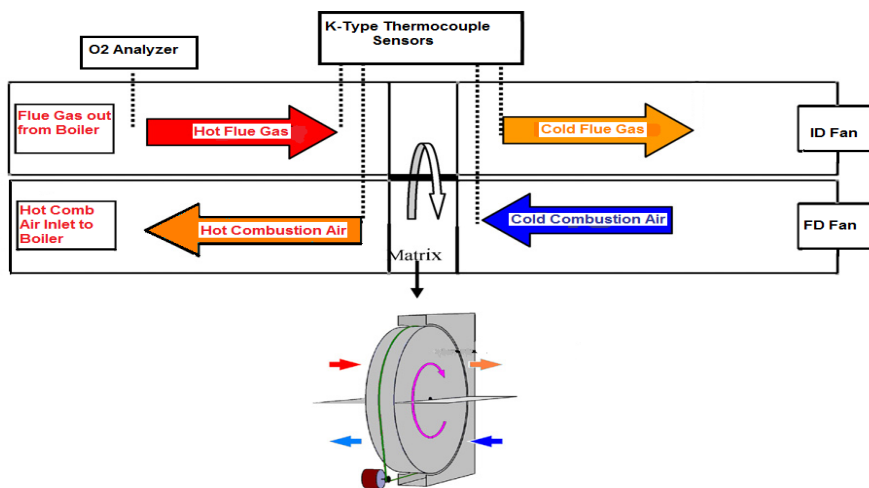


Fig. 3. The schematic view of the rotary air preheater.

3. Conventional Rotary Air Preheater Operation, Measurement of Leakages and Related Problems

3.1. Rotary Air Preheater and its Operation

For high capacity boilers as shown in Fig. 2, there are two rotary air preheaters present to recover the waste heat from flue gases. Both rotary air preheaters, located at the rear of the boiler, are of the rotary regenerative type with rotating elements arranged for air and flue gas in vertical contra flow. Each air preheater comprises a stationary casing with connections for flue gas and air ducts as shown in Fig. 1. A cylindrical rotor is segmented into twelve sectors radially disposed about a double bearing supported central shaft. Two horizontal layers of heating elements are arranged within the rotor. A schematic view of the rotary air preheater with different field instruments is shown in Fig. 3. Hot flue gas ducted from the economizer outlet enters the rotary air preheaters at the top and passes through the rotating heating elements whose surfaces extract the heat. The cooled gas is discharged through the bottom of the casing where it connects the induced draught duct. Air, via the forced draught fan, enters the rotary air preheaters at the bottom and passes through the heated rotating elements whose surfaces impart their heat to the combustion air. The rotating elements are continually regenerated and cooled as they pass through the gas and air paths. The top mounted discharge connects the air to plenum chamber duct, which is fitted with a hot air recirculation branch. During boiler startup conditions, hot air is returned to the forced draught suction thereby swiftly raising the element cold end temperature above the acid dew point.

Air flow is separated from the gas flow by radial plates which form a labyrinth type seal between rotor and casing. Air or gas is prevented from bypassing the rotor by circumferential plates, which locate against a sealing ring attached to the stator casing. Both types of double skin flexible seals are attached to the rotor and adapt to thermal deformation as well as axial movement. The main drive is from an electric motor located to one side of the unit. Diametrically opposite, an air motor provides a standby. Both drives engage their respective pinions into a common rotor pin-rack attached to the rotor outer circumference. The motors are geared and each attaches its final drive shaft to a pinion located in sealed housings. Only one drive must operate at a time and each pinion is engaged into the pin-rack by means of a feed screw sliding mechanism. Oil lubricated spherical roller thrust bearing supports the rotor at the bottom in the “cold end”. The “hot end” houses grease lubricated, self-aligning, double roller guide bearing. Heat is dissipated from both bearings and stub shafts by a cooling system, which circulates water in via the thrust bearing and out via the guide bearing. Single nozzle soot blowers are arranged above and below the rotor in the gas ducting such, that when the blowers traverse the rotating elements complete cleaning is effected. Both soot blowers are linked to an external common vertical pipe fitted with expansion bellows, sliding seals, an actuator and a steam connection. During the fifteen minutes sequential soot blowing cycle, the operation of the motorized actuator attaching the common vertical pipe actions the blowers to traverse in unison through an arc of approximately 40^oC.

Four weatherproof thermocouples, located in each of the gas inlet/outlet and air inlet/outlet ducts are connected by compensating cables to an externally mounted junction box. In old system (not present in existing system), there was fire alarm initiated If a higher air to gas temperature differences obtains and visual confirmation of a fire must be determined before operating the fire extinguishing system and then only after the emergency procedures have been implemented. The rotating, profiled guide bearing end cap is monitored by a sensor, which sends pulse signals to a control box. In the event that the signal is broken, an alarm indicating “Rotary Air Preheater Stopped” is initiated.

The basic element of a rotary heat exchanger’s operation is a rotating matrix in a compact casing that transfers the heat from the hot flue gas to the cold combustion air. The rotation of the matrix requires an appropriate sealing system to prevent mixing of the flue gas and the air, commonly referred to as

leakage. The importance of sealing and leakage and its influence on air-preheater performance checking is very much important in industry. At the same time, leakages require more air to be transported to the preheater and more flue gas to be transferred from the preheater, and larger quantities of gases require more power for forced draught and induced draught fans. These fans typically consumed more powers in the power plants. An increased amount of power required for the fan results directly in a noticeable drop in the power plant's overall efficiency. It is therefore important to pay special attention to the adjustment of the seals and to monitor the air leakages continuously.

3.2. Conventional Procedure for Measuring Leakages in Rotary Air Preheater

Different methods and procedures are discussed by different authors for low capacity applications in very small industries or laboratory experimental purpose. But yet these methods are very much away from high capacity industrial applications. Most of the industries, there is no standard procedure to check the amount of air leakages and also many boiler manufacturers do not provide the standard instrumentation system to measure the leakage percentage or leakage air amounts. Hence most industrial persons are not concentrating in this portion and try to avoid unless there is any big problem like high pressure drop across rotary air preheaters, high current consumption in induced and forced draught fans etc. In this situation, normally industries adopt the manual conventional method, i.e., plant person takes the flue gas samples from before and after rotary air preheater and analyzed in plant laboratory by measuring the excess oxygen percentage, carbon monoxide, carbon-di-oxide and nitrogen percentages in flue gas samples. From the laboratory analysis, normally check the difference of excess oxygen percentage before and after rotary air preheater, if experience persons found acceptable range, close the case of rotary air preheater leakages or if found big difference, try to delay the seal leakage inspection up to annual shutdown. But practically it is observed that this conventional method is tedious, very much error full method and these results also confuse the plant persons as stated below.

