



Industry 4.0: Future of Manufacturing Sector

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ABSTRACT

Industry 4.0 is a new paradigm that is transforming the industrial scenario. It has generated a large number of scientific studies, commercial equipment and, above all, high expectations. Nevertheless, there is no single definition or general agreement on its implications, specifically in the field of automation and supervision systems. In this paper, a review of the industry 4.0 concept, with equivalent terms, enabling technologies and reference architectures for its implementation, is presented. It will be shown that this paradigm results from the confluence and integration of both existing and disruptive technologies. Furthermore, the most relevant trends in industrial automation and supervision systems are covered, highlighting the convergence of traditional equipment and those characterized by the Internet of Things (IoT). This seminar is intended to serve as a reference document as well as a guide for the design and deployment of automation and supervision systems framed in Industry 4.0. Fourth Industrial Revolution, integrates digital technologies with traditional industrial systems. It leverages IoT, AI, cloud computing, big data, and cyber-physical systems to create smart factories. This report explores the pillars, applications, benefits, challenges, and case studies of Industry 4.0. It also highlights the future outlook and the shift towards Industry 5.0.

Keywords:- Paradigm, confluence and integration, Internet of Things, cyber-physical systems, architectures

1. INTRODUCTION

Automation and supervision systems are essential in any type of productive process. Indeed, these systems control vital infrastructure to ensure a well-functioning society, such as transportation systems, health systems, water, energy, economy and national security [1]. Sensors and actuators capture information from the process and manipulate its behavior, respectively, exchanging data with automation and control units, commonly industrial Programmable Logic Controllers (PLCs). In addition, supervisory and monitoring Supervisory Control and Data Acquisition, SCADA) systems allow for the visualization of the most relevant magnitudes in real time to track the evolution of the process, providing graphical and numerical information, as well as alarm generation [2–4]. Moreover, digital communication networks are used to transmit data among the aforementioned equipment. Since their inception in the 1970s, both hardware and software have been evolving through the introduction of advancements in technologies, like electronics, computation, communications and control algorithms [3]. The third industrial revolution was mainly caused precisely by the massive introduction of automation technologies in industrial processes. Regarding communication technologies, they are used to monitor, exchange and collect data in real time to promote productivity, efficiency, traceability, reliability and security, with reduced costs to support the so-called smart factory [5]. Nowadays, these systems are being increasingly deployed in processes, factories and facilities that try to adopt the principles and technologies of Industry 4.0 and the Industrial Internet of Things (IIoT) paradigms. Indeed, automation and SCADA systems are evolving towards Industry 4.0 and IIoT concepts.

Industry 4.0, also called the fourth industrial revolution, is taking place and involves a large number of new technologies, among which IIoT, Industrial Cyber-Physical Systems (ICPS), Artificial Intelligence (AI) and Cloud computing are found, just to name a few. The industry 4.0 denomination was coined within a strategic program of the German Government called Digital Agenda that started in 2009. Known as Industrie 4.0 in Germany, it was presented at the Hanover Fair in 2011 and started a new wave of developments for the digital industry. This paradigm has in-depth implications in a lot of aspects in industries related to efficiency, energy, sustainability, work conditions, human resources and production management, maintenance planning, etc. And, of course, the design and deployment of automation and supervision systems are also directly impacted by this new scenario.

1.1 What is Industry 4.0

In addition, the impact of this merging concept also affects non-industrial processes, such as smart grids, smart cities, etc. [6]. There are even terms that are accompanied by 4.0 in order to emphasize its advanced or innovative character, or that are framed in the industry 4.0 arena, such as Energy 4.0, Operator 4.0, Engineer 4.0 or Education 4.0, among others. Indeed, the literature shows an increasing number of publications dealing with



new technological developments oriented towards sensing, data acquisition, visualization, data storage and analytics, where PLC and SCADA systems are not being left behind. In fact, their presence and role in Industry 4.0-compliant facilities are still essential and needed [1,3,7,8]. Furthermore, more and more technologies outside the realm of pure automation and supervision are being incorporated into factories. For example, remote monitoring, web-based interfaces, cloud data storage and computing, cyber-security,



