

Advanced Beverage Can Crusher Machines: A Review

Ashraf Elfasakhany

Professor, Mechanical Engineering Department, College of Engineering, Taif University, PO Box 888, Taif, Saudi Arabia
E-mail: ashr12000@yahoo.com

Abstract – Beverage Can crushing machine is a device, which is used to compact scrap metal Cans into small size ones, and, in turn, the Cans would be reused later as new products. Many designs for the Can crushers are applied for such compacting process, some simple and other complicated. This work presents a review study for the advanced or up to date beverage Can crusher machines. Several issues described new designs for the advanced Cans crushing processes are presented in the current study.

Keywords: Beverage; Cancrusher; review; advanced designs.

I. INTRODUCTION

A Can drink is a metal container (mainly aluminum) designed to hold liquids. Its daily use worldwide poses a high threat to environmental pollution; aluminium is known as a sustainable metal that may take about 80 to 100 years to be decomposed but could be easily recycled in many times [1]. In 2004 for example, about 55 billion Cans of aluminium metal were filled into the ground, and about 9 billion or more were misplaced in 2000. This amount would be enough to fill the Empire State Building about 15 times or more [2]. Additionally, there is an enormous amount of Can wastes has been disregarded over the last decades. Aluminum Cans are considered as ones of the most important products to be economically recycled in increasing scales.

Aluminium Can recycling is the process by which the Aluminium Can scrap is reused in goods after its initial production. The process involves simply re-melting the material, which is far less costly and energy intensive than creating the new aluminum metal by means of aluminum electrolysis; the new aluminum metal must first be extracted from bauxite ore and then processed using the Bayer process[3].

Aluminium recycling accounts for simply 5 per cent of the energy used in the production of primary aluminum (new ore) and produces only 5 per cent of greenhouse gas emissions compared to primary aluminum production. Aluminum Can recycling offers a wide range of ecological, economic and community benefits to individuals, governments, organizations, companies, and industries. Aluminum Can is the most valuable packaging to be reused and the most recycled consumer product in the world today. The aluminum industry pays more than \$800 million each year for new aluminum Cans in the US [4].

There is some other gain of recycling as discussed next. Aluminum recycling Cans save valuable natural resources, fuel, time, and money that will help the planet as well as the economy and local communities. Aluminum Can is a green material that could be recycled repeatedly. Each aluminum Can shall be recycled and converted into a new Can within 60 days and reproduced again. In 2003, almost 54 billion Cans of aluminum were recycled in the U.S.A, saving energy equivalent to 15 million barrels of crude oil needed for another industries in the U.S.A. additionally there are some rewards for public in the recycling process. The public benefits of Can recycling would be summarized as follows. Aluminum Can recycling allows several charitable organizations to finance many local projects. The money earned raises services, neighbour hoods and improves the quality of people's lives [4].The production of primary aluminum requires approximately 45 kWh/kg of energy and emits about 12 kg of CO₂; however, the recycling of aluminum requires only 2.8 kWh of energy and emits about 0.6 kg of CO₂. As a result, 95 per cent of energy and environmental emissions have been saved due to the recycling process. Aluminum beverage Cans save a huge amount of energy; in addition, greenhouse gas emissions are dramatically reduced [5]. The recycling system of aluminum beverage Cans is therefore in rapidity development and economic growth modes [6]. Recycled 1 kg of aluminum drink Can saves up to 8 kg of bauxite, 4 kg of chemical products and 14 kWh of electricity [7]. In addition, the recycling of aluminum can waste helps to free up space, while the recycling of one ton of aluminum Cans saves up to 10 cubic meters of landfill space [8].Recycle of the aluminum Cans requires the crushing process of the used Cans firstly. Can crusher is defined as a device used for crushing aluminum Cans for compacting size for the easier storage in recycling bins, giving you extra space. Manual crushing operations were carried out early in the industrial operation, which is a time-consuming process and ultimately leads to a decrease in the production rate.Recently, machines are used the crushing operations of Cans, which compacts them into a small size. In the current study, can crusher machines been analyzed and discussed;advanced designs for the Can crusher machines are explained and reviewed. Adding, patents of Cans crusher mechanism are summarized in our early studies [9-17]. Such review study is a part of our early reviewstudies for important engineering topic, see e.g., [18-65].

II. A REVIEW OF ADVANCED DESIGNS FOR CAN CRUSHER MACHINES

Elfasakhany *et al* [66] introduced a development of a lightweight, economical, and autonomous machine for crushing aluminum beverage Cans. This work involves the design, development, manufacturing, testing, and validation

processes. The system was designed based on a collection of both horizontal and vertical crushing models and, in effect, the strength required to compress the Cans is much less. The unit, which comprises mechanical, electrical, and electronic parts, has been evaluated both and in general. Validation and testing of the machine display that it works the way it should be.



Fig.1 Dynamometer Used to Crush three Cans a Time Organized as Shown

Project conducted in depth through several stages. Originally, the authors analyzed different design concepts and described the strength needed to smash the Can at that idea. Tests were performed using a dynamometer for crushing Cans. For one sample, the researchers smashed three Cans at a time arranged as shown in Fig.1.