3.3. Different Problems Related Rotary Air Preheater

Different problems are observed in rotary air preheater, some are related to technical and some are related to practical operation problems as stated below.

3.3.1. Thermal Degradation

From the point of view of the user of the heat recovery equipment, the distinction between different types of regenerative heat exchange may be regarded as largely academic, as each type of heat exchanger in different categories has its own merits and drawbacks. A much more important distinction in the selection of heat recovery equipment is the operating temperature range. Temperature of course can have adverse effects on heat exchanger materials at both ends of the scale. If temperatures are too low, brought about by the removal of too much heat from the exhaust gases, the dew point may be reached and condensation can result in corrosive products affecting heat exchanger materials. The life of heat exchangers used at high temperatures can be seriously reduced if incorrect materials are selected. Even ceramics are not immune in exhausts from heavy oil-fired boilers or furnaces. The rotating matrix in a compact casing used in rotary air preheater or other heat recovery systems such as heat pipes and run-around coils may also be subject to thermal degradation if temperature limits are exceeded. Safety aspects in such pressurized systems should also not be neglected and use of toxic working fluids should be communicated to the customer--this is mandatory under some health and safety regulations, but is by no means universal.

3.3.2. Fouling

Another aspect of particular importance in process applications of gas-gas heat recovery equipment is fouling. The accumulation of matter on the heat exchange surface affects both pressure drop and heat transfer, and 'disposable' heat exchanger elements are offered by some manufacturers as an alternative to regular cleaning, which may be difficult or necessitate process shut-down for extended periods. The use of disposable units can generally only be entertained if the cost is low, however. The designer of gas-gas heat recovery systems must, because, at least in the case of industrial installations, the majority of units are still retrofitted to plant, make sure that the installation is easy to implement, and the unit has a minimum effect on plant operation. It may be said that practicalities associated with installation, operation, maintenance and, of course, economics, take precedence over thermal design. A few points improvement in thermal efficiency is meaningless to the process plant manager if the design does not meet his many other requirements.

3.3.3. Leakage Measurement in Manual Conventional Method

From the point of view of operation, leakage testing of conventional method is very tedious. Because flue gases are sucked by induced draught fans and also maintained the balanced draught in furnace (normally with vacuum pressure at -5 mmWC). Hence sample cannot be collected without motor operated pump. Normally samples are collected in 3 balloons to get the average value by the pump, where firstly sample collectors are to be ensured to avoid the chance of air mixing at the suction of the pump. Hence this is a tedious job to collect samples from 4 points (2 Nos. x 2 (before and after) for each rotary air preheater) for one boiler. Also it is required minimum 2 hours for arranging and taking the samples from these 4 points for one boiler. Then these samples are analyzed in the plant laboratory and observed three different values for the same point samples. Also observed same sample analyzed in different time span recording different result in the sense of higher oxygen percentage. This task repeated for continuous six days with maintaining same oxygen percentage in furnace measured by oxygen analyzer, but observed different results of flue gas in the inlet of rotary air preheater. Hence this method is very much unreliable and may cause faulty diagnosis about the leakage. These errors are come due to different probable reason as follows:

- Air mixing due to residual air presence or leakage in suction of pump.
- Flue gas condition changed as in before rotary flue gas temperature above 270°C and flue gas after collection in balloons less than 40°C .
- Manual analysis error.

4. The Model for Continuous Leakage Monitoring in Rotary Air Preheater

The idea of introducing a model of continuous rotary air preheater leakage monitoring originates from the above observed or faced problems with conventional measuring procedure for big industries. The basic function of this new approached continuous leakage monitoring system is to keep the close monitoring the performance of rotary air preheaters in boiler or furnace. This model will help to minimize all the above tedious and error full method and show the proper direction to improve the plant efficiency. The basic design concept is to introduce the another oxygen analyzer to measure the flue gas oxygen percentage in outlet of rotary air preheater as shown in Fig. 4 and then develop the mathematical model to find out the leakage percentage and amount of leakage air present in rotary air heater. For this model, considering the single unit system with single rotary air preheater, single forced draught and single induced draught fan, as shown in Fig. 4.

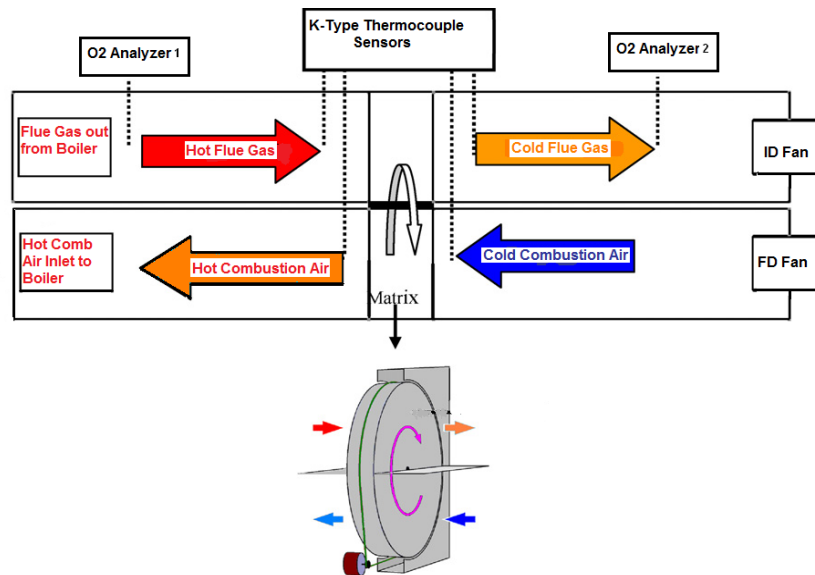


Fig. 4. The modified schematic view of the rotary air preheater.

In Fig. 4, new oxygen analyzer (O2 Analyzer2) is introduced with same make and same configuration to maintain the same reference of measurement. In this model, we are considering the single rotary air preheater with single forced draught and induced draught fans. Also considered single air flow transmitter to measure the combustion air to develop the simple model of rotary air preheater.

