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Solar Drying Technology in Indonesia: an Overview

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ABSTRACT

The most important benefit of solar energy is renewable and low pollutant source of energy (clean energy). Solar energy technology and research are developing fast and much of the technology needed for these applications in industry and agricultures is already available. Solar drying technology (SDT) is one of the most attractive and promising applications of solar energy technology. In this paper, the various performances of SDTs in Indonesia are summarized with details. Generally, the cabinet-type and tunnel-type SDTs are remarkably well suited to drying small quantities of vegetables and fruit on the household scale. Greenhouse and hybrid SDTs are suitable for use on a large scale by industries.

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1. INTRODUCTION

Due to the current trends towards scare and expensive of fossil fuel, and uncertainty regarding future cost and availability, use solar energy in drying of agricultural products will probably increase and become more economically feasible in the near future. Solar energy is a major renewable energy source that has the potential to supply daily energy without polluting the environment [1]-[8]. In addition, solar energy is vital to ensuring the continuity of energy resources to meet the demands of human energy. Solar energy is also the ultimate heat energy that is most readily available. The use of solar energy has now grown as for the use of air or water heater systems, air conditioning systems, drying, hydrogen production and electricity. This is because solar energy is a natural source of energy, not extinct and also environmentally friendly. As such, the advancement of active solar energy activation has begun since then and will continue to increase mainly by developing countries [9]-[18]. Solar energy has been used ever since to dry food, agricultural produce, marine products, herbs and so on. Currently, the drying process is widely run in industries such as fabric industry, paper industry, ceramic and so on.

Drying can be done either by direct sunlight, or by using dryers (indirect drying). Direct sunlight is traditional method known as open sun drying to preserve agricultural products in tropical and subtropical countries. Considerable saving can be made with this type of drying since the source of energy is free and sustainable. Traditional drying can be done easily and costs are cheap. However, open sun drying have many disadvantages such as degradation by rain, storm, wind-blown debris, dust, insect infestation, rodents, human and animal interference which will result in contamination of the product. Additionally, the drying time required for a given commodity can be quite long and result in post-harvest losses [19]-[20]. Solar drying technology (SDT) is introduced for the purpose of expediting the drying process. The SDT is much better than traditional drying. SDTs have several advantages such as: (i) no need for a large area, (ii) not depending on weather conditions, (iii) cleaner and can guarantee the quality of commodities, (iv) higher drying efficiency without damaging the yield quality, (v) can avoid the threat of insects and animals, and (vi) drying process can be controlled [21]-[24]. Various types of SDTs had been designed, evaluated and developed in various countries, yielding varying degrees of technical performance, also base on energy, exergy and economic analysis. The forced convection SDTs using double-pass solar collector with fins has been installed in Malaysia. The SDT consisted of double-pass solar collector, blowers, heaters and drying chamber. The SDTs has been evaluated for chili [25], [26], palm oil fronds [27] and seaweed [28]. For 40 kg chili, the drying time is 33 h for reduced moisture content from 80% to 10% (wet basis). SDT saved 49% more drying time than open sun drying (OSD) did. The collector, drying system pick-up and exergy efficiencies were about of 28, 13, 45 and 57% respectively. A hybrid SDT was evaluated for 51 kg of silver jewfish in Malaysia. This hybrid SDT reduced the moisture content from 64% (wb) to 10% (wb) in 8 h. Collector and drying system efficiencies were about 40% and 23%, respectively at an average solar radiation of 540 W/m2 and an airflow rate of 0.0778 kg/s. specific energy consumption (SEC) was 2.92 kWh/kg [29]. A greenhouse SDT with heat exchanger was evaluated for 200 kg of catfish in Perlis, Malaysia. This SDT reduced the moisture content of catfish from 73% (wb) to 30% (wb) in 18 h [30]. However, the main objective of this review is to describe the small-scale and large-scale SDT in food processing industries for high quality food, producing hygienic and income generation in Indonesia.

