UNIVERSITI PUTRA MALAYSIA

Programming SnO2 Gas Sensor Using Arduino Microcontroller

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Programming SnO_2 Gas Sensor Using Arduino Microcontroller

By:

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Thesis submitted to the School of Graduate Student, Universiti Putra Malaysia, in fulfillment of the requirement for the degree of Master of Computer Science

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DEDICATION

This Thesis is dedicated to:

The sake of Allah. My Creator and my Master.

.My great teacher and messenger, Amir (May Allah bless and grant him).

Who taught us the purpose of life.

My beloved Parents,

My Brothers and Sister,

And all my friends,

For

Their Endless Patience and Support

ABSTRACT

Abstract of this thesis is presented to the Senate of Universiti Putra Malaysia, in fulfillment of the requirement for the degree of Master of Computer Science

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Most of the gases are dangerous or bad for human being and environment. Proper attention should be taken while using or transporting these gases. In the present work, these gases will be detected according to the acceptable limits. The Arduino microcontroller attached to a personal computer will be used to detect several gases such as hydrogen, butane, humidity, etc. The sensitive gas is tin dioxide (SnO_2) that is fabricated as a unit called MQ-2, MQ-3, and MQ-135 …etc, or other sensors. As the sensors are exposed to a particular gas, a signal is transmitted to the Arduino microcontroller and attached to the personal computer. This signal is processed and

calibrated using C language programming to indicate the concentration of the gas. These sensors are necessary for safety and environmental monitoring of the gases mentioned above such as monitoring butane transportation and household usages. The monitored gas data can be shared with other Internet sites or the cloud that can act as a response to the values of gas concentration by giving sounds or turn lights on or other alarm responses. The alarm sounds, and a fan simultaneously can be operated to remove the excess gas and to reduce its concentration to the acceptable levels. The Arduino microcontroller can be operated without the need of a computer after loading the required program. The operation of the Arduino without a computer greatly reduces the cost of installation of a gas sensor. Transmitting of sensor data can be performed by using programs such as Teamviewer if the microcontroller is attached to a computer. Transmitting data can also be performed without a computer by using ESP8266 that can communicate directly to the Internet. The sensor calibration can be done using a linear fitting or exponential fitting. The use of the exponentials fitting is the ultimate accurate method because of the natural shape behavior of the gas sensing curves.

ABSTRAK

Kebanyakan gas adalah berbahaya dan memudaratkan bagi manusia dan alam sekitar. Oleh itu, perhatian yang sewajarnya perlu diambil semasa menggunakan atau memindahkan gas-gas ini. Di dalam penyelidikan ini, gas akan dikesan berpandukan had yang ditetapkan. Mikrokontroler Arduino yang dipasang pada komputer peribadi akan digunakan untuk mengesan beberapa jenis gas seperti hidrogen, butana, kelembapan, dan lain-lain. Gas sensitif adalah tin dioksida (SnO_2), yang direka sebagai unit yang dipanggil MQ-2, MQ-3, MQ- 135, dan lain-lain, atau sensor-sensor lain. Apabila sensor terdedah kepada gas tertentu, isyarat akan dihantar ke mikrokontroler Arduino, dan seterusnya ke komputer peribadi. Isyarat ini diproses dan ditentukur menggunakan bahasa pengaturcaraan, C untuk menentukan tahap kepekatan gas. Sensor-sensor ini diperlukan untuk pemantauan keselamatan dan alam sekitar dari gas yang dinyatakan di atas, seperti pemantauan pengangkutan butana dan kegunaan domestik. Data gas yang dipantau boleh dikongsi bersama laman web lain, atau di dalam storan awan, yang boleh bertindak sebagai tindak balas kepada nilai-nilai kepekatan gas, dengan mengeluarkan bunyi atau menghidupkan lampu, atau tindak balas penggera yang lain. Bunyi penggera dan kipas boleh dikendalikan secara serentak untuk mengeluarkan gas yang berlebihan, dan seterusnya mengurangkan kepekatannya ke tahap yang dibenarkan. Mikrokontroler Arduino boleh dikendalikan tanpa memerlukan komputer selepas memuatkan program yang diperlukan. Operasi Arduino tanpa komputer membantu mengurangkan kos pemasangan sensor gas. Pengiriman data sensor boleh dilakukan dengan menggunakan program seperti Teamviewer jika mikrokontroler dipasang pada komputer. Selain itu, penyaluran data juga boleh dilakukan tanpa komputer dengan menggunakan ESP8266, yang boleh