NOMENCLATURE

C_p	specific heat (kCal/kg/°C)	ac	refers to air to combustion
E	excess air (%)	ai	refers to air inlet
F	flow rate (kg/h)	al	refers to air leakage
HL	heat Loss (kCal/h)	ao	refers to air outlet
K	constant (dimensionless)	ca	refers to combustion air
L	infiltration in Furnace (kg/h)	gi	refers to gas inlet
O	oxygen concentration (%)	gl	refers to flue gas leakage
Q	heat flow rate (kCal/h)	go	refers to gas outlet
T	Temperature (°C)	gw	refers to flue gas waste to chimney
<i>Subscripts</i>		ta	refers to theoretical air
a	refers to air	tg	refers to total flue gas waste to chimney
f	refers to fuel	G	refers to gain
g	refers to flue gas	O	refers to oxygen
		R	refers to released
		AFR	refers to air fuel ratio

Let the fuel flow rate in boiler be F_f kg/h measured by fuel flow meter and the theoretical air requirement for stoichiometric combustion of fuel is K_{AFR} kg/h for per kg of fuel flow, which is constant for particular fuel, also called as theoretical air to fuel ratio.

Therefore theoretical air flow F_{ta} requirement for stoichiometric combustion of fuel be

$$F_{ta} = F_f \times K_{AFR} \quad (1)$$

But in practice, theoretical air is not sufficient for complete combustion. So certain amount of excess air is needed for good combustion and ensures that release of the entire heat contained in fuel. This excess air requirement depends upon the type fuel burning in furnace and the design of the burners. If too much air than what is required for complete combustion were allowed to enter, additional heat

would be lost in heating the surplus air to the chimney temperature. This would result in increased stack losses. With these heat losses, forced draught and induced draught fans load are also increased due to excess air and causes electric power losses. Again less air would lead to the incomplete combustion and smoke in chimney, i.e. air pollution. Hence, there is an optimum excess air level for each type of fuel.

Let the excess oxygen percentage in flue gas be O_{gi} at rotary air preheater inlet, which is measured by online oxygen analyzer that is mounted on path of flue gas exit from the boiler. Excess air E in percentage is given by the standard formula

$$E = \frac{O_{gi}}{21 - O_{gi}} \times 100 \quad (2)$$

Therefore required air flow supplied to the boiler be F_{ca} kg/h for maintaining the above excess air percentage in flue gas, which is called the combustion air.

$$F_{ra} = \left(1 + \frac{E}{100}\right) \times F_{ca} \quad (3)$$

Normally in air 77% by weight is nitrogen and 23% by weight oxygen present (K_o), which is constant. Nitrogen reduces the combustion efficiency by absorbing heat from the combustion of fuels and diluting the flue gases. This reduces the heat available for transfer through the heat exchange surfaces. It also increases the volume of combustion by products, which then have to travel through the heat exchanger and up the stack faster to allow the introduction of additional fuel air mixture. Now in combustion air (F_{ca}), net oxygen present be F_o kg, which takes part in combustion.

$$F_o = F_{ca} \times K_o \quad (4)$$

In rotary air preheater, sizable porous disk, fabricated with material having a fairly high heat capacity, rotates between two side-by-side ducts: one a cold gas duct, the other a hot gas duct. The axis of the disk is located parallel to, and on the partition between, the two ducts. As the disk slowly rotates, some amount cold air passes to the hot air path due to seal leakage and similarly some amount of hot air directly mix with the cold air due to ejecting process. Because cold air which passes through the rotary air preheater, having positive discharge pressure with high velocity developed by the forced draught fan and hot flue gases passes through the other side of the rotary air preheater, having negative suction pressure with low velocity developed by the induced draught fan.

Let the total cold air discharges from the forced draught fan be F_a kg/h, in which F_{ac} kg/h directly goes to the furnace as a combustion air and F_{al} kg/h goes to the stack as a leakage air.

$$F_a = F_{ac} + F_{al} \quad (5)$$

Let the flue gas flow amount be F_g kg/h, in which F_{gl} kg/h directly mixes with the combustion air due to leakage and F_{gw} kg/h goes to stack, which contains O_{gi} % oxygen.

$$F_g = F_{gl} + F_{gw} \quad (6)$$

But actual flue gas flow before rotary air preheater is the sum of combustion air, fuel flow (F_f) and infiltration air (L) in furnace (Considering all fuels causes approximately equal amount of flue gases). Therefore actual flue gas F_g can be written as by Mass Balance equation,

$$F_g = F_{ac} + F_{gl} + F_f + L \quad (7)$$

Therefore total flue gas flow (F_{tg}) after rotary air preheater is the sum of flue gas F_{gw} and leakage air F_{al} , which are sucked by induced draught fan and sent to the stack.

$$F_{tg} = F_{gw} + F_{al} \quad (8)$$

Now from the oxygen balance equation, Oxygen supplied through the combustion air is equal to the total oxygen required for the complete combustion.

$$F_{ac} \times K_O + F_{gi} \times O_{gi} + L \times K_O = F_O \quad (9)$$

Let the excess Oxygen percentage at the outlet of RA heater be $O_{go}\%$. Hence after rotary air preheater oxygen balance equation can be written as below.

$$F_{gw} \times O_{gi} + F_{al} \times K_O = F_{tg} \times O_{go} \quad (10)$$

or

$$F_{gw} \times O_{gi} + F_{al} \times K_O = (F_{gw} + F_{al}) \times O_{go} \quad (11)$$

Therefore equation (11) can be written as

$$F_{al} = \frac{O_{go} - O_{gi}}{K_O - O_{go}} \times F_{gw} \quad (12)$$

Let the inlet flue gas temperature at rotary air preheater be T_{gi} °C and the outlet flue gas temperature after heat transfer to cold air and mixing with leakage cold air from the rotary air preheater is T_{go} °C. At the same time, inlet cold air temperature is T_{ai} °C (which is also ambient temperature) and after heat gained from the rotary air preheater, hot combustion outlet air temperature is T_{ao} °C.

Now heat released Q_R by hot flue gas to the matrix of rotary air preheater is given by,

$$Q_R = F_{gw} \times C_{pg} \times (T_{gi} - T_{go}) + F_{gi} \times C_{pg} \times (T_{gi} - T_{ao}) \quad (13)$$

This heat gained Q_G by the cold air and some losses in rotary air preheater. Therefore total heat gained by the cold air

$$Q_G = F_{ac} \times C_{pa} \times (T_{ao} - T_{ai}) + F_{al} \times C_{pa} \times (T_{go} - T_{ai}), \quad (14)$$

where C_{pg} is the specific heat of flue gas and C_{pa} is the specific heat of air.