Fig -1: Industry 4.0 Review

IOT-enabled devices and Digital Twins are achieving a progressively increasing presence in industrial systems. This way, equipment like PLC and SCADA systems includes advancements and functionalities to support some of the aforementioned technologies in order to be part of the industry of the future, e.g., Industry 4.0. Consequently, the labor market related to the industry is progressively demanding profiles of engineers who know and handle Industry 4.0-associated technologies. For the Industry 4.0 scenario, diverse job profiles are required, such as informatics specialists, robot programmer, software engineer, data analyst, cyber security specialist and PLC programmers, the latter being an important job in this context [9]. In [10], 100 new professional profiles are identified for future factories adapted to Industry 4.0. The authors include PLC programmer, named as Industry 4.0 PLC programmer, and designers of industrial user interfaces, industrial UI designer [10]. In a similar sense, at the educational level, the number of degrees, master's degrees and training courses related to industry 4.0 is growing each day and proves interest in these topics. In fact, higher education must respond to the challenges and opportunities that Industry 4.0 poses [11]. Regarding the next generation of industrial engineers, training is a constant challenge for academia, specifically when dealing with Industry 4.0 [12].

The industry 4.0 vision needs significant preparation and training of engineering students so that they have the ability to solve problems and to face the challenges of this industrial revolution [11]. This way, the engineer must be trained in crucial technologies for Industry 4.0, highlighting automation equipment, communications and supervisory interfaces [13]. On the other hand, in current industry, there is a coexistence of both traditional legacy equipment as well as modern systems already designed following the industry 4.0 and IOT principles. Consequently, engineers and practitioners must be capable of solving the challenges and issues that both types of scenarios can pose. This paper presents a review about Industry 4.0 regarding its concept, functional architecture and recent trends, from the point of view of automation and supervision systems. Namely, a journey is made from the (non-standardized) concept of Industry 4.0 to the most recent trends in hardware and software equipment, going through the evolution from the automation pyramid towards decentralized architectures oriented to Industry 4.0 and IOT. The objective of the present paper is threefold. The first is to provide a panoramic view of the concepts and trends involved in the merging paradigms of Industry 4.0 and iot. Secondly, we will expound how the equipment (hardware and software) for industrial automation and supervision is being affected by such paradigms.

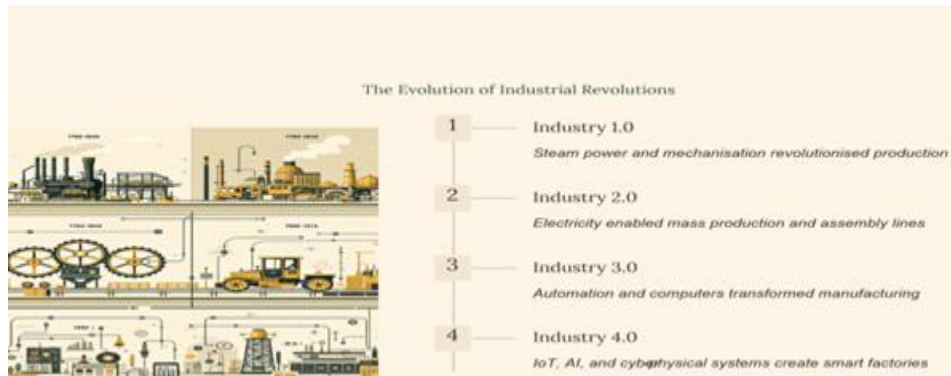


Fig-2: The Evolution of Industrial Revolutions

Thirdly, we will elaborate a comprehensive reference document that could be useful for practitioners, engineers and researchers whose activities are related to automation and supervision. The structure of the rest of the paper is as follows. Section 2 contextualizes Industry 4.0 as the fourth industrial revolution and provides different definitions and associated technologies. The Section 3 deals with the evolution from the hierarchical architecture of the automation pyramid towards decentralized and functional architecture for Industry 4.0 and IOT. Section 4 expounds new features and trends in the development of automation and supervision systems to be integrated in Industry 4.0-enabled infrastructure. To conclude, the final remarks of the work are provided

2. LITERATURE REVIEW

Ever since the envisioned fourth industrial revolution inspired the term “Industry 4.0” (I4.0), this new paradigm shift has been the subject of global discussion (Sauter et al., 2015).