The test reported a force ranging from 40 kgf to 55 kgf. The Can after crushing is shown in Fig.2, and as seen, the Can is not completely crushed. In another test, a single can shall be positioned to be crushed from its side, as shown in Fig.3. The crushing force ranged from 9 to 12 kgf; however, the crushed Can was not compacted efficiently (similar to the first test). In the third test, the authors crushed a single Can, but the force went from above (not from the side) as shown in Fig.4.

As seen in the figure, the deformation is concentrated mainly at the end of the Can and the Can was compacted to a small size in this test (compared to the first and second tests). The strength needed to crush the Can in a vertical position is between 23 and 26 kgf. Having regard to the three testes.

The final design is a combination of both horizontal and vertical crushing designs, as shown in Fig.5. The horizontal force will be the same as the side force in the second experiment, but the vertical force will be much less (about

17 kgf, this value is checked in the test and validation section). In addition, Can is compact to a very small size. Pistons are operated by means of a pneumatic system.

Elfasakhany [67] in another study changed the early design and awarded a patent (patent number KSA4610, 2016[68]) based on a new design. In the model, Cans are crushed by far less force than others. In addition, the machine uses a renewable energy source as a source of energy, i.e. without charge for its operation.

The unit consists of multi-piston, two horizontal and one vertical, a solar cell system for machine operation, a pneumatic device, a sensor, a servo motor, a controller, a computer and a wooden frame containing all machine parts as shown in Fig.6.

The system is designed to be used in many areas, such as aircraft, bathrooms, offices, and even in cars; this invention, in view of this, may restrict the use of Cans in the street or in the garbage.

The function of the system follows; first, the horizontal pressure is applied in the center of the Can to weaken its resistance and then the vertical piston completely crushes the Can to a very small size.



Fig.2 Crushed Can When We Organized Three Cans to Be Crushed a Time

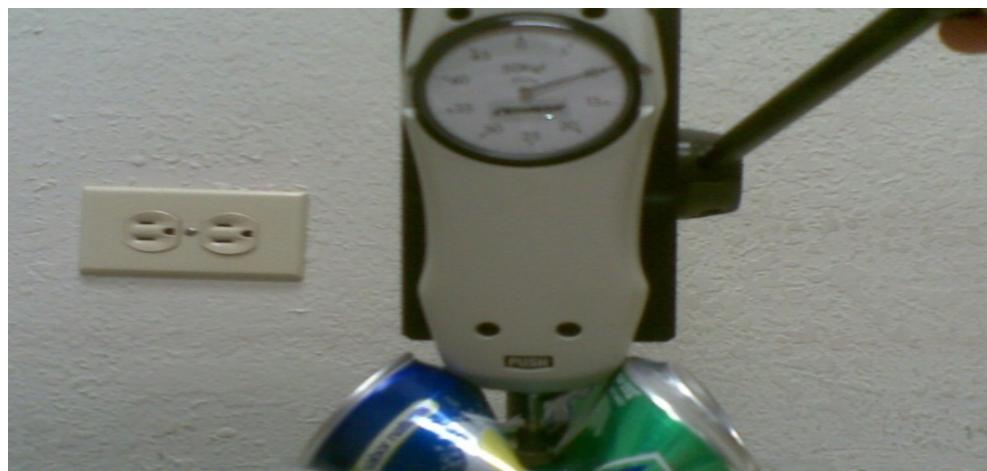


Fig.3 Dynamometer Used to Crush a Single CanOrganized Horizontally



Fig.4 Dynamometer Used to Crush a Single Can Organized Vertically

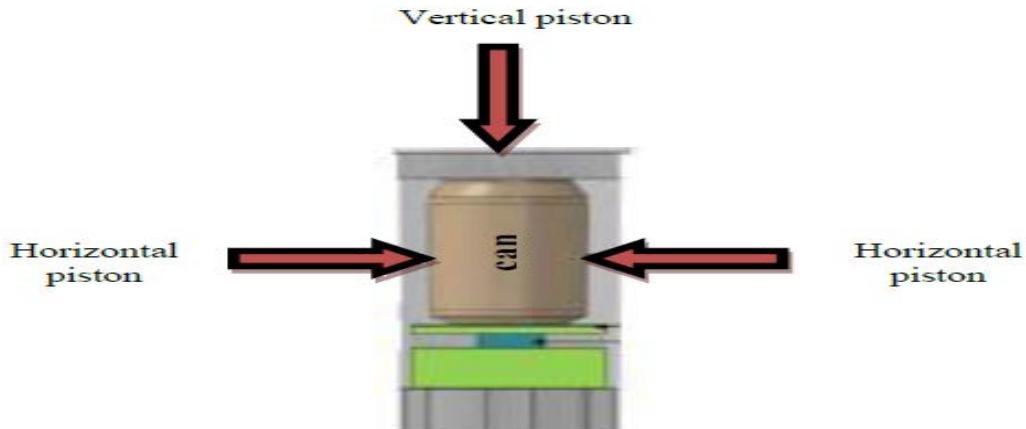


Fig.5. Pistons to Crush the Can

The machine development theory is based on the provision of one Can at a time for synchronization. Once the Can is inserted into the unit, it passes through the track to the frames of the pistons; the light sensor senses the Can in the field and sends a signal to the controller; the controller triggers the pistons to compress the Can where the two horizontal pistons operate the main and then the vertical one; then the crushed Can travels out of storage to the tank. The system has benefits because of its limited size and

requires a low supply of energy; its model is environmentally friendly, economical and uses renewable energy sources; it could be built anywhere, such as in parks, homes, restaurants, malls, aircraft, etc. The invention of a modern Can crusher machine may improve the crushing cycle and could be part of a future industrial recycling system. The force applied in this design is very small compared to others; see, for example, [69–72].

