Selection of the best plasma reactor for the diamond chemical vapor deposition operation of waste materials using multi-criteria decision-making models

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Research Article

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Abstract

Wastes emerged as potential alternative energy to flourish in various useful materials and commodities for human demands. In the civilized nation's variety of industrial projects of plasma, reactors underwent the decision-making models, project approval and even exploitation stages from long ago. The current study comprised waste materials utilization in diamond deposition purposes via chemical vapor deposition for constructing future industries firstly. To select the best plasma reactor were employed seven multi-criteria decision-making models in combination with three kinds of weighing systems to select the best plasma reactor empirically. Initial data for assessment possessed from a deep literature review based on probative technologies. It was classified and prioritized the plasma reactors in a coherent connection for direct gasification operation and placed them in a relevant arrangement media for partial gasification assortment. The developed assortment of plasma reactors was generally indicated as alternating current, direct current, glow, microwave, high-Frequency plasma, laser, Plasmatron and flame at direct gasification operation respectively. The high degree of stability among multi-criteria decision-making models and the sensitivity analysis employed for the weights and ranks released for alternatives and criteria had confirmed the precision and validity required. Also, on the global level, the findings of the present study proved the implementation of direct current plasma gasification reactors in large scale industries.

Keywords: Plasma reactors, Decision-making models, Diamond deposition, CVD, Waste materials stream

Nomenclature	
AC	Alternating Current
Am/h	Amper-minute/hour
A	Ampere
ARAS	Additive Ratio ASsessment
AI	Anti-Ideal
CVD	Chemical Vapor Deposition
CODAS	COmbinative Distance-based ASsessment
C	Carbon
COPRAS	COmplex PRoportional ASsessment
DC	Direct Current
DM	Decision Making
DDRs	Diamond Deposition Reactors
DDO	Diamond Deposition Operation
DD	Diamond Deposition
Ev	Electron volt
ES	Entropy Shannon
ECR	Electron Cyclotron Resonance
EDAS	Evaluation based on Distance from Average Solution
GHz	Gigahertz
H	Hour
HFP	High-Frequency Plasma
I	Ideal
KW	Kilowatt
K	Kelvin
MCDM	Multi-Criteria Decision Making
MW	Microwave
M	Meter
MABAC	Multi-Attributive Border Approximation area Comparison
MARCOS	Measurement Alternatives and Ranking according to COmpromise Solution
MAIRCA	Multi-Attributive Ideal-Real Comparative Analysis
NW	Normalized and Weighted

OPEC	Organization of the Petroleum Exporting Countries
RF	Radio Frequency
SCCM	Standard Cubic Centimeters per Minute
SAW	Simple Additive Weighting
SWARA	Step-Wise Weight Assessment Ratio Analysis
SA	Sensitivity Analysis
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
V	Volt
VIKOR	Vlse Kriterijumska Optimizacija I Kompromisno Resenje
WASPAS	Weighted Aggregated Sum-Product Assessment
W	Watt
Wj	Weight of each j criterion
Wje	Weight of each j criterion in ES

1. Introduction

The element of C is a remarkable matter for many reasons. Its different forms comprise one of the softest (graphite) and one of the hardest (diamond) substances known to human beings. Also, C great affinity for bonding with other small atoms, including other C atoms, and its small size allows you to create multiple links. These properties create ten million bounds and numerous C compounds. Also, C is utilized for the production of steel and rods in nuclear reactors and lots of other demands. At normal pressures, C graphite converts to form in which each atom with three other atoms makes hexagonal rings up like those in aromatic hydrocarbons connected. At very high pressures C allotropes appear as the diamond in the form in which each atom with four other atoms bonded. Perhaps the common perception about diamonds will change soon. Diamonds that for their beauty, rarity and long-time stability had tremendous value, today are prepared in about an hour in the laboratory (Purushothaman et al., 2011). Using diamond as a semiconductor claims some special characteristics such as the highest purity, crystallinity, and determination of the electrically active atoms to withstand an electrical bus of the device. However, all-natural diamonds are unsuitable for use in electrical usages because of defects, impurities, and weakness in the structure. Even though natural and artificial diamonds are gem-quality diamonds and extremely valuable, but it may be due to the insignificant traces of impurities that are not suitable for use as a semiconductor (Ismail and Ani, 2015). Only the purest of these rocks in power electronic applications ranging from film to personal computers and communication lines can be used. Historically a few major problems impede using natural diamonds existed in electronic applications. Natural diamonds have always been prohibitively expensive to use, their comprehensive and sufficient purity is also very difficult to find them in large stones. Nowadays diamond is formed by plasma techniques and CVD reactors based on combustion processes in the labs (Ahmad and Aitani, 2009, Stachel and Harris, 2008).