However, keeping pace in this revolution can be challenging for small or medium-sized enterprises (SMEs). While large companies have the ability to devote substantial funds and efforts into pursuing I4.0 related trends, SMEs tend to be much more constraint (Faller and Feldmüller, 2015). This is a problem because SMEs are a valuable asset to any nation’s innovation ecosystem, warranting them to receive special attention in the public eye to support their needs and facilitate their evolution (Hermann et al., 2016).

An industrial revolution is characterized by a new technology finding broad application in industry and thereby fundamentally changing established practices (Zhou et al., 2015). Such revolutions generally come in pairs, where a new technology is coupled with novel commercial logic in a push and pull scenario (Lasi et al., 2014). They are called revolutions because they redefine the levels of industrial performance by dramatically changing how products are produced and of the degree of productivity in value creation. Industrial revolutions have tremendous effect on the output of manufacturing and, as such, are often accompanied by macroeconomic growth and rise in human prosperity (von Tunzelmann, 2003).

Examples like the advancing development of information and communication technologies (ICTs), provide organizations with opportunity to be capable of an astounding employee to user ratio of 1:1000; with Netflix (~5000 employees), Facebook (~25000), and Google (~85000) serving over 100 million users (Statista, 2018).

The degree of productivity motivated Kagermann et al. (2013) to announce that the next industrial revolution is imminent. The intrigue of the fourth industrial revolution is that it has not yet occurred but is expected in the near future, raising significant interest in its opportunities and implications (Drath and Horch, 2014). This has driven European and North American governments to launch substantial programs to become proactive in shaping the industrial future and not be left behind (Liao et al., 2017). Expectations are high to be able to utilize relevant technological advancements to address stagnating economic growth in high-cost labor nations. Initiatives are targeting organizations to help them remain competitive by imitating the example of high-tech firms and drive innovation in the I4.0 era (Zhong et al., 2017).

A CPS is a combination of ICTs and production technologies (Niesen et al., 2016) to act as the enabling intelligence in a “smart” factory (Zhou et al., 2015). A smart factory is synonymous with a system of systems that receive data from a multitude of sources gathered from within and beyond the factory machine-park (Liu and Xu, 2016).

As production systems will be increasingly embedded with awareness (sensors), intelligence (processing) and at least passive communication capabilities (RFID’s) (Grangel-Gonzalez et al., 2016), the volumes of data will be unprecedented. This abundance of data, when processed and categorized, will enable replicating the performance (state and behavior) of the factory in a virtual (cyber) space in form of a digital twin (Posada et al., 2015).

Depending on the detail of the gathered data, production processes will become transparent and individual events accurately traceable (Shrouf et al., 2014). This is where the CPS brings about its greatest potential in the



form of optimization. Once all production systems have been digitized a core component of the CPS is to process this data into an operational understanding using artificial intelligence (Wang, Wan, Li et al., 2016a).

The most repeated prerequisite of I4.0 practice is adapting the system architectures. Adapting system architecture has been explained in a range from the networking of production systems. (Schlechtendahl et al., 2014)

Business sectors within a company (Liao et al., 2017) to the extremes of inter business relationships (Kagermann et al., 2013). This prerequisite, instructs that all interfaces be taken under deliberation to identify which complementary systems could or should be networked. Another prerequisite that the reviewed literature identifies in adapting system architectures is a shift toward horizontal integration of business processes. This is one of the prerequisites to enable production system, as information is shared and processed along the value chain (Almada-Lobo, 2016).

The reoccurring prerequisite for adapting the business model is the increasing focus on including services to the offering, before, during or after sales (Kans and Ringwald, 2016). No matter how these offerings incorporate a service, the literature highlights the need to develop the organization's customer/user knowledge by doing meticulous customer research or by analyzing the usage of deployed offerings (Zhong et al., 2017). Another consideration is made for how I4.0 will shape working conditions for future employees. Section 3.3 already outlined how monotonous repetitive operations will be replaced with non-routine tasks requiring creativity and problem-solving skills. However, employees must first have a common understanding of company goals (Sanders et al., 2016) and keep pace with industrial trends (Burmeister et al., 2015). Organizations must strive to employ capable individuals and encourage them to continuously seek further training (Gorecky et al., 2014).

Along the lines of continuous improvement, there is limited focus on Lean Production principles (Ohno, 1988) and their relevance in future manufacturing. The few papers which do explicitly define Lean Production systems state that they will remain instrumental for operational success (Erol et al., 2016; Kolberg and Zühlke, 2015). Adhering to Lean Production principles will continue to have relevance and will be significantly enabled using I 4.0 technologies. Pursuing preventive maintenance and monitoring key performance indicators are key features of I 4.0 capabilities.