2. TYPES AND REVIEW OF SDT

SDTs may be classified as (1) forced convection SDTs (active SDTs) and (2) natural convection SDTs (passive SDTs). Natural convection SDTs require no mechanical/electrical power to run a fan. By contrast, forced convection SDTs require the use of a fan or a blower to pump air through the product. Each of the natural or forced convection SDTs can further be classified as (1) direct-mode SDTs, (2) indirect-mode SDTs, and (3) mixed-mode SDTs. In development, SDTs may be classified as (1) SDTs with air-based and (2) water-based collectors. Recently, several review on SDT for various agricultural products are consolidated in Table 1. Solar drying is one of the best method to preserve crops for a long time. In developing and under developed countries; per capita electricity production is low; therefore the electricity uses for heating purpose cannot be economically and environmentally justified option. Greenhouse solar dryer operating in active mode is better as compared to passive mode. Quality, taste, color, and nutritious value of the dried product are better in greenhouse solar drying than open sun drying. [31], [32]. Mohanraj et al. [33] conclude that solar assisted compression heat pump system is the promising equipment used for heating applications (drying).

Table 1. Several Review of SDT

Year	Author(s)	Highlight
2018	Singh et al. [31]	Review on recent developments in greenhouse SDTs
2018	Tiwari et al. [32]	Review on photovoltaic thermal (PVT) air collector integrated greenhouse dryers
2018	Mohanraj et al. [33]	Review on research and developments on solar assisted compression heat pump systems
2017	Chauhan et al. [34]	Review on thermal models for greenhouse SDTs
2016	Prakash et al. [35]	Review on various modelling techniques for the SDTs
2016	Tiwari et al. [36]	Review on development and recent trends in greenhouse SDT
2016	Tiwari [37]	Review on SDT for various agricultural products
2016	Kumar et al. [38]	Review on SDT for drying various commodities
2016	Patil and Gawande [39]	Review on solar tunnel greenhouse type of SDT
2016	Yadav and Banerjee [40]	Review on solar thermochemical processes of SDT
2015	Fudholi et al. [41]	Review on SDT with air based solar collectors
2015	Fudholi et al. [42]	Review on SDT with water based solar collectors
2015	Chauhan et al. [43]	Review on applications of software in SDT
2015	Azmi et al. [44]	Review on research and development work of SDT in Universiti Kebangsaan Malaysia, Malaysia.
2015	Bano et al [45]	Review on greenhouse SDT for vegetables, fruits and herbs in India
2015	Sahdev [46]	Review on greenhouse SDT and open sun for agricultural and food products
2014	Piratesh et al. [47]	Review on development of SDT applications
2014	Prakash and Kumar [48]	Review on solar greenhouse type of SDT
2014	Shalaby et al. [49]	Review on SDT with phase change material as energy storage medium
2014	Mustayen et al. [50]	Review on performance of various SDT
2014	Sangamithra et al. [51]	Review on polyhouse type of SDT
2014	Chaudhari and Salve [52]	Review on various modes of SDT
2013	Amin and Hawlader [53]	Review on solar assisted heat pump systems in Singapore
2013	Toshniwal and Karale [54]	Review on various design of SDT

Year	Author(s)	Highlight
2013	Patel et al. [55]	Review on SDT for grains, vegetables and fruits
2013	Fudholi et al. [56]	Review on advanced SDT with air based solar collectors in Universiti Kebangsaan Malaysia, Malaysia.
2013	Sopian et al. [57]	Review on advanced SDT with water based solar collectors in Universiti Kebangsaan Malaysia, Malaysia.
2013	Misha et al. [58]	Review on SDT for agricultural products
2012	Misha et al. [59]	Review on solid/liquid desiccant SDT
2012	Sopian et al. [60]	Review on advances SDT for marine and agricultural products
2012	VijayaVenkataRaman et al. [61]	Review on design, development and performance of various SDT
2012	El-Sebaii and Shalaby [62]	Review on SDT for agricultural products
2012	Panwar et al. [63]	Review on energy and exergy analysis of SDT
2012	Bala and Debnath [64]	Review on potential and developments of SDT for vegetables, fruits, medicinal plant, fish and spices.
2012	Bennamoun [65]	Review on application of exergy and energy for determination of SDT efficiency
2012	Prakash and Kumar [66]	Review on historical and recent trends in SDTs
2011	Bennamoun [67]	Review on experience of SDT in Algeria with presentation of the different design aspects of SDT
2011	Belessiotis and Delyannis [68]	Review on various direct and indirect SDT applications with fundamental principles and parameters
2011	Jin et al. [69]	Review on heat pump SDT for agriculture, fruit, herbs, marine, food, wood and other
2011	Fadhel et al. [70]	Review on advanced chemical heat pump SDT for agricultural produce
2011	Bal et al. [71]	Review on SDT with latent heat storage systems for agricultural products
2010	Bal et al. [72]	Review on SDT with thermal energy storage systems for drying agricultural food products
2010	Wakjira [73]	Review on SDT for fruits in Ethiopia
2010	Daghigh et al. [74]	Review on heat pump SDT for agriculture and marine products
2010	Fudholi et al. [75]	Review on design and performance of SDT for agricultural and marine products