The high quantity of waste materials generated encountered to unsurmountable difficulties and challenges for human life and societies with restricted space for the accommodation of waste materials stream due to overpopulation and overconsumption in parallel with economic development. Waste materials can alter from initial form to useful gaseous products via chemical, biological and integrated practices as well as gasification operation. The output (syngas) products can be utilized to produce diamond and diamond-like materials using MW, gliding arc, plasmatron, DC, AC, RF plasmas, plasma torch (flame), and other cold and thermal plasmas with high efficiency in comparison with traditional methods in terms of useful gasses generation yield (Bosmans et al., 2013; Sekiguchi and Orimo 2004). The yield encompasses CH_4, N_2, CO, H_2, CO_2 and H_2O generation via plasma pyrolysis reactors, gasifiers and plasma treatment as a unique feedstock of diamond generation precursors (Bilous et al., 2014). Nucleation is one of the most prominent initial steps of the diamond synthesis from a gas phase. The process of diamond nucleation pertains to many conditions of the experiment, in which several cases can vary in time. Now the knowledge and skill in the nucleation area critically depend on perfect thin film growth, adhesion, and progress in heteroepitaxy expansion of a diamond. Due to surging interests towards nanomaterials generation of CVD at the early stage of its emergence paved the direct route to nanodiamond formation and deposition. Initially, chemical transport reaction on Cu, Au, and then on carbide-forming substrates, such as the silicon, W and Mo procured in the first time nucleation and growth of microcrystals of diamond with Cubo octahedral characteristics. Feasibility of homogeneous nucleation at CVD of diamond can be determined by following parameters of a gas phase encompassing chemical content, presence of ions, temperature, level of activation, gas flow through activation zone, total pressure, phase structure and topography of substrate, temperature of surface, electrical properties and charge of a substrate about a gas phase, effective distance between activation zone and substrate surface (Renno and Haubner, 1994). The increase of concentration in C precursor's preservation of the same level of activation of a gas phase will increase C precursors, CnHm and their concentrations. At the same time, the stationary concentration of atomic H falls at the presence of other radicals such, as CH_3.

Therefore, in supersaturation conditions, should grow considerably and provide more intensive nucleation. The experimental data are in good consent with such assumption, but only in the limited range of total pressure values. Recently manifested, that density of nucleation in MW plasma can be very low near pressure approximately 1.5 meters of the water column and then, passing through a maximum, again is reduced. The experiments carried out with the application of electrical bias on a substrate. That's why at low-pressure action of ions with higher energy levels more pronounced. The new nucleation mechanism is taken into consideration with the basic precursor of C_2 molecule generated by using fullerene–Ar or CH_4–Ar mixtures with very low content of H_2. By the way, it has been revealed an original path for new C atom addition through the insertion of the C_2 molecules in C-C and C-H bonds (Renno and Haubner, 1994).