2.1 Findings of literature Review

This review analyzed a sample of literature sources specific to I4.0 to identify themes of this anticipated industrial paradigm. The content of the reviewed literature was categorized into four themes that emerged from the analysis. The literature focuses on novel I4.0 technologies, the benefits of realizing I4.0 in the factory, the challenges of implementing I4.0 in the organization what future industrial practice would require. We intend for this discussion to support SMEs in providing clarification for understanding I4.0 and recommending means for implementation. This section discusses our observations about how I4.0 supports improvement activities and how organizations can leverage the activity of offering development to prepare for I4.0 endeavors.

3. INDUSTRY 4.0 CONCEPT

This section presents several extant definitions of Industry 4.0, along with considerations on the associated concepts and technologies. The aim is to provide a comprehensive outlook, given the current absence of a singular and universally accepted definition. For the more, prior to expounding upon these definitions, a concise historical perspective on preceding industrial revolutions is provided, as Industry 4.0 is commonly aligned with the fourth revolution. Additionally, a series of related public and private programs and initiatives are listed, which underscore the generated interest. 2.1. Industrial Revolutions Industry 4.0 is considered the Fourth Industrial Revolution, making it pertinent to provide a historical perspective before delving into its definitions. Conventionally, four, or even five, industrial revolutions are identified, as described below. The First Industrial Revolution emerged in the late 18th century, thanks to the steam engine invented by James Watt. This invention facilitated the introduction of mechanical equipment driven by steam power into various industries.

In addition to the technological implications, profound social and economic changes ensued. This era is commonly referred to as Industry 1.0. The Second Industrial Revolution (Industry 2.0) commenced in the late 19th century and extended until the mid-20th century. Its key technological advancements included the utilization of electricity as a source of energy and the implementation of the assembly line or mass production system.

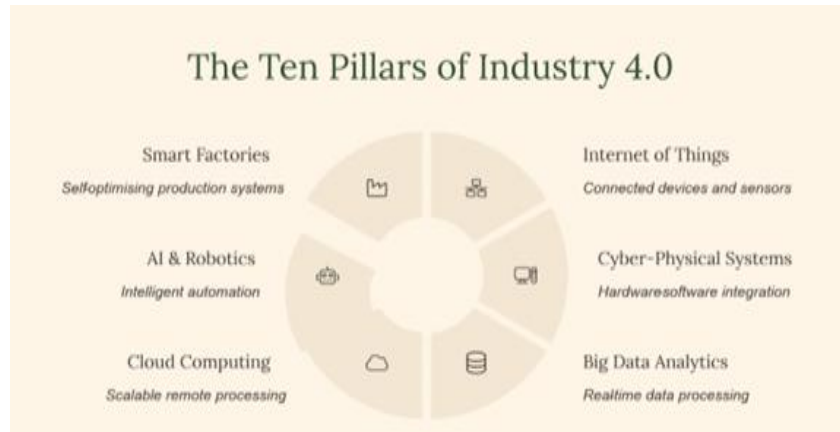


Fig -3: The Ten Pillars of Industry 4.0

The Third Industrial Revolution (Industry3.0), also sometimes referred to as the Digital Revolution, began in the mid-20th century and is characterized by the automation of production, particularly with the introduction of industrial Programmable Logic Con trollers (PLCs), invented in 1969. Additionally, industrial plants integrated advancements in robotics, electronics, information technology and telecommunications. Thus, the digitization of factories commenced with the incorporation of PLCs to automate certain processes and gather or share data [14].

The Fourth Industrial Revolution (Industry 4.0) has been advancing since the beginning of the 21st century [15], heralding the convergence of the digital, physical and virtual realms through the interplay of emerging technologies, such as Artificial Intel license, blockchain, robotics, IoT, nanotechnology, bioinformatics, advanced materials, quantum computing and 3D printing, among others [16]. This could be described as a revolutionary transformation driven by a diversity of recent technologies [15]. Unlike previous revolutions, these emerging technologies and innovations are spreading much faster and more extensively [17]. One of the anticipated effects of Industry 4.0 is complete factory automation, enabled by the extensive use of these new technologies, which allows for highly advanced configurations of automated production [18].