3. SDT IN INDONESIA

Table 2 shows performances of SDTs for agricultural and marine products in Indonesia. A solar-assisted fluidized bed dryer was tested for 12 kg of paddy. Paddy was dried to the final moisture content of 14% from 20% (wet basis) in 0.66 h with a relative humidity and temperature about 23% and 50^{o}C. The efficiency of collector varies from 53 to 60%, and the average of 56% at solar radiation about 900 W/m^2. The specific moisture extraction rate (SMER) was obtained of 0.195 kg/kWh [76]. Exergy efficiency were 47.6 and 49.5% [77]. A solar-assisted heat pump dryer (SAHPD) integrated with biomass furnace was designed, constructed and evaluated for red chili. This SDT reduced the weight paddy from 22 kg to 4.5 kg in 11 h with mass flow rate 0.124 kg/s. Result shows that drying rate (DR) is 1.57 kg/s. A 82 % saving in drying time was obtained for SDT compare with that of the OSD. The SMER is 0.14 kg/kWh. The drying efficiencies range of 1.34 to 15.36% with the average of 9.03% [78]. A SAHPD was evaluated for curcuma. The drying of 30.7 kg to 8.4 kg of curcuma via this SDT reduced the moisture content from 80% (wet basis) to 7.5% (wet basis) in 8.5 h with average temperature of 58^{o}C and relative humidity of 20%. At solar radiation about 870 W/m^2 and mass flow rate of 0.06 kg/s obtained coefficient of performance (COP) dehumidifier and SMER, was 2.17 and 0.55 kg/kWh, respectively. The average and maximum of drying system efficiency was 36% and 58%, respectively [79]. A hybrid solar-biomass dryer was evaluated for curcuma. The drying of 30.7 kg to 8.4 kg of curcuma via this hybrid SDT reduced the moisture content from 80% (wet basis) to 7.5% (wet basis) in 9.5 h with average temperature of 61^{o}C. At solar radiation about 870 W/m^2 and mass flow rate of 0.06 kg/s obtained drying system efficiency, SMER, solar and biomass fractions is 26%, 0.4 kg/kWh, 0.47 and 0.19, respectively. The collector efficiency varies from 47 to 65% with the average of 54% [80]. A hybrid PV-solar dryer was tested for 48 kg of cocoa. The hybrid SDT consists of solar collector, fans, drying chamber, chimney with wind ventilator, and photovoltaic (PV) system. This SDT was reduced the moisture content of the cocoa from 66% to 6% in 18 h with average temperature and solar radiation of 49^{o}C and 680 W/m^2. The drying efficiency of this dryer varies from 19 to 59%, and the average of 34% [81]. A SAHPD was evaluated for 50 kg of cocoa. The SDT consists of heat pump (evaporator, condenser, and compressor), solar collector, blower, drying chamber, chimney and wind ventilator. This SDT was reduced to the final moisture content of 7.5% from 67% (wet basis) in 21 h (3 d) with temperature and relative humidity about 53^{o}C and 27%. Result shows that drying efficiency of this SDT was 38% [82] and thermal efficiency was 19.9% [83]. A heat pump dryer was reduced the weight of the cocoa from 30.7 kg to 8.4 kg in 12 h with average temperature of 49^{o}C and relative humidity of 27%. The curcuma's moisture content was reduced to 7.5% from 80% (wet basis) with an air velocity of 0.8 m/s. The coefficient of performance (COP) dehumidifier and specific moisture extraction rate (SMER) was 2.27 and 0.83 kg/kWh, respectively. The average of drying efficiency of this dryer is 55% [84]. A greenhouse type SDT have been evaluated for coffee, cocoa, fish, sliced meat and other tropical products in Indonesia. This SDT showed that for 228 kg of cocoa bean reduced the moisture content from 60 % (wb) to 6.7% (wb) in 40 h with an average relative humidity and temperature were 35% and 45 ^{o}C respectively. Drying efficiency was 18 to 55%. For 48.8 kg of banana jerky, SDT took only 5.1 h for reduce moisture content from 60.4% (wb) to 26.8 (wb) with biomass fuel, but took 8.6 h for reduce moisture content from 63.6% (wb) to 25.4 (wb) without biomass fuel [85], [86]. The moisture content of cassava decreased to 10.5% from 61% (wet basis) within 9 and 13 h at average temperatures of 45 °C and 40 °C by using SAHPD and solar dryer, respectively. The average thermal efficiencies for SAHPD and solar dryer was 31% and 26%, respectively. The pickup efficiencies and SMER were 44% and 39% and 0.47 and 0.38 kg/kWh for SAHPD and solar dryer, respectively [87]. Prototypes of greenhouse effect (GHE) solar dryer have been tested and their technical performances for chili, fermented cocoa beans, coffee berries, banana, papaya, sliced meat, seaweed, fish and it has great potential for application in the rural areas of Indonesia as shown in Table 3 [88]. A simple test with 70 kg seaweeds showed that the product could be dried to a final weight of 12 kg within two days while smelt fishes (stolephorus family) with initial weight of 65 kg could be dried within 7 hrs, under drying temperature of 51^{o}C. Other purpose of technology dissemination was to train the local people so that they are capable in constructing, operating and administrating the facility. As negotiations on with local food industry, new opportunities was explored to make use of the facility to dry vegetables, and to export dried marine products such as seaweed and fishes to overseas market [88].