Employing MWCVD by ITO et al (1990) succeeded in diamond formation by a mixture of CO (up to 8 vol %) + H_2 with dramatically faster evolving than CH_4 precursor. In some studies examined the heavy metals (Co, Ni, Cu, Ag, and Mn) effects on DD and compared CH_4 precursors with graphite via a combination of hot filaments and MWCVD. By the way, it reported to a uniform made up of diamond films using 1 % CH_4/H_2 and supported with graphite/H_2 particles. So, the highest efficiency encompassed the Co or Ni catalysts but they are not encouraging in lots of studies and total efficiency resembled CVD methods holding back the graphite seeding (Wong et al., 2000). Barrat et al (2001) examined DD on silicon via coupling and incorporating MWCVD and ultra-short bias enhanced nucleation process. This procedure had completed by promoting the localization and the stability of the double-discharges (DC and MW discharges). Bhattacharyya et al (2001) investigated the DD by introducing a mixture of gaseous compounds comprising up to 1-20% N_2 concentration and CH_4 (1%) /Ar onto Si at 800℃, 1.36 m pressure and 800 W, MW power. It resulted in the ultra nano-crystalline diamond film formations with a dramatic growth rate in parallel with a rise in N_2 concentration. Also, nano/micro-diamond overlayer films (4–5 nm) settled on Si in MWCVD connected to a negative bias midway and maintaining a mixture of H_2 + 0.5 % CH_4 at 0.408 m pressure, 100 v bias, 950 ℃, and 100 sccm by 1 or 2-h deposition period (Jiang et al., 2002).

Hiramatsu et al (2002) revealed that DD hastened using various kinds of substrates (e.g. Si, c-BN, SiC, Ni, Co, Pt, Ir, and Pd) in conventional MWCVD (2.45 GHz and 2-kW) with input gases of CH_4 (3–4 sccm) and H_2 (200 sccm) at a 0.612 m pressure and 700 ℃. Honga et al (2002) devised the nano-crystalline diamond film formed on silicon in 10 % CH_4–H_2 gas mixtures at 640–680 ℃, 0.3264 m pressure exploiting a coaxial antenna-type MWCVD (1.8–2.2 kW) in a period of 20 h. Achard et al (2005) pursued the synthesis of homoepitaxial single-crystal diamond with the presence of 0-10 mgl^{-1} N_2, 2-7.2 % CH_4 and H_2 addition (A total flow of 500 sccm of a CH_4 – H_2) using the MWCVD. The growth rates have been achieved up to 16 mm/h at 2.45 GHz, 750–1000℃. The MW power pulsing lets a rise of near 40 % in growth rate for the same average input power. The addition of N_2 entailed a dramatic rise in the growth rate. Das et al (2006) found that polycrystalline diamond films are formed on both Si (100) and SiC with an optimized Ar-rich Ar/H_2/CH_4 gas combinations at 370–530℃, 2.45 GHz applying MWCVD. A very high growth rate of up to 1.3 Am/h on SiC was perceived.

Huang et al (2006) asserted that roughness and uniform ultra-nanocrystalline diamond films were formed on silicon substrate by MWCVD and injected gas combinations of Ar/H_2/CH_4 at 0.816–3.264 m pressure and 400–850℃. A rise in induced pressure, H_2 and CH_4 gaseous combination percentages and MW power will take a rise in growth rate. The highest growth value of around 1.12 Am/h came in to view at 2.448 m pressure, H_2/Ar/CH_4 (4:100:2) sccm and 1.5 kW power. Toyota et al (2008) innovated a high-rate crystal diamond synthesis technique using MW plasma submerged in liquid alcohol (90 ml of CH_3OH and 10 ml of C_2H_5OH) and diamonds grown 100 μm/h at 2.45 GHz, 300W, 60 kPa, and 670 °C.