The relevance of this revolution that, in fact, the recent COVID-19 pandemic and the ensuing lockdowns highlighted the necessity of updating and modernizing system to address tasks remotely [19], as well as achieving greater flexibility, agility and resilience through digital transformation [20], which is directly related to Industry 4.0 and its associated technologies. Such is the relevance of this revolution that, in fact, the recent COVID-19 pandemic and the ensuing lockdowns highlighted the necessity of updating and modernizing systems to address tasks remotely [19], as well as achieving greater flexibility, agility and resilience through digital transformation [20], which is directly related to Industry 4.0 and its associated technologies. The definition and implications of this fourth revolution are discussed in greater detail in the following subsection. Meanwhile, Figure 1 visually and schematically represents the definition and implications of this fourth revolution are discussed in greater de tail in the following subsection. Meanwhile, Figure 1 visually and schematically represents the aforementioned revolutions, as well as the fifth revolution, which is described following

Finally, the fifth industrial revolution, also known as Industry 5.0, is currently being defined, even before its actual commencement. In fact, discussions about this revolution have been ongoing since 2017 [21]. However, this concept has gained greater prominence since the publication, in 2021, of a document titled “Industry 5.0: Towards a Sustainable, Human-centric, and Resilient European Industry” by the European Commission [22]. This document presents three main objectives that define Industry 5.0: a focus on the wellbeing of people (investors, workers, consumers), the resilience of the industry and the sustainability of the planet, going far beyond the mere production of goods and services for economic gain [23] While Industry 4.0 is primarily centered on digitization and technologies to enhance production efficiency and flexibility, Industry 5.0 acknowledges the industry long-term potential to serve humanity within the limits of the planet [21].



Fig-4: Industry 5.0 Overview

The concept of Industry 5.0, introduced by the European Commission, expands upon its predecessor (4.0) by ensuring that technological research and development not only consider industry competitiveness but also its contribution to society and the environment [23]. In this sense, Industry 5.0 does not seek to replace Industry 4.0 but rather appears as a complement to further progress achieved by various technologies and to strengthen the positive relationship between humans and machines [24]. Interesting review papers can be found in the literature to delve deeper into Industry 5.0 [25,26]. gain [23] While Industry 4.0 is primarily centered on digitization and technologies to enhance production efficiency and flexibility, Industry 5.0 acknowledges the industry’s long-term potential to serve humanity within the limits of the planet [21]. The concept of Industry 5.0, introduced by the European Commission, expands upon its predecessor (4.0) by ensuring that technological research and development not only consider industry competitiveness but also its contribution to society and the environment [23]. In this sense, Industry 5.0 does not seek to replace Industry 4.0 but rather appears as a complement to further progress achieved by various technologies and to strengthen the positive relationship between humans and machines [24]. Interesting review papers can be found in the literature to delve deeper into Industry 5.0.



Fig -5 Success stories of Industry 4.0

Many multinational companies across the world adopted the AI technology and switched to industry 4.0. Famous name from this category are Siemens Amberg, Bosch, GE Aviation some Indian companies such as tata steel, Mahindra etc.



3.1 Main Enabling Technologies of Industry 4.0

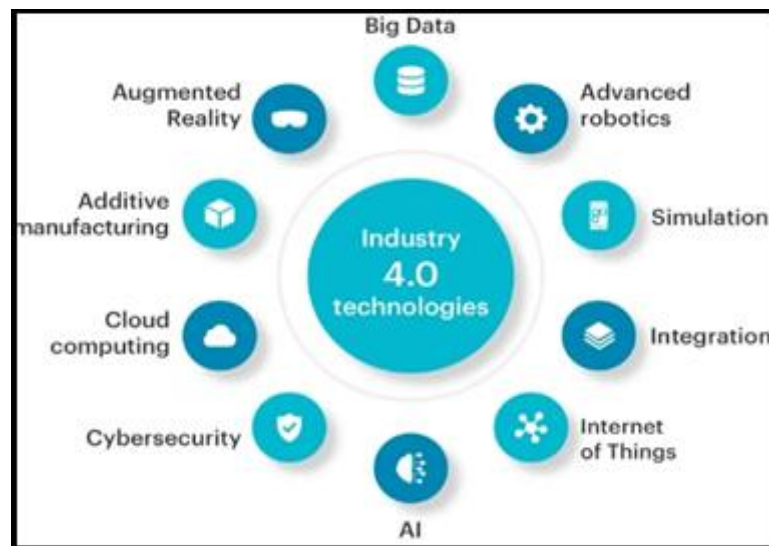


Fig- 6 Key components of industry 4.0

“Industry 4.0 is the implementation of CPS for creating Smart across the Value Chain”. Below are the components of industry 4.0