Table 2. Performance of SDTs in Indonesia [76]-[87]

Produce,	M (%wb)		t (h)		S_t	SMER	Efficiency (%)				Ref.
load (kg)	M_i	M_t	OS	SDT	(%)	(kg/kWh)	η_t	η_d	η_p	η_{Ex}	
Paddy											
12	20	14	-	0.66	-	0.19	56	-	-	-	[76]
12	20	14	-	0.36	-	-	-	13.4	-	47.6	[77]
12	20	14	-	0.22	-	-	-	16.3	-	49.5	[77]
Chili											
22	-	-	62	11	81	0.14	-	9	-	-	[78]
Curcuma											
30.7	80	7.5	-	8.5	-	0.55	-	36	-	-	[79]
30.7	80	7.5	-	9.5	-	0.40	54	26	-	-	[80]
Cocoa											
48	66	6	-	18	-	-	-	34	-	-	[81]
50	67	7.5	-	21	-	-	-	38	-	-	[82]
48	67	8.6	-	20	-	-	19.9	-	-	-	[83]
30.7	67	7.5	-	12	-	0.83	-	55	-	-	[84]
228	60	6.7	-	40	-	-	-	18	-	-	[85]
400	60	6.7	-	32	-	-	-	55	-	-	[85]
Coffee											
1114	-	-	-	58	-	-	-	58	-	-	[85]
Banana jerky											
46.8	60	27	-	5.1	-	-	-	-	-	-	[86]
46.8	64	25	-	8.6	-	-	-	-	-	-	[86]
Cassava											
30.8	61	10.5	-	9	-	0.47	31	-	44	-	[87]
30.8	61	10.5	-	13	-	0.38	26	-	39	-	[87]

S_t – saving in time; t – drying time; SMER – specific moisture extraction rate; η_d – drying efficiency; η_t – thermal efficiency; η_p – pick-up efficiency; SDT – solar drying technology; OS – open sun;

Table 3. Performance of (GHE) Solar Drying in Indonesia [88]

Produce,	M (%wb)				Es	Auxiliary	Efficiency (%)			
load (kg)	M_i	M_t	T (^{o}C)	t (h)	(MJ/kg water)	heat source	η_t	η_d	η_p	η_{Ex}
Chili										
1.6	-	-	40	4	-	none	-	-	-	-
Cucumber										
5.4	-	-	40	9.5	-	none	-	-	-	-
Cocoa										
228	60	-	47	40	12.9	kerosene	33.3	18.4	-	-
400	56	-	47	32	5.2	kerosene	-	55	-	-
190	-	-	-	43	14.4	charcoal	-	18	-	-
Robusta coffee										
1114	-	11.2	37	58	5.5	none	-	57.4	-	-
Banana										
18	-	-	41	11	-	none	-	9.7	-	-
25	-	-	-	57	19.2	none	-	11.1	-	-
Bayur wood										
728	-	-	39	158	25.8	charcoal	-	8.1	-	-