Therefore from the heat balance equations (13) & (14), we get

$$F_{gw} \times C_{pg} \times (T_{gi} - T_{go}) + F_{gi} \times C_{pg} \times (T_{gi} - T_{ao}) = F_{ac} \times C_{pa} \times (T_{ao} - T_{ai}) + F_{al} \times C_{pa} \times (T_{go} - T_{ai}) + HL \quad (15)$$

where HL is the heat losses in rotary air preheater.

For Ideal Case, if we assume negligible infiltration of leakage air L into the furnace, and heat loss in the RA heater HL be small compared with the heat transferred to combustion air to preheat, then from equations (6), and (7),

$$F_{gw} = F_{ac} + F_f \quad (16)$$

The equation (9) can be written as,

$$F_{ac} \times K_O + F_{gl} \times O_{gl} = F_{ca} \times K_O \quad (17)$$

Again, F_{gl} leakage flue gas, which directly mixes with the combustion air due to rotary air preheater leakage, is not taking part the combustion as oxygen concentration is very low than the air and equal to flue gas oxygen concentration. Therefore from equation (18),

$$F_{ac} = F_{ca} \quad (18)$$

Then equation (16), can be written as

$$F_{gw} = F_{ca} + F_f \quad (19)$$

And equation (11) and (19), we can get leakage air F_{al} in rotary preheater,

$$F_{al} = \frac{O_{go} - O_{gl}}{K_O - O_{go}} \times (F_{ca} + F_f) \quad (20)$$

As heat loss in the RA heater HL is small compared with the heat transferred to combustion air to preheat, then from equations (15), leakage flue gas F_{gl} can be derived by

$$F_{gl} = \frac{F_{ca} \times C_{pa} \times (T_{go} - T_{ai}) + F_{al} \times C_{pa} \times (T_{go} - T_{ai}) - F_{gw} \times C_{pg} \times (T_{gl} - T_{go})}{C_{pg} \times (T_{gl} - T_{go})} \quad (21)$$

where F_{ac} , F_{al} and F_{gw} are already derived from equations (18), (20) and (19) respectively. All temperatures T_{gi} , T_{go} , T_{ai} and T_{ao} are online process parameters measured by K-type thermo-couple sensors and C_{pa} , C_{pg} are constant.

The schematic model for continuous leakage monitoring system is shown in Fig. 5, which is DCS based system.

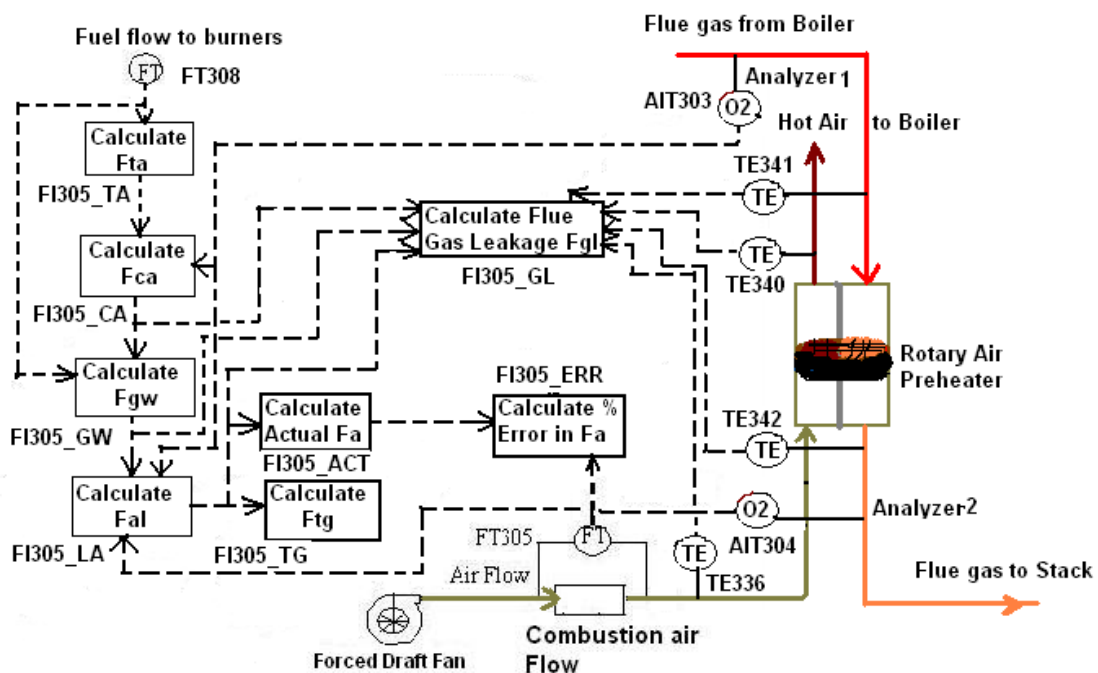


Fig. 5. Proposed DCS based Model for Continuous Leakage Monitoring.

By using this model, any operator can also easily diagnose the problem of rotary air preheater, cross check the total air discharge flow by the forced draught fan, different losses of air and heat and also compare the induced draught fan and forced draught fan motor energy consumption with air leakage and without air leakage through rotary air preheater. Hence the effective efficiency of the power plant will increase since for the same output power the flue gas flow rate decreases after rectification of leakage.

5. Implementation and Testing of the Proposed Model for Continuous Leakage Monitoring of Rotary Air Preheater on Three High Capacity Boilers of a Biggest Fertilizers Industry in India

The proposed model for continuous monitoring of rotary air preheater leakage as shown in Fig. 5 has been designed and installed in a DCS based control systems in steam generation plant of naphtha and natural gas based fertilizer plant at the Thal unit of Rashtriya Chemicals and Fertilizers Ltd. (RCF) in India. The description of the steam generation plant is as under. A photo of Steam Generation Plant is showing in Fig. 6.



Fig. 6. Steam Generation Plant.