- Smart Factories• Internet of Things (IoT)
- Cyber-Physical Systems (CPS)
- Big Data & Analytics
- Cloud Computing
- Artificial Intelligence & Machine Learning
- Robotics & Automation
- Additive Manufacturing (3D Printing)
- Augmented & Virtual Reality (AR/VR)

4. ADVANTAGES OF INDUSTRY 4.0

There are many advantages of industry 4.0 some of them are highlighted below

- Higher efficiency and productivity
- Reduced operational costs
- Real-time decision making
- Better product quality
- Enhanced customer satisfaction
- Reduce labor dependency
- Rationalization of process

5. CHALLENGES AND LIMITATION OF INDUSTRY 4.0

Though industry 4.0 is beneficial in many ways but still we have to face some challenges while switching to industry 4.0. Some of them are explain below

- High adoption costs
- Cybersecurity risks
- Legacy system integration
- Change management complexity
- Workforce skill gaps

6. APPLICATIONS OF INDUSTRY 4.0

Industry 4.0 has very vast range of application. Some of the areas are explained below Manufacturing: Smart factories, predictive maintenance, digital twins.

- Automotive: Connected vehicles, digital twin testing.
- Aerospace: Predictive maintenance of engines and components.
- Healthcare: Smart devices, AI-driven diagnostics.



- Agriculture: IoT-enabled precision farming.
- Supply Chain: Real-time tracking, warehouse automation, blockchain.

7. CONCLUSIONS

Industry 4.0 represents a paradigm shift in how industries operate, blending digital and physical systems. Despite challenges such as cybersecurity and workforce readiness, it offers immense benefits in efficiency, cost reduction, customization, and sustainability. The evolution towards Industry 5.0 will further emphasize human-centric and eco-friendly approaches.