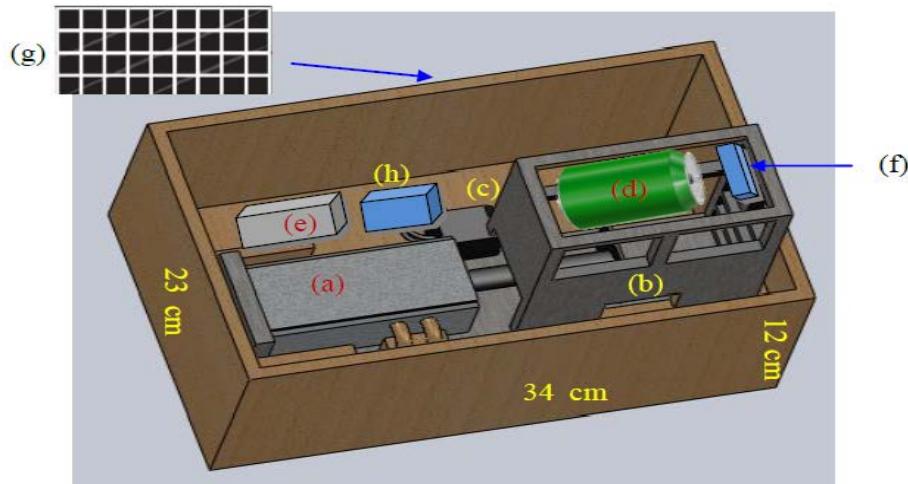


Fig.6 The Structure of Can Crusher Machine Containing Different Components Inside; (a) Pistons Operating System (pneumatic system), (b) Bodymetal, (c) Servomotor, (d) Can, (e) Controller, (f) Sensor, (g) Solar Cell, and (h) Battery.

The energy to charge the compressor and other components of the system is a very important part of the design. This energy should be as low as possible to encourage both the public and the industry to use such a tool. In the design, the power is obtained from the battery; the battery is charged via the solar cell and, therefore, the machine could be operated without running costs. The circuit is designed as a solar cell connected to a diode and a battery, as shown in Fig.7. The battery is therefore charged and then the various components of the machine would be operated. After the design has been completed, the tests are carried out. El-Zomoret *et al*[73] presented a Can crusher machine using a scotch yoke mechanism with a multi or two side crushing

capability. Such a Can crusher machine is used only for the crushing of aluminum Cans. The scotch yoke mechanism transforms rotating motion into reciprocating motion, and this is the concept used for the Can crusher in this model. Buzaet *al* [74] introduced a small presser / crusher tool for Cans. Real-time testing of the equipment was successful in providing a good initiative for the aluminum Can recycling system in response to environmental concerns. The system is lightweight and would be easily transferred to another venue. The development of Qais *et al*[75] is environmentally friendly and uses basic properties such as mechanical single slider and automation properties that use microcontrollers and sensors. Anuar's work [76] includes the design of a new

Can crusher machine. The author argued that the model needed little strength to smash aluminum Cans, which would crush one Can at a time. Figs 9 and 10 showed a few

different designs for Can crushers. Fig. 8 displays the two-plate crusher and the Fig. 9 reveals the twin screw crusher.

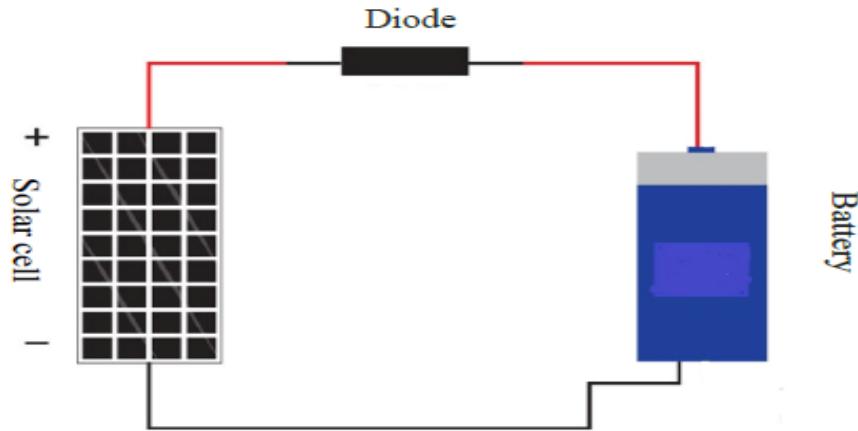


Fig.7 Circuit of Solar Cell Connected With DiodeandBattery.