berkomunikasi secara langsung secara atas talian. Penentukuran sensor boleh dilakukan dengan menggunakan pemasangan linear atau eksponen. Penggunaan pemasangan eksponen adalah kaedah terbaik dan tepat, disebabkan oleh bentuk lengkung semulajadi pengesan gas.

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APPROVAL

This thesis was submitted to the Faculty of Computer Science and Information Technology of Universiti Putra Malaysia and has been accepted as partial fulfillment of the requirement for the degree of Master of Computer Science.

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DECLARATION

I declare that the thesis is my original work, except for the quotation and citations, which have been duly, acknowledge. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or any other institution.

HASAN MUDAR ALMAROOF

Date: ----------

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LIST OF ABBREVIATIONS

a, b, c	Calibration coefficients of a gas sensor
A0-A5	Arduino analog pins
ADC	Analog to digital converter
R_0	The sensor resistance when it is exposed to air
R_L	The loud resistance of the sensor
Rs	The sensor resistance when it is exposed to a certain gas
RX	Receiving pin of Arduino used for serial communication
SnO_2	Tin dioxide (sensing material)
TX	Transmitting pin of Arduino used for serial communication
USB	Universal Serial Bus
VC	Gas sensor circuit voltage

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CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter represents an overview of the gas sensors and their applications. The structure of the thesis and its scope, motivation, and objective will also be presented. This chapter will also serve as an index for the content and organization of the present thesis.

1.2 Introduction to Gas Sensors

The field of gas sensing is a wide field that involves both experimental and programming efforts. It has broad applications that include medical, environmental, robotics, vehicle monitoring, Internet of things, mobile applications, etc. However, the basic principles start by using a sensitive material of the gas and recording its reaction as the monitored gas passes over this material. The sensitive material in the present project is SnO_2 which is the most widely used material in gas sensing. This material is heated to become more sensitive and reacts with gases that pass over it. To be able to collect data to a computer, an Arduino microcomputer is used to transfer the analog data from the sensor to digital data in the computer. The computer registers the resistivity of the active material as a function of time intervals. To analyze the data, the resistivity should be calibrated to show the concentration of the gas at the surface of the active material. The calibration is usually performed for a specific range in which the relation is linear. In this work, we shall employ nonlinear functions for this purpose. The monitored gas data can

be shared with other Internet sites or the cloud that can act as a response to the values of gas concentration to give sounds or lights or other alarm responses.

1.3 Problem Statement

The problem that will be solved in this project is to advance the numerical calibration process of the present sensors so that a better fitting to the experimental results is obtained. Several gases will be examined in the present project with a better calibration to check the validity of our method. Normally a linear fitting for the concentration data is performed. However, we shall show that a better fitting can be obtained using another kind of functions that are more accurate and covers wider range of calibrated data. The Internet alarms are solicited to avoid gas concentration from passing certain limits.

1.4 Research Objective

The present project aims to perform a better calibration function instead of a linear calibration method used previously for gas sensors. The computer or Wi-Fi is used to transform the signal via the Internet to other Internet sites or the cloud to the alarm of certain limit crossing of the gas concentration.

1.5 Research Scope

The present project aims to include important gas sensors to a better understanding of the mechanism of the sensing operation. The present work includes sensing H_2, butane, and

humidity. Sensor temperatures will also be discussed since their values affect the values of gas sensors calibration.

1.6 Research Motivation

As we shall see in chapter two for the literature review that the first use of an Arduino microcontroller for gas sensing is in 2012. Although this study is new, its applications spread widely in gas sensing applications to include more than a hundred published researches in SCOPUS database. However, this study still needs more sophisticated mathematical and programming procedures as we shall see in the next chapters.