8. REFERENCES

- [1] Abdelaal, M. M., Rabee, B. A., Hegab, A. H. Effect of adding oxygen to the intake air on a dual-fuel engine performance, emissions, and knock tendency. *Energy*, 2017; 61: 612–20.
- [2] Bo, Y., Xing, W., Chengxun, X., Yifu L., Ke Z., and Ming, H. N. Experimental study of the effects of natural gas injection timing on the combustion performance and emissions of a turbocharged common rail dual-fuel engine. *Energy Conversion and Management*, 297–304.
- [3] Braisher M, Stone R., Price P. Particle number emissions from a range of European vehicles. *SAE*, 2010; 01-0786.
- [4] Chen, Y. H., Huang, B. Y., Chiang, T. H., Tang, T. C. Fuel properties of microalgae (*Chlorella protothecoides*) oil biodiesel and its blends with petroleum diesel, *Fuel*, 2012; 94: 270-273.
- [5] Irimescu, A., Marchitto L., Merola, S. S. Combustion process investigations in an optically accessible DISI engine fueled with n-butanol during part load operation. *Renew Energy*, 2015; 77: 363-76.
- [6] Kumar, C., Athawe, M., Aghav, Y., Gajendra, B. M. Effects of ethanol addition on performance, emission and combustion of DI diesel engine running at different injection pressures. *SAE Technical Paper*, 2017; 01-0626.
- [7] Meng, F., Yu, X., He, L. Study on combustion and emission characteristics of a n butanol engine with hydrogen direct injection under lean burn conditions. *Int J Hydrogen Energy*, 2018; 43(15): 7550-7561.
- [8] Ozsezen, A. N., Canakci, M., Turkcan, A., Sayin, C. Performance and combustion characteristics of a DI diesel engine fueled with waste palm oil and canola oil methyl esters. *Fuel*, 2011; 88: 629-636.
- [9] Papagiannakis, R. G., Hountalas, D. T. Combustion and exhaust emission characteristics of a dual fuel compression ignition engine operated with pilot Diesel fuel and natural gas. *Energy Conversion and Management*, 2014; 2971–2987.
- [10] Tüccar, G. U., Aydın, K. B. Evaluation of methyl ester of microalgae oil as fuel in a diesel engine. *Fuel*, 2013; 112: 203-207.
- [11] Wahlen, B. D., Morgan, M. R., McCurdy, A. T., Willis, R. M., Morgan, M. O. Biodiesel from microalgae, yeast, and bacteria: engine performance and exhaust emissions, *Energy Fuels*, 2012; 27: 220-228.
- [12] *Convers. Manag.* 93 (2015) 289–297. A. Sharma, S. Murugan, Investigation on the behavior of a DI diesel engine fueled with *Jatropha Methyl Ester (JME)* and *Tyre Pyrolysis Oil (TPO)* blends, *Fuel*. 108 (2013) 699–708. <https://doi.org/10.1016/j.fuel.2012.12.042>.
- [13] A. Devaraj, M. Nagappan, D. Yogaraj, O. Prakash, Y.A. Rao, A. Sharma, Influence of nano-additives on engine behaviour using diesel-biodiesel blend, *Mater. Today Proc.* (2022).
- [14] A. Sharma, S. Murugan, Influence of fuel injection timing on the performance and emission characteristics of a diesel engine fueled with *Jatropha methyl ester-tyre pyrolysis oil* blend, *Appl. Machmeter.* 592–594 (2014) 1627–1631. <https://doi.org/10.4028/www.scientific.net/AMM.592-594.1627>.
- [15] A. Sharma, M. Sivalingam, Impact of Fuel Injection Pressure on Performance and Emission Characteristics of a Diesel Engine Fueled with *Jatropha Methyl Ester Tyre Pyrolysis Blend*, *SAE Tech. Pap.* 2014-October (2014) 2650. <https://doi.org/10.4271/2014-01-2650>.
- [16] Q. Pham, S. Park, A.K. Agarwal, S. Park, Review of dual-fuel combustion in the compression-ignition engine: Spray, combustion, and emission, *Energy*. 250 (2022) 123778. A. Sharma, G. Gupta, A. Agrawal, Utilization of Waste Lubricating Oil as a Diesel Engine Fuel, *IOP Conf. Ser. Mater. Sci. Eng.* 840 (2020). <https://doi.org/10.1088/1757-899X/840/1/012015>.
- [17] M. Karthick, K. Logesh, S. Baskar, A. Sharma, Performance and Emission Characteristics of Single Cylinder Diesel Engine Fueled with Biodiesel Derived from Cashew Nut Shell, in: *Adv. Mater. Manuf. Energy Eng. Vol. II*, Springer, 2022: pp. 521–529.
- [18] G.N.V. Siddartha, C.S. Ramakrishna, P.K. Kujur, Y.A. Rao, N. Dalela, A.S. Yadav, A. Sharma, Effect of fuel additives on internal combustion engine performance and emissions, *Mater. Today Proc.* (2022)
- [19] K. Logesh, M. Karthick, S. Baskar, A. Sharma, Performance and Emissions Characteristics of Diesel Engine Run on *Citrullus Colocynthis* Biodiesel with Zinc Oxide Additive, in: *Adv. Mater. Manuf. Energy Eng. Vol. II*, Springer, 2022: pp. 513–520.



- [20] A. Sharma, S. Murugan, Effect of blending waste tyre derived fuel on oxidation stability of biodiesel and performance and emission studies of a diesel engine, *Appl. Therm. Eng.* 118 (2017) 365–374. <https://doi.org/10.1016/j.applthermaleng.2017.03.008>.
- [21]. Wan, N. W. Dual Fuel Engine Combustion and Emissions – An Experimental Investigation Coupled with Computer Simulation. PhD Thesis Colorado State University, 2014.
- [22]. Wang, X., Liu, H. B., Zheng, Z. O., Development of a reduced n- butanol/biodiesel mechanism for a dual fuel engine. *Fuel*, 2015; 157: 87–96.
- [23] Yilmaz, I. U., Tas, M. V. Investigation of hydrogen addition to methanol-gasoline blends in an SI engine. *Int J Hydrogen Energy*, 2016; 43(44): 20252-61.
- [24]. Yu, X. B., Guo, I. Z. Effect of gasoline/n- butanol blends on gaseous and particle emissions from an SI direct injection engine. *Fuel*, 2018; 229: 10.