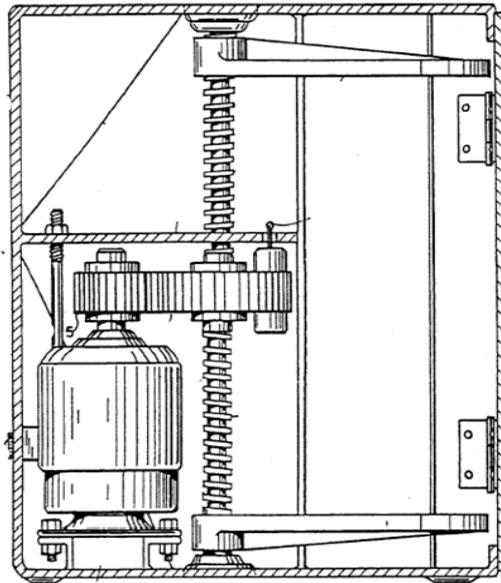


Fig. 8 Dual Plate Crusher

The design of the Can crusher system by Kshirsagar *et al.*[77] consists of the design and manufacture of an automatic Can/bottle crusher unit. The Can design reduces the volume of aluminium Cans/plastic bottles by approximately seventy percent. This machine is essentially based on the principle of the Single Slider Crank Mechanism, which is the heart of this machine and converts rotary motion into a reciprocating machine for the crushing

of Cans. The system demonstrates that the volume would be reduced to a large extent, i.e. almost seventy percent of the volume would be reduced quickly, so that the amount of transport could be increased and transport costs could be reduced to a large extent and would be recycled. In another research, Kshirsagar *et al.* [78] improved early development to be commonly used in the beverage industry or in scrap dealers to reduce the volume of Cans/bottles.

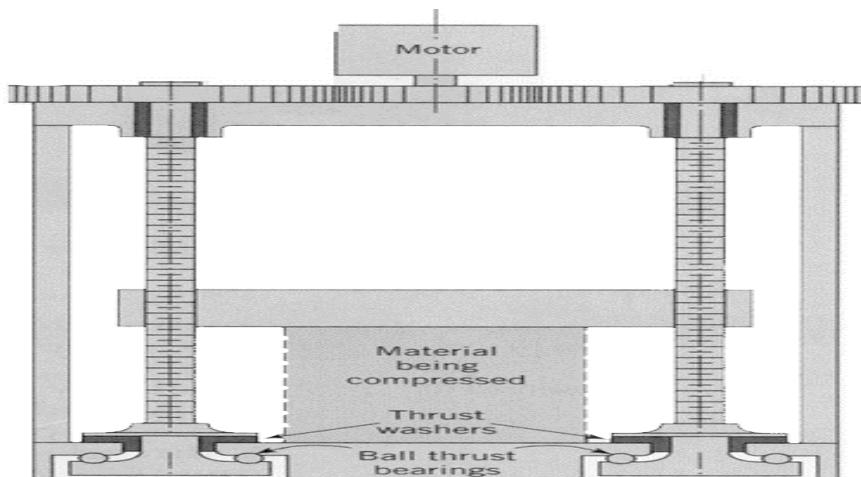


Fig.9 Twin Screw Crusher

Zulkifli [79] proposed three different designs for Can crusher machines (1) Jaw crusher, (2) Gyratory crusher and (3) Impact crushers. A jaw or toggle crusher consists of a pair of vertical jaws, one jaw is fixed, and the other is moved back and forth by a cam or pitman mechanism. The jaws are further apart at the top than at the bottom, forming a tapered fall so that the material is progressively crushed smaller and smaller as it travels down until it is small enough to escape from the bottom opening. The motion of the jaw may be quite slow, as full crushing is not done in one stroke. The inertia needed to crush the material is provided by a weighted flywheel which pushes the shaft producing an eccentric motion that causes the gap to close. Single and double toggle jaw crushers are made of heavy-duty plate frames with reinforcement ribs throughout. The crusher components are of a high strength nature that embraces high horsepower. Manganese steel is used on both fixed and movable jaw faces. Heavy flywheels allow the crushing of hard material peaks. Double Toggle jaw crushers Can feature hydraulic toggle adjustment mechanisms.

As a basic concept, a rotary crusher is like a jaw crusher, consisting of a concave surface and a conical head; both surfaces are typically lined with manganese steel surfaces. The inner cone has a slight circular motion, but it does not rotate; the movement is caused by an eccentric arrangement. As with the jaw crusher, the material moves down between the two surfaces and is compressed gradually until it is soft enough to fall through the gap between the two surfaces. Impact crushers, however, require the use of impact rather than force for crushing materials. The material is sealed inside the jar, with the bottom, middle or side openings of the desired size to allow the crushed material to escape.

The work of Palanivelu *et al.*[80] deals with the experimental and numerical blast study of a single recyclable metal beverage Can. Close range free air blast tests were conducted to understand the crushing behaviour and energy absorption of a single empty Can beverage in detail. A special small-scale test set-up was designed and

manufactured to conduct such an air blast test. The effect of the surface area of the skin plate and its presence on the parameters of blast are discussed. In addition, the influence of skin plate inertia on the crushing performance of the Can drink is evaluated. Tests were carried out on different plates (made of aluminum and sandwich composite materials) with different weights, representing the skin of the proposed sacrificial structure. The determined blast parameters of the tests were compared to the expected results. The deformation behaviour and subsequent energy absorption of the empty drink Cans was assessed.