Yu - Feng et al (2001) opined that the Nano-crystalline diamond films are intensively deposited on silicon substrates via the HFCVD process using a CH_4//H_2/Ar gas mixture. High purity DD achieved by integrating both reactors of HFCVD and MWCVD employing 0.5-2.0 % C_2H_5Cl + H_2, at 650 - 1073 K onto Si, Zn, Al and glass (DESAG type D263) substrates (Schmidt and Benndorf 2001). Takeuchi et al (2001) believed that diamond deposited via CVD generates the polycrystalline form of diamonds. But uniting HFCVD with frequent and intermittently bias current succeeded in multilayer diamond films on silicon. Wang et al (2015) exploited various organic and carbonaceous inorganic compounds, such as CH_4, C_2H_5OH, CH_3OH, C_3H_6O, C_2H_2, $(C_2H_5)_2O$, C_3H_9N, and CO_2, as C sources to deposit diamond films using HFCVD. The research accomplished to assess the modern DCCVD reactor for DD efficiency using a liquid compound (CH_3CO_2K) as an additive, under a constant power current, pressure (3.06-6.12 m), recirculation of additive at 900 ℃ and 1 h. It resulted in poor efficiency with the current additive (Suzuki et al., 1999). According to the report of Nong et al (2000), all the techniques of low-pressure CVD diamond synthesis require the existence of electric charge along with H_2 concentration. The CVD raised from the electrolysis process also led to the diamond synthesis of CH_3^0 and H^0 radicals via anodic oxidation and cathodic reduction at 70 ℃ greatly and successfully (Aublanc et al., 2001). But diamond formation without H_2 could be carried successfully out using a negatively charged cluster model or suspending hundreds to thousands of atoms in the gas phase and rising the high capillary pressure within the cluster. Diamond-like carbon made up of a newly matured electro-deposition possessing a voltage between 2.87–3.08 and 1.55–1.61 eV for liquids (Roy et al., 2002).

In the case of DD by glow discharge, the study of Sciortino et al (2002) discerned that the Raman quality and the morphology of the diamond films emerged a strong dependence on the discharge pulse circumstances. Pulsed glow discharge CVD procedure does not claim any substrate pretreatment, and the nucleation rate is represented to rise with current density, CH_4 concentration, and pressure. The current density (3.9-7.9 A/cm^2) is recommended with pulse shapes, CH_4 concentration, pressure and temperature of around 7.5 kHz frequency, 3 %, 3.41 m and 850–950 ℃ respectively. The temperature and pressure ranges are the same for all plasma CVD reactors of DD. The quality of the product has no association with an inter-electrode distance in the 25–35 mm range.

A study receded the application of vacuum chamber to diamond synthesis using CVD of CO_2 optical laser plasmatron to generate accelerated and enhanced deposition rate of Nano and polycrystalline-diamond films on W substrate with presence of atmospheric-pressure and Xe (Ar): H_2: CH_4 gas mixtures at flow rates of 2 l/min and 2.5-kW laser beam (Konov et al., 1998). Moreover, the progress in diamond synthesis also attempted to unite and integrate various gaseous mixtures along with technologies. So, the novel methods introduced photon plasmatron integrated with the CVD process of high-power CO_2 laser radiation regardless to couple the vacuum chamber (but including an electromagnetic field) and developed the diamond formation in an open-air atmosphere. The mixture of input precursors comprised Ar, N_2, O_2, CO_2, C_2H_2, CH_4 and H_2 at 15000-20000 K, pressure (equal or upper than 10.33 m) using substrates of Mo, Si, and WC in air. The output of current novel technology led to demystify a linear DD rate of 2 mm/min ensuring quality and homogeneity of the product (Metev et al., 2002). In the following steps scientists considered to exploit a strong magnetic field in the industrial scale-up of technologies to accelerate diamond formation. Therefore, the developed technology no need to employ H_2 etchant. The main achievement of mentioned scientists can be noticed to progress in design and introduce a united technology able to implement in the industrial dimension (Reginald et al., 2005).

The diamond formation has been reported by the combustion of O_2 in the vicinity of C_2H_2, C_2H_4 and CH_4 using a flame along with burning a mixture of O_2 and C_2H_2 to complete the process. It has come into view a rampant deposition and growth rate of about 100-170 µm/h faster than other CVD techniques. Taking into consideration a ratio of around 0.47 and 1.04 for the fuel (premixed C_3H_6 /O_2 and C_2H_2/O_2)/O_2 and presence of 2.448 m pressure for the flame were made up well-faceted films and 1.5 nm C clusters respectively (Hirosi 1990; Ahn et al 2002).