Produce, load (kg)	M (%wb) M_i	M_t	T (°C)	t (h)	Es (MJ/kg water)	Auxiliary heat source	Efficiency (%) η_t	η_d	η_p	η_{Ex}
Kemiri wood 780	-	-	48	96	-	none	-	-	-	-
Vanilla pods 52	-	-	51	52	-	charcoal	-	7.5	-	-
Papaya 40	-	-	39	33	-	none	-	10.5	-	-

4. CONCLUSIONS

In this paper, an overview on performances of SDTs for agricultural and marine products in Indonesia. The significant outcomes from this review are summarize below:

a. SDTs are ideally suitable to preserve agricultural and marine products in Indonesia.

b. Generally, greenhouse SDT and hybrid SDT is suitable for use on a large-scale by industries. A green house effect (GHE) solar drying system has been tested for chili, fermented cocoa beans, coffee berries, banana, papaya, sliced meat, seaweed, fish and it has great potential for application in the rural areas of Indonesia.

c. SDT appreciably improves the quality of products, and reduced the drying time as compared to OSD.

d. PVT collector integrated greenhouse dryer are the best option for remote locations where electricity is not easily available.

e. A combination of fluidized bed with solar-assisted heat pump dryer (SAHPD) integrated with and without biomass furnace was evaluated for red chili, cocoa, curcuma, paddy, and cassava in Indonesia.

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Ahmad Fudholi, Ph.D, M.Sc obtained his S.Si (2002) in physics. He was born in 1980 in Pekanbaru, Indonesia. He has working experience about 4 years (2004-2008) as Head of Physics Department at Rab University Pekanbaru, Riau, Indonesia. A. Fudholi started his master course in Energy Technology (2005-2007) at Universiti Kebangsaan Malaysia (UKM). His M.Sc thesis was on Wind/PV Hybrid System and the Ph.D thesis was about the Finned Double-Pass Solar Collectors for Drying of Seaweed. His M.Sc and Ph.D thesis under supervisor by Prof Dato' Dr. Kamaruzzaman Sopian. After his master he became Research Assistant at UKM up to 2012. After his Ph.D (2012) in renewable energy, he became Postdoctoral in Solar Energy Research Institute (SERI) UKM up to 2013. He joined the SERI as a Lecture in 2014. More than USD 310,000 research grant (15 grant/ project) in 2014–2017 was involved. More than 25 M.Sc project supervised and completed. Until now, he managed to supervise 5 Ph.D (4 main supervisors and 1 Co. supervisor), 3 Master's student by research mode, and 5 Master's student by coursework mode, he was also as examiner (3 Ph.D and 1 M.Sc). His current research focuses on renewable energy, especially solar energy technology, micropower system, solar drying systems, and advanced solar thermal systems (solar assisted drying, solar heat pump, PVT systems). He has published more than 120 peer-reviewed papers, which 25 papers in ISI index (20 Q1, impact factor more than 3) and more than 60 papers in Scopus index, 16 more currently accepted manuscript, 20 more currently under review, and 2 book chapters. Addition, he has published more than 70 papers in international conferences. His total citations of 810 and h-index of 14 in Scopus (Author ID: 57195432490). His total citations of 1387 and h-index of 20 in google scholar. He is appointed as reviewer of high impact (Q1) journal such as Renewable and Sustainable Energy Reviews, Energy Conversion and Management, Applied Energy, Energy and Buildings, Applied Thermal Engineering, Energy, Industrial Crops and Products, etc. He is appointed as reviewer of reputation journals such as Drying Technology, International Journal of Green Energy, Biosystem Engineering, Journal of Sustainability Science and Management, Journal of Energy Efficiency, Sains Malaysiana, Jurnal Teknologi etc. He is also appointed as editor journals. He has received several awards such as Gold Medal Award at the International Ibn Al-Haytham's Al-Manazir Innovation and Invention Exhibition 2011, Silver Medal Award at the International Technology EXPO (ITEX) 2012, Silver Medal Award at the Malaysia Technology Expo (MTE) 2013, Bronze Medal Award at International Exposition of Research and Invention (PECIPTA) 2011, also 2 Bronze Medal Award at PECIPTA 2017. He was also invited as speaker: Workshop of Scientific Journal Writing; Writing Scientific Papers Steps Towards Successful Publish in High Impact (Q1) Journals. He has 1 patent and 2 copyrights.