The paper by Palanivelu *et al.* [81] focuses on the axial impact crushing behaviour of the Cans recyclable empty metal beverage available on the market. Axial fall weight tests were conducted to explain in detail the crushing characteristics and the resulting energy absorption of a single empty Can drink. The deformation mechanisms and corresponding energy absorption of the Cans beverage have been studied in detail at different initial impact speeds (1.4 m / s, 2.2 m / s, 3.1 m / s, 3.8 m / s, 4.4 m / s, and 4.9 m / s). In addition, an experimental approach is proposed for calculating the crushing parameters of empty metal beverage Cans. Verran and Kurzawa [82] investigates Cans compacted in high-pressure packages. Initially, the amount of flux remained constant (20 wt. percent), but the temperature of the bath and the treatment of the melt was changed. First, two separate bath temperatures (750 and 850 C) and melt treatment with an intense mixture of flux in molten aluminum were used, and the volume of flux was modified. Aluminum recovered was poured into permanent molds. Results indicated that the use of bath temperatures above 750 C and a flow rate of at least 10 wt. per cent lead to a good recovery of aluminum after the Cans have been recycled.

III. CONCLUSION

Can crusher machines offer the convenience of reducing the volume of usedCans into a very small one. In literatures, there are many Can crusher machines proposed by

scientists, some very advanced and others in a simple design. The current study aims to present a review of the different design of the Can crusher machines (advanced and simple design ones). The current study may facilitate in development a new design for the Can crusher machines. Based on current study, one may point out that the advanced design provides a Can crusher in a simple and lightweight design; such design provides a machine relatively easy to operate and economically, and that would increase productivity of recycling.