According to recent studies, the plasmatron reactor can be used as an evaporator and enricher for inlet gases (CH_4 and H_2) derived from biomass, fuels, oily and heavy hydrocarbon fuels, and their sludge's, and similar liquids. Also, the reactor can be employed for coupling or combining in the DD purposes as partial oxidation. Films created may also be of poor quality, so using a laser as the heat source (in partial oxidation), adjusting temperature gradient, and avoiding unwanted gas-phase reactions can recoil the mentioned drawbacks in this method. About the possibility of the high demand for required energy to DDO of waste materials, it can be considered to either nuclear energy, renewable energy exploitation or recycling thermal energy to compensate for the energy consumed in prominent industrial scale-up purposes (Unnisa and Hassanpour 2017).

On the other hand, we are aware of this fact that DC gasification reactor getting more popularity these days and lots of projects have been identified to construct to manage the municipal solid waste, wastewater sludge's, auto shredder residue, hazardous waste, biomass, shipboard waste, residual waste, tire-derived fuel, etc. all over the world (Hassanpour 2018). Diamond is formed via plasma CVD techniques introducing a mixture of H_2, hydrocarbons, N_2, CO, CO_2, and H_2O into reactors in various configurations generally. But diamond components analysis detected a variety of some other components along with the mentioned cases. Also, high purity of input gasses injection into reactors assuming the reactions start-up and initiation by CH_3 radicals deemed to be indispensable. Therefore, the gasification operation of waste materials proceeds with generating highly enriched gaseous components rich in the mentioned gaseous compounds for DD targets (Unnisa and Hassanpour 2017; Hassanpour 2018).

To make up various types of diamond materials in the CVD method lots of criteria or factors interfere and also participate. By the present study, the author tried to introduce the main plasma reactors posed in DDO by selecting the prominent interfering criteria. By the way, it was determined around 14 criteria along with 8 plasma reactors. Then the formation of the matrix for the chosen criteria has relied on a strong literature review. In the next steps, the current study fled towards DM systems to obtain and achieve the right and absolute reactor prioritization in this regard. The weighting systems were chosen based on the circumstances and conditions of available factors in the selection of DDRs. The MCDM models applied in this research comprised TOPSIS, SAW, ARAS, WASPAS, CODAS, MABAC and MARCOS (Oliveira et al., 2018). The MCDM models matured to take into account the uncertainty and contradictory objectives in real-world difficulties and sought the proper path towards the best DM in assessments comprising conflicting criteria and alternatives. The previous evaluations by the MADM models can be found in variety of fields pioneered as employing ARAS model for combustion plant location selection of waste materials

(Turskis et al., 2012), TOPSIS model for choosing the best catalyst system of CO_2 removal, the best contractor of construction operation and dominant technology for weapon system (Dace et al., 2014; Farzami and Vafaei, 2013; Georgiadis et al., 2013), COPRAS model to select the best investment projects and the indicator of fluorescent lamp purchase (Popovic et al., 2012; Vujicic et al., 2016), the MABAC model for the supplier selection with regard to risk factors (Yazdani et al 2019) and Mukhametzyanov and Pamucar (2018) employed the MCDM models (such as SAW, TOPSIS, ARAS, CODAS, MABC, and MARCOS, etc.) for SA. Finally, by the present study as an assessment conducted the following objectives such as (1) To develop a new type of classification (ranking) for plasma gasification operation of waste materials stream in order to DD aim (2) To study and demystify the main criteria of plasma reactors for gasification operation of waste materials stream in diamond CVD process (3) To find the significant differences and correlations among main criteria of plasma gasification reactors in diamond CVD process (4) To identify the best plasma reactor for DD of waste materials flow (5) To examine the traditional to novel MCDM models and select the best reactor (6) To investigate the sensitivity of MCDM systems employed in this regard. To the best of our knowledge, this is for the first time that the waste materials stream deals and assesses with DDO and conversion in participating with plasma technology.