The Steam Generation Plant consists of three boilers, each having capacity of 275 MT/H steam pressure and temperature is maintained 100 kg/cm^2 (Design: 105 kg/cm^2) and $510 \text{ }^\circ\text{C}$. in H.P steam header, respectively. Out of the three boilers, two boilers are in service and third boiler is kept as standby. These boilers are designed for natural gas as a fuel. Since 1997 naphtha is as a supplement to natural gas fuel.

The proposed model firstly installed in one boiler, where previously Rosemount RS-3 DCS and now Honeywell Experion PKS DCS has been used for operation and controlling the full steam generation plant and Rockwell Control-Logix systems used for burner management system of each boiler. Before taking in line, this model was simulated and tested many times and successfully implemented this proposed design of continuous leakage monitoring in rotary air preheater. This boiler was tested after implementing this model with load variation from 60 % to 100 % of MCR as per steam demand by downstream plants, where normal running load is 70 % to 80 %. In the proposed model is very much useful to plant person to continuous monitor of leakage air, leakage flue gas in rotary air preheater, total flue gas, total required combustion air and also accuracy of air flow meter. After satisfactory operation, this new approached for continuous monitoring model implemented in other two boilers and quite satisfactory operation has been observed for a long period of 4 years. The typical parameters are recorded in different time for different boilers as shown in below. In Table 1 is showing the design

data of boiler for natural gas and naphtha fuel supplied by boiler manufacturer. In Table 2, some data are given for Boiler-3, where steam load are almost same level. These data are taken after implementation of this continuous leakage monitoring model with old DCS (Rosemount RS-3) and found results in Table 3, which gives surprising results about the performance of the proposed model. Table 4 & Table 5 give a comparative study between the operation of the previous system without the proposed model and the present system with the proposed model.

After implantation and attending jobs, observed some behavior O₂ Analyzer2 (AIT304) reading as shown in Fig. 7.

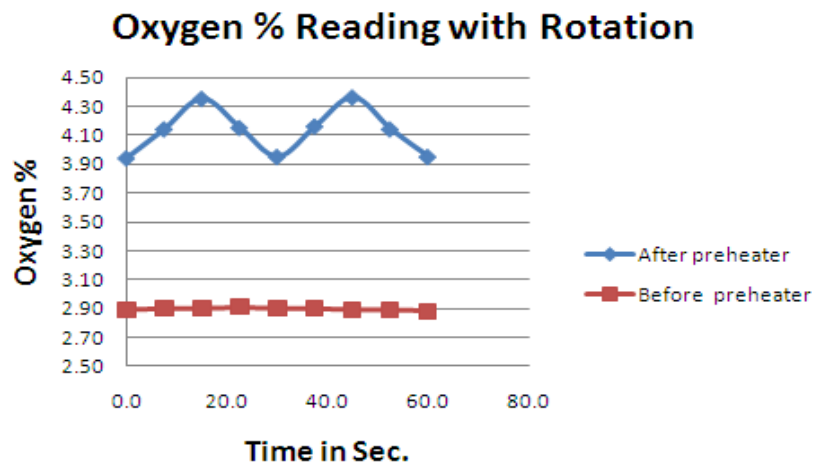


Fig. 7. Leakage Characteristics in Rotary Air Preheater.

6. Discussions on Operation Strategy and Advantages

In the proposed model for continuous leakage monitoring system of rotary air preheater as shown in Fig. 6, where new O₂ Analyzer2 (AIT304) is installed after rotary air preheater with same make, model (Rosemount – World Class 3000) and same configurations of existing O₂ Analyzer1 (AIT303) to remove the measurement error. In this model, other measuring points, fuel flow meter (FT308), air flow meter (FT305), oxygen analyzer1 (AIT303), cold air temperature (TE336), hot air temperature (TE340), hot flue gas temperature to rotary air preheater inlet (TE341) and cold flue gas temperature from rotary air preheater outlet (TE342) are used for this model as shown in Fig. 6. In this model, firstly calculated the theoretical air F_{ta} in FI305_TA block by equation (1). Then combustion air F_{ca} in FI305_CA by equation (2), flue gas to stack F_{gw} in FI305_GW by equation (19), leakage air F_{al} in rotary air preheater in FI305_LA by equation (20), and leakage flue gas F_{gl} in rotary air preheater in FI305_LA by equation (21) are calculated followed by one another respectively. In this model, also total flue gas F_{tg} in FI305_TG and actual air flow F_a in FI305_ACT block are configured for continuous monitoring. Lastly another important block FI305_ERR is configured to know the accuracy of air flow meter as shown in Fig. 6. All these blocks are configured in DCS of Honeywell Experion PKS for continuous monitoring of rotary air heater performances.

The some experimental data in Table 2 and Table 4 are recorded, where Table 2 showing the normal running condition of boiler after immediate implementation of continuous leakage monitoring model in boiler-3 and Table 4 showing the improved condition after attending seal leakage in rotary air preheater. Table 1 is showing the design data for these boilers. Table 3 and Table 5 are showing the results before attending and after attending seal leakage in rotary air preheater respectively. Before implementation of this model, many times samples taken by Lab person as per conventional method for the same boiler and every time found different reading, which confused the management to get the

clear idea, whether rotary air preheater is running with leakages in acceptable or unacceptable condition. After implementation of this model in DCS, the result shown in Table 3 surprised and found higher leakages (almost 16 %) in rotary air preheater, although new rotary air preheater replaced within a year in place of old damaged rotary air preheater, where all matrix were totally damaged and more energy were consumed by forced and induced draught fans. In the other boilers also we observed more than 20 % leakages after implementation of this continuous leakage monitoring model. Also it is observed from Table 2, air flow meter reading is showing too much high than the actual value and from Table 3, result showing almost 30% error in flow meter reading. These boilers were running with this inaccurate reading last 23 years since plant commissioning. After attending all jobs, Table 4 and Table 5 are showing the improvement of the rotary air performance, where air leakage reduced from 16 % to 8.6 %. Actual air flow also reduced from 314 T/H to 285 T/H, although another part of air flow reduction is maintaining lower excess percentage of oxygen in furnace, as new optimum combustion control system is installed in place of conventional cross-limiting combustion control. The basic design concept of optimum combustion control system is to introduce the parallel type air-fuel combustion control and cross-limiting type (or lead-lag type) combustion control technique designed in one control system. More details are explained in another research paper.

Table 1. Design data of boiler for natural gas and naphtha fuel.