REFERENCES

[1] Arízaga JA, De La Calleja J, Hernández R, Benitez A. Automatic control for laboratory sterilization process based on arduino hardware. In: CONIELECOMP 2012 - 22nd International Conference on Electronics Communications and Computing ; 20122012. p. 130-3.

[2] Abdullah A, Sidek O, Amran NA, Za'bah UN, Nikmat F, Jafar H, Hadi MA. Development of wireless sensor network for monitoring global warming. In: 2012 International Conference on Advanced Computer Science and Information Systems, ICACSIS 2012 - Proceedings ; 20122012. p. 107-11.

[3] Abu Al-Haija Q, Al-Qadeeb H, Al-Lwaimi A. Case Study: Monitoring of AIR quality in King Faisal University using a microcontroller and WSN. In: Procedia Computer Science ; 2013 2013. p. 517-21.

[4] Ramadhani MF, Yuliarto B, Nugraha N. Design and fabrication of real time air quality monitoring system based on web application. In: Proceedings of 2013 3rd International Conference on Instrumentation, Control and Automation, ICA 2013 ; 20132013. p. 270-3.

[5] Saparkhojayev N, Kanatbekkyzy A. Smart home assistant. World Appl Sci J. 2013;28 (8):1075-81.

[6] Aloisio D, Donato N, Neri G, Latino M, Wagner T, Tiemann M, Capra PP. Arduino-based shield for resistive gas sensor array characterization under UV light exposure; 2014. 411 p.

[7] Abraham S, Li X. A cost-effective wireless sensor network system for indoor air quality monitoring applications. In: Procedia Computer Science ; 20142014. p. 165-71.

[8] Cabrera-López JJ, Latorre Victoria ME, Mejia Jaramillo PA. An electronic and transportable nose for environmental gases monitoring based on mixed-signal SoC and open hardware. In: 2014 IEEE 9th IberoAmerican Congress on Sensors, IBERSENSOR 2014 - Conference Proceedings.

[9] Manna S, Bhunia SS, Mukherjee N. Vehicular pollution monitoring using IoT. In: International Conference on Recent Advances and Innovations in Engineering, ICRAIE 2014 ; 20142014

[10] Silva SM, Gamarra JD, Hernández CA, Osma JF. Design and fabrication of a sensor for explosives as a first step to an IED detection device. In: 2014 IEEE 9th IberoAmerican Congress on Sensors, IBERSENSOR 2014 - Conference Proceedings ; 20142014

[11] Maegawa H, Ishihara S. Experimental implementation of drifting wireless sensor networks which have intermittent connectivity to access points for sewer inspection. In: 2014 7th International Conference on Mobile Computing and Ubiquitous Networking, ICMU 2014 ; 20142014. p. 87-8.

[12] Seesaard T, Seaon S, Lorwongtragool P, Kerdcharoen T. On-cloth wearable E-nose for monitoring and discrimination of body odor signature. In: IEEE ISSNIP 2014 - 2014 IEEE 9th International Conference on Intelligent Sensors, Sensor Networks and Information Processing, Conference Proceedings ; 20142014

[13] Piedrahita R, Xiang Y, Masson N, Ortega J, Collier A, Jiang Y, Li K, Dick RP, Lv Q, Hannigan M, Shang L. The next generation of low-cost personal air quality sensors for quantitative exposure monitoring. Atmos Meas Tech . 2014;7(10):3325-36.

[14] Soto Otálora A, Achury Bohorquez CA, Gómez Gutiérrez MJ. Design and evaluation of a portable meter oil pollution prototype wastewater with temperature control using Arduino technology. ARPN J Eng Appl Sci . 2015;10(14):6065-71.

[15] Ileanwa OP, Ngozi EO, Chigozie UP, Eyo AA. Design of a coordinates aware remote module for effective oil and gas pipeline monitoring using GPRS, GPS and google maps on android devices. In: Society of Petroleum Engineers - SPE Nigeria Annual International Conference and Exhibition, NAICE 2015 ; 20152015

[16] Chen Y-, Wang J-. Wearable computing connecting gas sensor to detector harmful air - Implement; 2015. 1271 p.

[17] Sarathkumar M, Rajeevrathan J, Perumalraja R, Anandhavalli D, Seema M. Smart air pollution monitoring system for industries using IOT techniques. Int J Appl Eng Res. 2015;10(55):1448-51.