REFERENCES

- [1] S. A. Buza, K. A. Buza and K. Pllana, "Can crusher design in response to environmental concerns", *Journal of Trends in the Development of Machinery and Associated Technology*, Vol. 18, No. 1, pp. 179-182, 2014.
- [2] A. Alshammari and f. Alanazi, "Beverage can compaction machine", Mechanical Engineering Department, PMU, *Learning outcome assessment*, ASSE2111
- [3] S. Husain and M. S. Sheikh, "Can crusher machine using scotch yoke mechanism", *International Conference on Advances in Engineering & Technology* (ICAET-2014), pp. 60-63, 2014.
- [4] M. Belinda, "Analysis of the Recycling Method for Aluminum Soda Cans", B.Sc. thesis, University of Southern Queensland, *Faculty of Engineering and Surveying*, 2006.
- [5] D. G. Altenpohl, *Aluminum Technology Applications and Environment: A profile of a Modern Metal*, The Aluminum Association, Washington D.C. and TMS, Warrendale, PA, pp.328-335, 1998.
- [6] H. Cheng, and X. Du, "On the dynamic Mechanism of developing recycling Economy for Enterprises in China", *International Journal of Social Ecology and Sustainable Development*, Vol. 1, pp. 20-29, 2010.
- [7] A. Henry, "Aluminum engine", Recycle Today, *International Aluminum Institute*, Vol. 44, pp. 8–12, 2007.
- [8] H. M. El-Zomor and M. Hany, "Enhancement in a Mechatronic Aluminum Beverage Cans Recycling Machine", *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering* Vol.7, No. 9, 2013.
- [9] A. Elfasakhany, "Patented of beverage cans crusher machine: A Brief Description Review", Sent for publication to ARME, 2020.
- [10] A. Elfasakhany,"Beverage Can Crusher Machine Patents: A Review: Part I", *Asian Review of Mechanical Engineering*, Vol. 7, No. 2, pp. 62–69, 2018.
- [11] A. Elfasakhany,"Beverage Can Crusher Machine Patents: A Review (Part II)", *Asian Review of Mechanical Engineering*, Vol.7, No. 2, pp. 76–82, 2018.
- [12] A. Elfasakhany,"Beverage Can Crusher Machine Patents: A Review Part (III)", *Asian Review of Mechanical Engineering*, Vol. 8, No. 1, pp. 1–7, 2019.
- [13] A. Elfasakhany,"Beverage Can Crusher Machine Patents: A Review (Part IV)", *Asian Review of Mechanical Engineering*, Vol. 8, No. 1, pp. 11–17, 2019.
- [14] A. Elfasakhany,"Beverage Can Crusher Machine Patents: A Review (Part V)", *Asian Review of Mechanical Engineering*, Vol. 8, No. 1, pp. 31–38, 2019.
- [15] A. Elfasakhany, "Beverage Cans Crusher Machine Patents: A Review: Part VI", *Journal of Environmental and Soil Sciences*, vol. 4, No.3, pp.511–518, 2020.
- [16] A. Elfasakhany, "Beverage Cans Crusher Machine Patents: A Review: Part VII", *International Journal of Research and Scientific Innovation (IJRSI)*, Vol.7, No.4, pp. 239–247, 2020.
- [17] A. Elfasakhany "Beverage Cans Crusher Machine Patents: A Review: Part VIII", *International Journal of Research and Scientific Innovation (IJRSI)*, Vol.7, No.5, pp. 6–15, 2020.
- [18] L. Tao, N. Berge, A. Elfasakhany and X.S. Bai, "Experimental and Numerical Studies of A Pulverised Wood Flame", *6th Europ. Conf. on Industrial Furnaces and Boilers*, Portugal, 2002.
- [19] A. Elfasakhany, and X.S. Bai, "Simulation of Wood Powder Flames in a Vertical Furnace", *3rd Medit. Combustion Symposium*, Marrakech, pp. 144, 2003.
- [20] A. Elfasakhany, X.S. Bai, B. Espenas, L. Tao and J. Larfeldt, "Effect of Moisture and Volatile Releases on Motion of Pulverised Wood Particles", *7th Int. Conf. on Energy for a Clean Environment*, Lisbon, Portugal, pp. 167, 2003.
- [21] A. Elfasakhany, "Modeling of Pulverised Wood Flames", PhD Thesis, fluid mechanics Dept., Lund, Sweden, ISBN-13/EAN: 9789162864255, 2005.
- [22] A. Elfasakhany and X.S. Bai, "Modeling of Pulverised Wood Combustion: A Comparison of Different Models", *Prog. Comp. Fluid Dynamics (PCFD)*, Vol. 6, No. 4/5, pp. 188–199, 2006.
- [23] A. Elfasakhany, T. Klason and X.S. Bai, "Modeling of Pulverised Wood Combustion Using a Functional Group Model", *Combustion Theory and Modeling*, Vol. 12, No.5, pp. 883–904, 2008.
- [24] A. Elfasakhany, E.Y. Rezola, K.B. Quiñones and R.S. Sánc, "Design and Development of a Competitive Low-cost Robot Arm with Four Degrees of Freedom", *Modern Mechanical Eng*, Vol. 1, pp. 47–55, 2011.
- [25] A. Elfasakhany, J. Hernández, J. C. García, M. Reyes and F. Martell, "Design and Development of House-Mobile Security System", *Engineering*, Vol. 3, pp. 1213–1224, 2011.
- [26] A. Elfasakhany, A. Arrieta, D. M. Ramírez and F. Rodríguez, "Design and Development of an Autonomous Trash Sorting System.", *Global J. of Pure and Applied Sciences and Tech.*, Vol. 0113, pp. 56–64, 2011.
- [27] A. Elfasakhany, L. Tao, B. Espenas, J. Larfeldt and X.S. Bai, "Pulverised Wood Combustion in a Vertical Furnace: Experimental and Computational Analyses," *International Conference of Applied Energy*, 2012.
- [28] A. Elfasakhany, "Improving Performance and Development of Two-Stage Reciprocating Compressors", *Int. J. of Advanced Research in Eng. Tech.* Vol. 3, No. 2, pp. 119–136, 2012.
- [29] A. Elfasakhany, "Modeling of Secondary Reactions of Tar (SRT) Using a Functional Group Model", *Int. J. of Mech. Eng. Tech.* Vol. 3, No. 3, pp. 123–136, 2012.
- [30] A. Elfasakhany, J. A. Alarcón and D. O. S. Montes, " Design and Development of an Automotive Vertical Doors Opening System (AVDOS)", *Int. J. of Advanced Research in Eng. Tech.* Vol. 3, pp. 176–186, 2012.
- [31] A. Elfasakhany, J. L. Jiménez, I. A. Rentería, J. M. Rubio and W. D. Ricardez, "Design, Development, Testing and Validation of an Automower Machine", *Int. J. of Applied Mechanics and Physics*, Vol. 1, No. 1, pp. 1–15, 2013.
- [32] A. Elfasakhany, "Investigation on performance and emissions characteristics of an internal combustion engine fuelled with petroleum gasoline and a hybrid methanol–gasoline fuel", *Int. J. of Eng. Tech. (IJET-IJENS)* Vol.13 No. 5, pp. 24–43, 2013.
- [33] A. Elfasakhany, L. Tao, B. Espenas, J. Larfeldt and X.S. Bai, "Pulverised Wood Combustion in a Vertical Furnace: Experimental and Computational Analyses", *Applied Energy*, Vol. 112, pp. 454–464, 2013.
- [34] A. Elfasakhany, "The Effects of Ethanol-Gasoline Blends on Performance and Exhaust Emission Characteristics of Spark Ignition Engines", *Int. J. of Automotive Eng.*, Vol. 4, No. 1, pp. 608–620, 2014.
- [35] A. Elfasakhany, "Experimental study on emissions and performance of an internal combustion engine fueled with gasoline and gasoline/n-butanol blends", *Energy Conversion Manage*, Vol. 88, pp. 277–283, 2014.
- [36] A. Elfasakhany, L.X. Tao and X.S. Bai, "Transport of pulverized wood particles in turbulent flow: numerical and experimental studies", *Energy Procedia*, Vol. 61, pp. 1540–1543, 2014.
- [37] A. Elfasakhany, "Experimental investigation on SI engine using gasoline and a hybrid iso-butanol/gasoline fuel", *Energy Conversion and Management*, Vol. 95, pp. 398–405, 2015.
- [38] A. Elfasakhany,"Investigations on the effects of ethanol-methanol-gasoline blends in a spark-ignition engine: performance and emissions analysis", *Engineering Science Technology*, Vol. 18, pp. 713–719, 2015.
- [39] A. Elfasakhany,"Experimental study of dual n-butanol and iso-butanol additives on spark-ignition engine performance and emissions", *Fuel*, Vol. 163, pp. 166–174, 2016.