Fuel	Natural Gas (NG)		Naphtha	
	MCR	75 %	MCR	75 %
Evaporation rate (T/H)	275.00	206.50	275.00	206.50
Fuel consumption (T/H)	16.454	12.350	17.20	12.90
Air to fuel ratio (T/T)	17.35	17.35	15.2	15.2
Excess air in furnace (%)	8.0	8.0	10.0	10.0
Excess air in rotary air preheater inlet (%)	10.0	10.0	12.0	12.0
Excess air in rotary air preheater outlet (%)	20.0	20.0	22.00	22.00
Total combustion air (T/H)	285.5	214.3	261.4	196.1
Air to FD fan (T/H)	308.3	231.4	287.5	215.7
Rotary air preheater inlet air (T/H)	314.1	237.7	292.8	219.6
Rotary air preheater outlet air (T/H)	342.6	257.2	318.9	239.2
Leakage air in rotary air preheater (T/H)	28.5	19.5	26.1	19.6
Total air flow from forced draught fan (T/H)	336.8	250.9	313.6	215.7
Hot air to windbox temperature ($^{\circ}$ C)	200	168	200	168
Rotary air preheater inlet temperature ($^{\circ}$ C)	272	251	272	251
Rotary air preheater outlet temperature ($^{\circ}$ C)	135	135	135	135
Flue gas at induced draught fan and stack temperature ($^{\circ}$ C)	130	130	130	130
Ambient temperature ($^{\circ}$ C)	40.0	40.0	40.0	40.0

Table 2. Experimental Data of Boiler-3 after implementation on April' 2006.

Time	Steam Flow (T/H)	Naphtha Flow (T/H)	Burn NG Pr. Kg/cm ²	Steam Temp. $^{\circ}$ C	Air Flow (T/H)	Flue Gas O ₂ % before Air pre heater	Flue Gas O ₂ % after Air pre heater
13.00	236	13.6	0.138	511	406	3.65	5.68
18.00	238	13.7	0.135	512	409	3.57	5.60
19.00	238	13.7	0.135	512	409	3.58	5.60
20.00	237	13.6	0.135	512	407	3.64	5.67

Table 3. Average reading and experimental result of boiler-3 on April'2006.

Fuel	Naphtha
Average evaporation rate (T/H)	237
Average naphtha fuel consumption (T/H)	15.0
Average excess O ₂ % before air preheater	3.61
Average air flow (T/H)	408
Average excess O ₂ % after air preheater	5.64
Hot air to windbox temperature (°C)	179
Rotary air preheater inlet temperature (°C)	252
Rotary air preheater outlet temperature (°C)	112
Ambient temperature (°C)	30
Atomizing steam flow rate (T/H)	1.0
Air to fuel ratio (T/T)	15.2
Specific heat of air (kCal/kg/°C)	0.22
Specific heat of flue gas (kCal/kg/°C)	0.23
Results	
Theoretical combustion air F _{ta} (T/H) from equation (1)	228
Excess air in air preheater inlet E (%) from equation (2)	20.8
Excess air out air preheater Outlet (%) from equation (2)	36.7
Total combustion air F _{ca} with 20.8% excess air into air preheater (T/H) from equation (3)	275.4
Flue gas to stack F _{gw} (T/H) from equation (19)	291.4
Leakage air F _{al} in rotary air preheater (T/H) from equation (20)	38.5
Total flue gas F _{tg} to stack (T/H) from equation (8)	330
Leakage flue gas F _{el} in rotary air preheater (T/H) from equation (21)	20.2
Actual air flow F _a in forced draught fan discharge (T/H) from equation (5)	314
Error in flow measurement by aerofoil in boiler (%)	29.9

Table 4. Experimental Data of Boiler-3 after attending the problems on May'2006.

Time	Steam Flow (T/H)	Naphtha Flow (T/H)	Burn NG Pr. Kg/cm2	Steam Temp. °C	Air Flow (T/H)	Flue Gas O ₂ % before Air pre heater	Flue Gas O ₂ % after Air pre heater
6.00	240	13.7	0.135	508	309	2.91	4.17
7.00	240	13.7	0.135	508	311	2.90	4.16
8.00	240	13.7	0.135	508	311	2.88	4.15
9.00	240	13.7	0.135	508	312	2.91	4.16
10.00	240	13.7	0.135	508	312	2.89	4.15
11.00	240	13.7	0.135	508	312	2.90	4.15
12.00	240	13.7	0.135	508	312	2.88	4.13
13.00	240	13.7	0.135	508	313	2.91	4.16
14.00	240	13.7	0.135	508	313	2.90	4.15
15.00	240	13.7	0.135	508	313	2.90	4.15
16.00	240	13.7	0.135	508	313	2.92	4.17
17.00	240	13.7	0.135	508	313	2.90	4.15
18.00	240	13.7	0.135	508	313	2.91	4.16
19.00	240	13.7	0.135	508	313	2.89	4.15
20.00	240	13.7	0.135	508	313	2.90	4.15
21.00	240	13.7	0.135	507	313	2.90	4.15
22.00	240	13.7	0.135	508	313	2.90	4.15
23.00	240	13.7	0.135	508	313	2.92	4.17
0.00	240	13.7	0.135	508	313	2.90	4.15
1.00	240	13.7	0.135	508	312	2.90	4.15
2.00	240	13.7	0.135	508	312	2.90	4.15
3.00	240	13.7	0.135	508	312	2.91	4.16
4.00	240	13.7	0.135	508	312	2.90	4.15
5.00	240	13.7	0.135	508	311	2.89	4.14

Table 5. Average reading and experimental result of boiler-3 on after attending the problems on May'2006.