[18] Chen Y-, Wang J-. The disaster rescue robot design and implementation using open source; 2015. 53 p.

[19] Pinar A, Wijnen B, Anzalone GC, Havens TC, Sanders PG, Pearce JM. Low-cost open-source voltage and current monitor for gas metal arc weld 3D printing. J Sensors . 2015;2015

[20] Szabra D, Prokopiuk A, Bielecki Z, Majsterek D, Zając A. Microprocessor-based co2 sensor. Prz Elektrotech . 2015;91(9):181-3.

[21] Ansah AK, Ansah JA, Anokye S. Technology for the aging society - A focus and design of a cost effective smart home for the aged and disabled. In: Lecture Notes in Engineering and Computer Science ; 20152015. p. 104-8.

[22] Amirudin Ngah M, Ahmad A, Samad AA. A low cost method to analyse concentration of carbon monoxide (CO). J Teknol. 2015;73(3):43-7.

[23] Reddy GN, Venkatesan V, Maniyar U. Estimation of harvestable energy from vehicle waste heat. In: 2015 International Conference on Renewable Energy Research and Applications, ICRERA 2015 ; 20152015. p. 618-25.

[24] Amirudin Ngah M, Ahmad A. A low cost method to analyse the concentration of carbon monoxide (CO). J Teknol. 2015;73(6):147-51.

[25] Noto J, Radhakrishnan A, Sun Y, Ferreira J, Compere M. Diesel emission test stand for advanced SCR control. In: ASME International Mechanical Engineering Congress and Exposition, Proceedings (IMECE) ; 20152015

[26] Gotor R, Gaviña P, Costero AM. Low-cost, portable open-source gas monitoring device based on chemosensory technology. Meas Sci Technol . 2015;26(8)

[27] Sinha N, Pujitha KE, Alex JSR. Xively based sensing and monitoring system for IoT. In: 2015 International Conference on Computer Communication and Informatics, ICCCI 2015 ; 20152015

[28] Herutomo A, Abdurohman M, Suwastika NA, Prabowo S, Wijiutomo CW. Forest fire detection system reliability test using wireless sensor network and OpenMTC communication platform. In: 2015 3rd International Conference on Information and Communication Technology, ICoICT 2015 ; 20152015. p. 87-91.

[29] Rubio JDJ, Silva Ortigoza R, Avila FJ, Melendez A, Stein JM. A fuzzy inference system for the identification. IEEE Lat Am Trans . 2015;13(9):2823-9.

[30] Chaudhry V, Mishra I. ZENITH: A nano-satellite for atmospheric monitoring. SAE Techni Paper. 2015;2015-September

[31] Delgado-Castro A, Rojas-Bolaños O. Building a low cost system for the use and evaluation of semiconductor gas sensors. Educ Quim . 2015;26(4):299-306.

[32] Iqbal S, Mufti GM, Khan MB, Ansari SH, Naveed S. Advance instrumentation and control of FTS-GTL facility by means of PLC-SCADA system. In: 2014 International Conference on Energy Systems and Policies, ICESP 2014 ; 20152015

[33] Mishra M, Jaiswal V. Development of dissolved gas analyser for transformer oil using nano gas sensor and arduino. Int J Control Theory Appl . 2016;9(41):219-26.

[34] Germanese D, D'Acunto M, Salvetti O. Design of a breath analysis device for self-monitoring and remote health-care. In: BIOSTEC 2016 - 9th International Joint Conference on Biomedical Engineering Systems and Technologies - Doctoral Consortium ; 20162016. p. 9-14.

[35] Pitarma R, Marques G, Caetano F. Monitoring indoor air quality to improve occupational health; 2016. 13 p.

[36] Lopes CR, Oliveira MRP, Silva RE, Rodrigues TV, Souza VAD, Morais WSC. Intelligent control of showers in solar heating systems and gas to water economy. In: GHTC 2016 - IEEE Global Humanitarian Technology Conference: Technology for the Benefit of Humanity, Conference Proceedings ; 20162016. p. 825-30.