Abrar Ridwan, S.Si, ST, MT is the head of centre of applied technology, head of mechanical engineering laboratory and a lecturer at Muhammadiyah University of Riau. His research interest includes combustion engineering, biomass gasification, energy conversion and solar energy. He was graduated from physic department of Brawijaya university and also in mechanical engineering at Muhammadiyah University of Malang (UMM). Since 8 years of his lecture was granted by Research and Technology Ministries of Indonesia (RistekDikti) for his research project. He is also involved in the UNDP-UNFCC program regarding municipal solid waste project in Riau Province and graduated his master of mechanical engineering from University of Indonesia. Currently he is focusing the research of how to optimize solar updraft power generator with any material as its heat storage.

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Dr Majid Khan joined the School of Mathematical Sciences, USM, as a lecturer (Operational Research) in May, 2017. He is a researcher and appointed fellow working in the field of seaweed cultivation, solar drying systems, processing, modelling and simulation. His research uses application of Iot, big data and simulation methods to improve model predictions of moisture losses during drying in control and uncontrolled environment. He is also interested in modelling the problems in engineering and other biological systems such as tissue culture and aquamarine. He uses the techniques from statistical theory, approach and existing application tools to develop mathematical model and finally to transform the model in industry application and to answer a range of inspired questions.

Tri Suyono, ST, M.Sc.,REN graduated with the M.Sc REN in Renewable Energy from Solar Energy Research Institute (SERI), UKM, Malaysia. The M.Sc thesis was about the Design and Performance of Solar Assisted Drying System with Solid Desiccant Wheel. He received "SUBROTO Award in Energy Inovation Field" from Minister of Energy and Mineral Resources Republic of Indonesia in 2017. He has working as Lecturer at Universitas Khairun, Indonesia since 2004. He has working experience more than 10 year as Consultant and Contractor in Marine Technology, Renewable Energy, Water Supply Systems Engineering, Subsea Pipeline Engineering, Energy Coversion, Drying Technology and Air Conditioning Systems.

Prof Dato' Dr. Kamaruzzaman Sopian graduated with the BS Mechanical Engineering from the University of Wisconsin-Madison in 1985, the MS in Energy Resources University of Pittsburgh in 1989 and PhD in Mechanical Engineering from the Dorgan Solar Laboratory, University of Miami at Coral Gables in 1997. He has been involved in the field of renewable energy for more than 25-years. He has secure research funding from the Malaysian Minstry of Science and Malaysian Ministry of Education and industry for more than USD 6 million. He has conducted renewable enery courses the Asian School of Energy (2007-2014) funded by ISESCO, COMSAT, TIKA and UNESCO. He has published over 800 research papers in journals and conferences (SCOPUS h index = 53, no. of citation = 9386) (Google Scholar h index = 64, no. of citation = 15531). A total of 32 MSc (coursework), 15 MSc (research mode) and 50 PhD candidates from various countries. He has undertaken short assignments in about 10 countries for international agencies and programs such as UNDP-GEF, UNIDO, ASEAN EU-Energy Facility, ASEAN-Australia Economic Co-operation Program, ASEAN-CIDA, JSPS-VCC, British Council CHICHE, ISESCO and UNESCO related to renewable energy technology. He has been appointed as the Honorary Professor of Renewable Energy, at University of Nottingham, United Kingdom (2009-2013). In addition, he has been appointed as the associate editors in high impact journals. He won several international awards for his academic contribution in renewable energy including the IDB (Islamic Development Bank) S&T Prize 2013, World Renewable Energy Network Pioneer Award 2012, Malaysia Green Technology Award 2012, and the ASEAN Energy Awards (2005, 2007, 2013 and 2014). He has 4 patents, 20 patents pending, 6 copyrights, and 1 trademark for his innovation in renewable energy technology. The innovation and invention in renewable energy technology have won 80 medals in national and international innovation and invention competitions including special innovation awards such as Prix de L 'Environnement by the Swiss Society for Environmental Protection, 2001, Geneva, Sustainable Development Award INNOVA 2007, Special Prize, Korea Invention Promotion Association at the INPEX Pittsburgh 2008 and Energy and Environmental Award, at INNOVA 2013 in Brussels. His Royal Highness The Sultan of Perak conferred the Paduka Mahkota Perak and the Dato' Paduka Mahkota Perak in 2013. He was conferred as a Fellow of the Malaysia Academy of Sciences (FASc) in 2011.