Fuel	Naphtha
Average evaporation rate (T/H)	240
Average naphtha fuel consumption (T/H)	15.0
Average excess O ₂ % before air preheater	2.90
Average air flow (T/H)	312
Average excess O ₂ % after air preheater	4.15
Hot air to windbox temperature (°C)	181
Rotary air preheater inlet temperature (°C)	252
Rotary air preheater outlet temperature (°C)	114
Ambient temperature (°C)	30
Atomizing steam flow rate (T/H)	1.0
Air to fuel ratio (T/T)	15.2
Specific heat of air (kCal/kg ⁰ C)	0.22
Specific heat of flue gas (kCal/kg ⁰ C)	0.23
Results	
Theoretical combustion air F _{ta} (T/H) from equation (1)	228
Excess air in air preheater inlet E (%) from equation (2)	16
Excess air out air preheater Outlet (%) from equation (2)	24.6
Total combustion air F _{ca} with 16% excess air into air preheater (T/H) from equation (3)	264.5
Flue gas to stack F _{gw} (T/H) from equation (19)	280.5
Leakage air F _{al} in rotary air preheater (T/H) from equation (20)	20.8
Total flue gas F _{lg} to stack (T/H) from equation (8)	301.3
Leakage flue gas F _{gl} in rotary air preheater (T/H) from equation (21)	16.4
Actual air flow F _a in forced draught fan discharge (T/H) from equation (5)	285.3
Error in flow measurement by aerofoil in boiler (%)	9.3

With the above points, one peculiar behavior observed in O₂ Analyzer2 (AIT304) readings as shown in Fig. 7, where graph is showing in sinusoidal characteristics with time and the same time O₂ Analyzer1 (AIT303) graph is almost straight line. Also observed that two sinusoidal wave form within one minute, which is indicating the rotation of rotary air preheater. This is also indicating that seal setting is not perfectly done at every point.

Above model is discussed for single rotary air preheater with single forced and induced draught fans boiler for simplifying and better understanding of this model. Actually two rotary air preheaters system with two forced and induced draught fans boiler is more complicated, because two models are combining in one boiler with load sharing block between forced draught and induced draught fans. Hence in this paper, simple model is considering for single rotary air preheater with single forced and induced draught fans for all combustion air and flue gas flow.

Since this continuous leakage monitoring model is designed and implemented in a big industry, so it was not possible to show all results and the performance of the rotary air preheater than the conventional method. Although some improvements are observed from the Table 4 and Table 5 than the Table 2 and Table 3. With that some other advantages have been achieved by using this continuous leakage monitoring system as follows:

- 1) By adopting this model, plant person can avoid the conventional tedious and error full methods. Also this method directs the pin point of rotary air preheater problem, which was not possible by conventional method.
- 2) This model helps to set the rotary air heater seal by showing the leakage characteristics, which cannot imagine by conventional method.

- 3) This continuous leakage monitoring model indicates the performance of rotary air preheater, which was not possible by conventional method.
- 4) Also by this model, measure the accuracy of air flow meter. Plant was running with 30% inaccurate air flow indication last 23 years since commissioning. Although in high capacity boiler, normally air flow measures by aero-foil, whose accuracy is $\pm 10\%$. After implementing this model, observed the accuracy beyond the limit, diagnosis and rectified the problem, result in Table 5 showing now within the limit.
- 5) As leakage air decreases, then power consumption in forced draught and induced draught fans also decreases. Previously observed higher current readings for the same steam production.
- 6) As leakage air decreases after attending the seal leakage, hot air temperature (TE340) increases by 2°C . Hence proposed model must help for improving the efficiency of power plant.

7. Conclusion

Proposed continuous leakage monitoring system is the real industries based application and it is very much simple to understand and also easily can implement by plant instrument or control system person. This continuous leakage monitoring system definitely helps to minimize all above problems and try to reduce the environmental effect. Hence our vision is to be published this model for industrial growth to achieve more efficiency and minimize the loss of global energy.

Acknowledgements

The authors would like to acknowledge the RCF management to study, diagnosis the problems, design a continuous leakage monitoring system and incorporate such of type new design in high capacity boilers.

References

- [1]. Operation and Maintenance Manual for Dual Fuel Conversion (Naphtha/ Natural Gas) of existing Service Boilers, Vol-1 for Burners Logic and Combustion Control, *Thermax Babcock & Wilcox Limited*.
- [2]. Steam, Its Generation and Use, *BabCock & Wilcox Co*, New York.
- [3]. Technical, Operation, Maintenance & Controls Manuals, Vol. 1 -13, Vol. 1 for Design Data and others for Operation and Maintenance manual for Boiler and Common Section, *Foster Wheeler Power Project Ltd*.
- [4]. Bela, G. Liptak, Process measurement and Analysis, 3rd edition, Boiler Controls and Optimization, section, *Butterworth Heinman Ltd.*, 1999.
- [5]. W. M. Kays, A. L. London, Compact Heat Exchangers, *McGraw Hill*, New York, 1984.
- [6]. Janez Oman, Bos' tjan Drobnic', Matija Tuma, A numerical model for the analyses of heat transfer and leakages in a rotary air preheater, *International Journal of Heat and Mass Transfer*, 49, 2006, pp. 5001–5009.
- [7]. Hyung Taek Kim, Hong Yue Wang, Ling Ling Zhao, Zhi Gao Xu, Won Gee Chun, The study on heat transfer model of tri-sectional rotary air preheater based on the semi-analytical method, *Applied Thermal Engineering*, 28, 2008, pp. 1882–1888.
- [8]. Sepehr Sanaye, Saeid Jafari, Hadi Ghaebi, Optimum operational conditions of a rotary regenerator using genetic algorithm, *Energy and Buildings*, 40, 2008, pp. 1637–1642.
- [9]. D. A. Reay, A review of gas-gas heat recovery systems, *Heat Recovery Systems*, Vol. 1, *Pergamon Press Ltd.*, 1980, pp. 3-41.
- [10]. Hyungtaek Kim, Hongyue Wang, Lingling Zhao, and Zhigao Xu, Analysis on thermal stress deformation of rotary air-preheater in a thermal power plant, *Korean J. Chem. Eng.*, 26, 3, 2009, pp. 833-839.
- [11]. E. J. MacDuff, N. D. Clark, Ljungstro'm air preheater design and operation, Part I: Sealing and Leakage, *Combustion*, 47, 1976, pp. 7–11.

- [12].S. Nair, S. Verma, T. S. C. Dhingra, Rotary heat exchanger performance with axial heat dispersion, *International Journal of Heat and Mass Transfer*, 41, 1998, pp. 2857–2864.
- [13].T. Skiepko, Indirect estimation of leakage distribution in steam boiler rotary regenerators, *Heat Transfer Eng.*, 18, 1, 1997, pp. 56–81.
- [14].R. K. Shah, T. Skiepko, Influence of leakage distribution on the thermal performance of a rotary regenerator, *Appl. Therm. Eng.*, 19, 7, 1999, pp. 685–705.
- [15].T. Skiepko, Method of monitoring and measurement of seal clearances in a rotary heat exchanger, *Heat Recov. Syst. CHP*, 8, 1988, pp. 469–473.
- [16].T. Skiepko, Irreversibilities associated with a rotary regenerator and the efficiency of a steam power plant, *Heat Recov. Syst. CHP*, 10, 3, 1990, pp. 187–211.
- [17].Wright, Thermosyphons as heat transfer elements in large air pre-heaters—the testing of a 16 m 20 kW thermosyphon, *Heat Recovery Systems*, Vol. 4, No. 4, 1984, pp. 239-245.