- [40] A. Elfasakhany, "Performance and emissions analysis on using acetone–gasoline fuel blends in spark ignition engine", *Engineering Science Technology*, Vol. 19, pp. 1224–1232, 2016.
- [41] A. Elfasakhany, T. K. Kassem, A.-F. Mahrous and K. K. Matrawy, "Study of heat storage using of PCM in solar distiller", *WULFENIA*, Vol. 23, No. 5, pp. 19–31, 2016.
- [42] A. Elfasakhany and A.-F. Mahrous, "Performance and emissions assessment of n-butanol–methanol–gasoline blends as a fuel in spark-ignition engines", *Alexandria Engineering J.*, Vol. 55, pp. 3015–3024, 2016.
- [43] A. Elfasakhany, "Performance assessment and productivity of a simple-type solar still integrated with nanocomposite energy storage system", *Applied Energy*, Vol. 183, pp. 399–407, 2016.
- [44] A. Elfasakhany, "Engine performance evaluation and pollutant emissions analysis using ternary bio-ethanol–iso-butanol–gasoline blends in gasoline engines", *Cleaner Production*, Vol. 139, pp. 1057–1067, 2016.
- [45] A. Elfasakhany, "Performance and emissions of spark-ignition engine using ethanol–methanol–gasoline, n-butanol–iso-butanol–gasoline and iso-butanol–ethanol–gasoline blends: a comparative study", *Engineering Science Technology*, Vol. 19, pp. 2053–2059, 2016.
- [46] A. Elfasakhany, "Investigations on performance and pollutant emissions of spark-ignition engines fueled with n-butanol–, iso-butanol–, ethanol–, methanol–, and acetone–gasoline blends: a comparative study", *Renewable & Sustainable Energy Reviews*, Vol. 71, pp. 404–413, 2017.
- [47] A. Elfasakhany, "Design, analysis and optimization of the tail bearing housing of jet engine", *J. Advances in Vehicle Engineering*, Vol. 3, pp. 99–111, 2017.
- [48] A. Elfasakhany, "Reducing automobile pollutant emissions and re-using some of such emissions as a fuel", *Ciência e Técnica J.*, Vol. 32, No 11, pp. 160–176, 2017.
- [49] M. M. Bassuoni, A. Elfasakhany, K. K. Matrawy and A.-F. Mahrous, "Applying a hybrid air conditioning system for reducing energy consumption inside buildings using a desiccant cycle regenerated with solar energy", *Ciência e Técnica J.*, Vol. 33, No.2, pp. 54–70, 2018.
- [50] A. Elfasakhany, "Exhaust emissions and performance of ternary iso-butanol–bio-methanol–gasoline and n-butanol–bio-ethanol–gasoline fuel blends in spark-ignition engines: assessment and comparison", *Energy*, Vol. 158, pp. 830–844, 2018.
- [51] Kh. Abdel-Aziz, Abo El-Nasr A. A., A. Elfasakhany, D. Saber, and M. Helal, "Influence of casting mould wall thickness on the properties and microstructure of A356 alloy reinforced with micro/nanoalumina particles", *Arctic Journal.*, Vol. 71, pp. 26–39, 2018.
- [52] A. Elfasakhany, "Powder biomass fast pyrolysis as in combustion conditions: Numerical prediction and validation", *Renewable Energy Focus*, Vol. 27, pp. 78–87, 2018.
- [53] A. Elfasakhany, M. M. Bassuoni, B. Saleh, M. Alsehli and Ayman A. Aly, "Biomass powder as a renewable fuel for internal combustion engines", *Arctic Journal*, Vol. 71, pp. 42–52, 2018.
- [54] A. Elfasakhany and X. S. Bai, "Numerical and experimental studies of irregular-shape biomass particle motions in turbulent flows", *Engineering Science Technology*, Vol. 22, pp. 249–265, 2019.
- [55] B. Saleh, Ayman A. Aly, M. M. Bassuoni, M. Alsehli, A. Elfasakhany and Khaled I.E. Ahmed, "Performance assessment of an integrated desiccant air conditioning system powered by solar energy using back propagation artificial neural network", *Arctic Journal.*, Vol. 72, No. 3, pp. 1–18, 2019.
- [56] A. Elfasakhany, "Adjustable throat-area expansion valves used in automotive air conditioning systems: A mini review", *International J. of Automotive Eng.*, Vol. 9, No. 1, pp. 2868–2875, 2019.
- [57] A. Elfasakhany, "Tire pressure checking framework: a review study", *Reliability Engineering and Resilience*, Vol. 1, No. 1, pp. 12–28, 2019.
- [58] A.A Aly, B. Saleh, M.M. Bassuoni, M. Alsehli, A. Elfasakhany and K. Ahmed, "Artificial neural network model for performance evaluation of an integrated desiccant air conditioning system activated by solar energy", *AIMS Energy*, Vol. 7, No.3, pp. 395–412, 2019.