[37] Muckley ES, Anazagasty C, Jacobs CB, Hianik T, Ivanov IN. Low-cost scalable quartz crystal microbalance array for environmental sensing. In: Proceedings of SPIE - The International Society for Optical Engineering ; 20162016

[38] Bietresato M, Renzi M, Mischiatti S, Mazzetto F. Engine test stand layout and post processing tools for the detection of many engine performance parameters. ARPN J Eng Appl Sci . 2016;11 (2):1309-16.

[39] Mathupala SP, Kiousis S, Szerlip NJ. A lab assembled microcontroller-based sensor module for continuous oxygen measurement in portable hypoxia chambers. PLoS ONE. 2016;11(2)

[40] Abraham S, Li X. Design of A low-cost wireless indoor air quality sensor network system. Int J Wireless Inf Networks . 2016;23(1):57-65.

[41] Yousif TM, Alharam AK, Elmedany W, Khalaf AAA, Fardan Z. ROBODEM remote monitoring system using web/mobile applications. In: Proceedings - 2015 5th International Conference on e-Learning, ECONF 2015 ; 20162016. p. 285-9.

[42] Zaman HU, Hossain MS, Wahiduzzaman M, Asif S. A novel design of a robotic vehicle for rescue operation. In: 2015 18th International Conference on Computer and Information Technology, ICCIT 2015 ; 20162016. p. 507-10.

[43] Sunehra D, Jhansi K. Implementation of microcontroller based driver assistance and vehicle safety monitoring system. In: Proceedings - IEEE International Conference on Information Processing, ICIP 2015 ; 20162016. p. 423-8.

[44] Jurek M, Škuta J. Open-source smart home modules. In: Proceedings of the 2016 17th International Carpathian Control Conference, ICCC 2016 ; 20162016. p. 286-90.

[45] Marques G, Pitarma R. Health informatics for indoor air quality monitoring. In: Iberian Conference on Information Systems and Technologies, CISTI ; 20162016

[46] Gangopadhyay S, Mondal MK. A wireless framework for environmental monitoring and instant response alert. In: International Conference on Microelectronics, Computing and Communication, MicroCom 2016 ; 20162016

[47] Shariqsuhail M, Viswanathareddy G, Rambabu G, Dharmasavarni CVR, Mittal VK. Multi-functional secured smart home. In: 2016 International Conference on Advances in Computing, Communications and Informatics, ICACCI 2016 ; 20162016. p. 2629-34.

[48] Marques G, Pitarma R. An indoor monitoring system for ambient assisted living based on internet of things architecture. Int J Environ Res Public Health . 2016;13(11).

[49] Sri Sravani B, Prem Kumar S. Application of ivrs based system for traffic monitoring measurement using uno arduino. Intl J Pharm Technol . 2016;8(4):20869-72.

[50] Hussin ZM, Sulaiman MS, Arasu PT. Highly sensitive portable liquid petroleum gas leakage detector. J Telecommun Electron Comput Eng . 2017;9(2-8):109-12.

[51] Järvinen T, Lorite GS, Rautio A-, Juhász KL, Kukovecz Á, Kónya Z, Kordas K, Toth G. Portable cyber-physical system for indoor and outdoor gas sensing. Sens Actuators, B Chem . 2017;252:983-90.

[52] Kanaparthi S, Badhulika S. Low cost, flexible and biodegradable touch sensor fabricated by solvent-free processing of graphite on cellulose paper. Sens Actuators, B Chem . 2017;242:857-64.

[53] Bimaridi A, Putra KD, Djunaedy E, Kirom MR. Assasment of Outside Air Supply for Split AC system - Part A: Affordable Instrument. In: Procedia Engineering ; 20172017. p. 248-54.

[54] Rajendra Prasad A, Rohit BK, Varun Kalyanaraman V, Vasanth S, Vignesh S. Prevention of air suffocation inside a car cabin using a mechatronic system. Int J Mech Eng Technol . 2017;8 (8):738-47.

[55] Rohani MF, Ahmad NA, Sahibuddin S, Daud SM. OPC protocol application for real-time carbon monitoring system for industrial environment. Int J Electr Comput Eng . 2017;7(2):1051-9.