2011 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.
(<http://www.sensorsportal.com>)



SENSORS WEB PORTAL 

- **MEMS**
- **NEMS**
- **NANOSENSORS**
- **SMART SENSORS**

All about SENSORS
<http://www.sensorsportal.com>

The graphic features a dark blue background with a grid pattern. On the right, a computer monitor displays the Sensors Web Portal website. The text is primarily in yellow and white, with the IFSA logo in white and yellow.



The Second International Conference
on Sensor Device Technologies and Applications

SENSORDEVICES 2011

August 21-27, 2011 - French Riviera, France



Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:

- Sensor devices
- Photonics
- Infrared
- Ultrasonic and Piezosensors
- Sensor device technologies
- Sensors signal conditioning and interfacing circuits
- Medical devices and sensors applications
- Sensors domain-oriented devices, technologies, and applications
- Sensor-based localization and tracking technologies

<http://www.iaria.org/conferences2011/SENSORDEVICES11.html>



The Fifth International Conference on Sensor
Technologies and Applications

SENSORCOMM 2011

August 21-27, 2011 - French Riviera, France



Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:

- APASN: Architectures, protocols and algorithms of sensor networks
- MECSN: Energy, management and control of sensor networks
- RASQOFT: Resource allocation, services, QoS and fault tolerance in sensor networks
- PESMOSN: Performance, simulation and modelling of sensor networks
- SEMOSN: Security and monitoring of sensor networks
- SECSN: Sensor circuits and sensor devices
- RIWISN: Radio issues in wireless sensor networks
- SAPSN: Software, applications and programming of sensor networks
- DAIPSN: Data allocation and information in sensor networks
- DISN: Deployments and implementations of sensor networks
- UNWAT: Under water sensors and systems
- ENOPT: Energy optimization in wireless sensor networks

<http://www.iaria.org/conferences2011/SENSORCOMM11.html>



The Fourth International Conference on Advances
in Circuits, Electronics and Micro-electronics

CENICS 2011

August 21-27, 2011 - French Riviera, France



Important deadlines:

Submission deadline	March 23, 2011
Notification	April 30, 2011
Registration	May 15, 2011
Camera ready	May 22, 2011

Tracks:

- Semiconductors and applications
- Design, models and languages
- Signal processing circuits
- Arithmetic computational circuits
- Microelectronics
- Electronics technologies
- Special circuits
- Consumer electronics
- Application-oriented electronics

<http://www.iaria.org/conferences2011/CENICS11.html>

Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726-5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In addition, some special sponsored and conference issues published annually. *Sensors & Transducers Journal* is indexed and abstracted very quickly by Chemical Abstracts, IndexCopernicus Journals Master List, Open J-Gate, Google Scholar, etc.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

Submission of papers

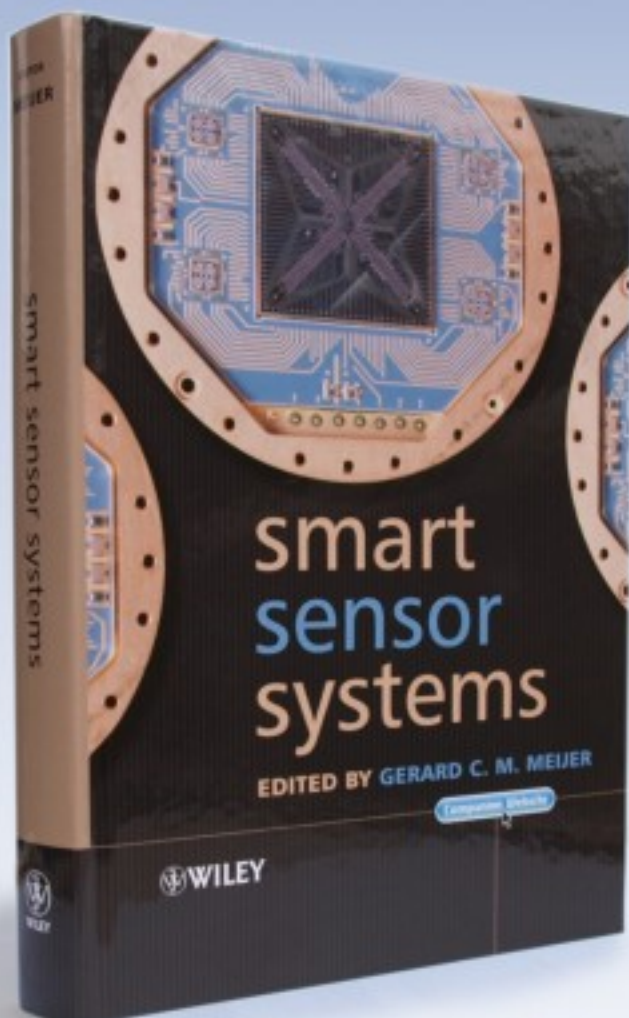
Articles should be written in English. Authors are invited to submit by e-mail editor@sensorsportal.com 8-14 pages article (including abstract, illustrations (color or grayscale), photos and references) in both: MS Word (doc) and Acrobat (pdf) formats. Detailed preparation instructions, paper example and template of manuscript are available from the journal's webpage: <http://www.sensorsportal.com/HTML/DIGEST/Submission.htm> Authors must follow the instructions strictly when submitting their manuscripts.

Advertising Information

Advertising orders and enquires may be sent to sales@sensorsportal.com Please download also our media kit: http://www.sensorsportal.com/DOWNLOADS/Media_Kit_2009.pdf

 **WILEY**
1807-2007

KNOWLEDGE FOR GENERATIONS



'Written by an internationally-recognized team of experts, this book reviews recent developments in the field of smart sensors systems, providing complete coverage of all important systems aspects. It takes a multidisciplinary approach to the understanding, design and use of smart sensor systems, their building blocks and methods of signal processing.'



Order online:

http://www.sensorsportal.com/HTML/BOOKSTORE/Smart_Sensor_Systems.htm

www.sensorsportal.com