- [59] B. Saleh, A.A. Aly, M. Alsehli, M.M. Bassuoni and A. Elfasakhany, "Performance investigation of a solar-driven ejector refrigeration cycle", *World Journal of Engineering*, Vol. 16/5, pp. 625–635, 2019.
- [60] A. Elfasakhany, "How Evaporator of Automotive Air Conditioner is modelled? A Systematic Review", *Applications of Modeling and Simulation (AMS)*, Vol. 4. No.1, pp. 64–70, 2020.
- [61] M. Alsehli, B. Saleh, A. Elfasakhany, Ayman A. Aly, and M. M. Bassuoni, "Experimental study of a novel solar multi-effect distillation unit using alternate storage tanks", *Journal of Water Reuse and Desalination*, In press, 2020.
- [62] A. Elfasakhany, Mishal Alsehli, Bahaa Saleh, Ayman A. Aly and Mohamed Bassuoni, "Renewable Pulverized Biomass Fuel for Internal Combustion Engines", *Processes*, Vol. 8, No.4, pp. 465, 2020.
- [63] A. Elfasakhany, "Gasoline engine fueled with bioethanol-bio-acetone-gasoline blends: Performance and emissions exploration", *Fuel*, Vol. 274, 117825, 2020.
- [64] A. Elfasakhany, *Alcohols as Fuels in Spark Ignition Engines: Second Blended Generation*, Book, Germany, ISBN: 978-3-659-97691-9, 2017.
- [65] A. Elfasakhany, *Benefits and drawbacks on the use biofuels in spark ignition engines*, Book, Mauritius, ISBN: 978-620-2-05720-2, 2017.
- [66] A. Elfasakhany, J. Marquez, E.Y. Rezola, and J. Benitez "Design and Development of an Economic Autonomous Beverage Cans Crusher", *Int. J. of Mech. Eng. Tech.* Vol. 3, No. 3, pp. 107–122, 2012.
- [67] A. Elfasakhany, "A new Patent of Beverage Cans Crusher Machine", *Current Alternative Energy*, Vol. 2, pp. 123–131, 2018.
- [68] A. Elfasakhany, "Beverage cans crusher machine patent, Patent number: 4610", Jan 10, 2016.
- [69] D. Mayo, "United States Patent No. 5967029", 19 Oct. 1999.
- [70] G. Fry, "United States Patent No. 5469783", 28 Nov. 1995.
- [71] R.M. Davis, "United States Patent No. 5203261", 20 April 1993.
- [72] M.H. Hiatt, "United States Patent No. 4103609", 1 Aug. 1978.
- [73] H. M. El-Zomor and M. Hany, "Enhancement in a Mechatronic Aluminum Beverage Cans Recycling Machine", *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, Vol.7, No. 9, 2013.
- [74] A. Buza, Kastriot A. Buza and Krenar Pllana, "Can Crusher Design In Response To Environmental Concerns", *Journal of Trends in the Development of Machinery and Associated Technology*, Vol. 18, No. 1, pp. 179–182, 2014.
- [75] S. Qais, S. Saif, S. Jafar and S. Nadeem, "FULLY AUTOMATIC CAN CRUSHER", *International Journal of Mechanical and Industrial Technology*, Vol. 2, No. 2, pp. 155–159, 2015.
- [76] C. M. Akhairil and A. C. Zanuar, "Development of the can crusher machine", Diploma in Mechanical Engineering, Faculty of Mechanical Engineering, Univerisity of Malaysia Pahang, Nov. 2008.
- [77] V. N. Kshirsagar, S.K. Choudhary and A.P. Ninawe, "An Automatic Approach for Can/Plastic Bottle Crusher Machine, *International Journal Of Research In Aeronautical And Mechanical*", Engineering, Vol.2, No. 7, pp.102-113,2014.
- [78] V. N. Kshirsagar, S.K Choudhary and A.P Ninawe, "Design Consideration in an Automatic Can/Plastic Bottle Crusher Machine", *International Journal of Engineering Research and General Science*, Vol. 2, No. 4, pp 769-779, 2014.
- [79] M. Zulkifli, "Design of recycle bin tin can crusher", Diploma of Mechanical Engineering thesis, Faculty of Mechanical Engineering, University Malaysia Pahang, Oct. 2008.
- [80] S. Palanivelu, W. V. Paepelgem, J. Degrieck, B. Reymen, J.-M. Ndambi, J. Vantomme, D. Kakogiannis, J. Wastiels and D. V. Hemelrijck, "Close-range blast loading on empty recyclable metal beverage cans for use in sacrificial cladding structure", *Engineering Structures*, Vol. 33, pp. 1966–1987, 2011.
- [81] S. Palanivelu, W. V. Paepelgem, J. Degrieck, S. De Pauw, J. Vantomme, J. Wastiels, D. Kakogiannis and D. V. Hemelrijck, "Low velocity axial impact crushing performance of empty recyclable metal beverage cans", *International Journal of Impact Engineering*, Vol. 38, pp.622–636, 2011.
- [82] G.O. Verran, and U. Kurzawa, "An experimental study of aluminum can recycle using fusion in induction furnace", *Resources, Conservation and Recycling*, Vol. 52, pp. 731–736, 2008.