[56] Sachdeva C, Gupta M. A nano-satellite system for atmospheric monitoring and ground imaging. In: AIAA SciTech Forum - 55th AIAA Aerospace Sciences Meeting ; 20172017

[57] Pitarma R, Marques G, Ferreira BR. Monitoring indoor air quality for enhanced occupational health. J Med Syst . 2017;41(2)

[58] Muheden K, Erdem E, Vancin S. Design and implementation of the mobile fire alarm system using wireless sensor networks. In: CINTI 2016 - 17th IEEE International Symposium on Computational Intelligence and Informatics: Proceedings ; 20172017. p. 243-6.

[59] Heredia APD, Cruz FR, Balbin JR, Chung W-. Olfactory classification using electronic nose system via artificial neural network. In: IEEE Region 10 Annual International Conference, Proceedings/TENCON ; 20172017. p. 3569-74.

[60] Mutha VR, Kumar N, Pareek P. Real time standalone data acquisition system for environmental data. In: 1st IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems, ICPEICES 2016 ; 20172017

[61] Widodo S, Supani A. Implementation of dangerous gas detection equipment co security on cars using fuzzy logic smartphone with information and data logger. Adv Sci Lett. 2017;23(3):2351-3.

[62] Adsul S, Sharma AK, Mevekari RG. Development of leakage detection system. In: International Conference on Automatic Control and Dynamic Optimization Techniques, ICACDOT 2016; 20172017. p. 673-7.

[63] Gunawan TS, Yaldi IRH, Kartiwi M, Ismail N, Za'bah NF, Mansor H, Nordin AN. Prototype design of smart home system using internet of things. Indones J Electrical Eng Comput Sci 2017;7 (1):107-15.

[64] Hin TV, Ramli NI. Design and Development of a Salbutamol Intake Detector for Low Respiratory Treatment. In: IOP Conference Series: Materials Science and Engineering.

[65] Dhanalakshmi, Leni AES. Instance vehicle monitoring and tracking with internet of things using arduino. Int J Smart Sensing Intelligent Syst . 2017;2017(Special issue):123-35.

[66] Colombo F, Maffiodo D, Raparelli T. Active gas thrust bearing with embedded digital valves and backpressure sensors. Tribol Trans . 2017;60(5):807-13.

[67] Calvi A, Ferrari A, Sbuelz L, Goldoni A, and Modesti S, Recognizing Physisorption and Chemisorption in Carbon Nanotubes Gas Sensors by Double Exponential Fitting of the Response, Sensors 2016, 16, 731.

[68] Rupali Gupta, Pankaj Kumar Rastogi, Vellaichamy Ganesan, Dharmendra Kumar Yadav,Piyush Kumar Sonkar, Gold nanoparticles decorated mesoporous silica microspheres:

Aproficient electrochemical sensing scaffold for hydrazine andnitrobenzen, Sensors and Actuators B 239 (2017) 970–978.

[69] Junqiao Lee, Ghulam Hussain, Craig E. Banks and Debbie S. Silvester, Screen-Printed Graphite Electrodes as Low-Cost Devices for Oxygen Gas Detection in Room-Temperature Ionic Liquids, Sensors 17 (2017) 2734.

[70] Joao Flávio da Silveira Petrucia, Peter C. Hausera, Arnaldo Alves Cardoso, Colorimetric paper-based device for gaseous hydrogen cyanidequantification based on absorbance measurements, Sensors and Actuators B 268 (2018) 392–397.

[71] Caroline Schultealbert, Tobias Baur, Andreas Schütze and Tilman Sauerwald, Facile Quantification and Identification Techniques for Reducing Gases over a Wide Concentration Range Using a MOS Sensor in Temperature-Cycled Operation, Sensors 18 (2018) 744.

[72] Praxair Canada Inc. Hydrogen material safety data sheet, 1980, P4604.

[73] Abdulsattar, M. A., & Almaroof, H. M. Adsorption of H2 and O2 Gases on ZnO wurtzoid nanocrystals: A DFT study. Surface Review and Letters, 2017, *24*

[74] Praxair Canada Inc. Butane material safety data sheet, 2016, P4572.