2. Methodology

2.1. The weighing systems

Actually by present research was used three types of weighing systems. It was used a weighing system as ($\sum_j^n \mathrm{Wj} = 1$), (j=0-1), with the numerical values of 1, 2, 3, 4, 5, 6, 7 for the criteria that encompassed linguistic words as very low, low, slightly low, medium, slightly high, high and very high respectively. The second weighing system was chosen considering the presence of both negative and positive criteria. Therefore, the ES weighing system assigned to figure out the values of weights according to equations 1 to 5. In the third weighting system was used the equal weighing for the criteria pays attention to this fact that criteria may have the same significance. To set up the matrix of data and introduce into the MCDM models was used a strong literature review at least 500 papers published from recent studies in the present research. Therefore, Table 1 was composed based on papers published during 20 years (It needs to explain that Table 1 published by the author with the same details once before (Hassanpour 2018)). Figure 1 displays the flow-diagram of followed work.

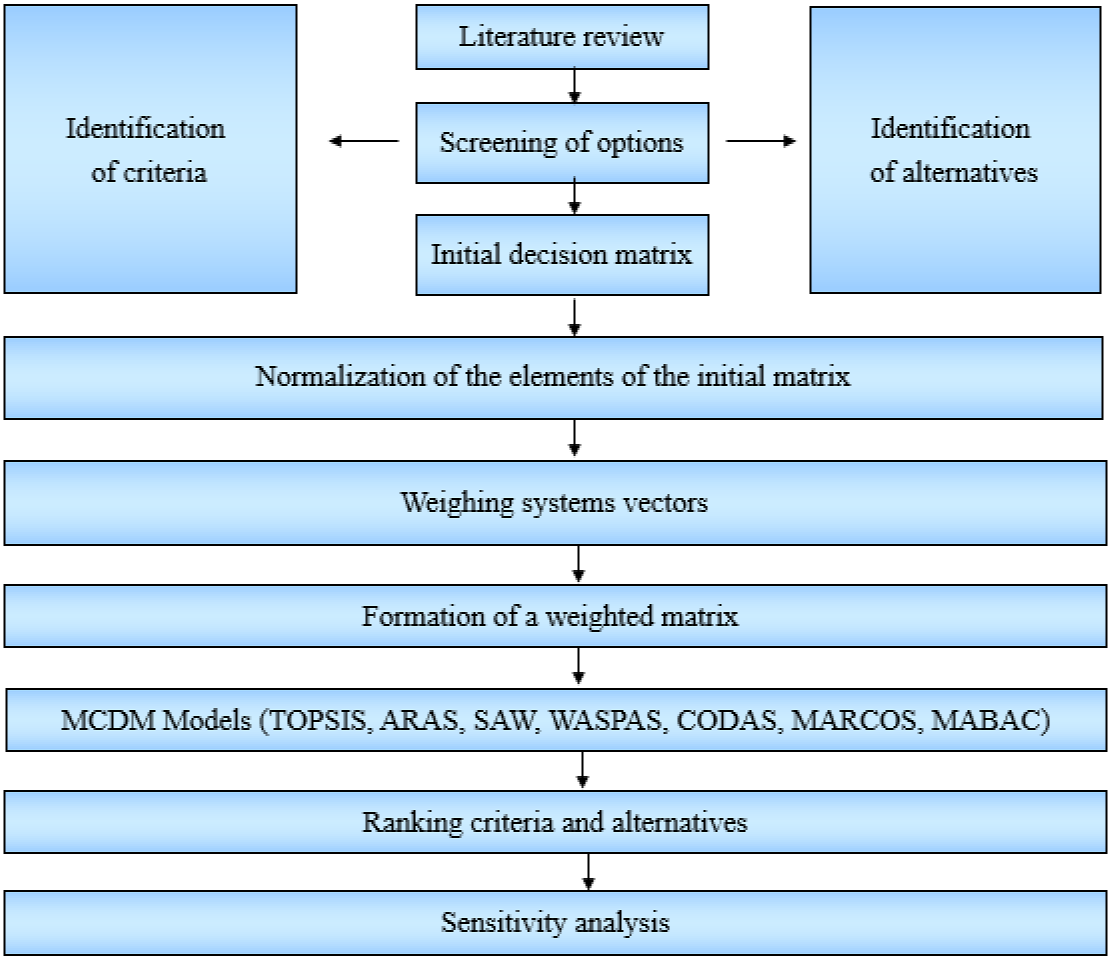


Figure1. Flow-diagram of followed work

$$\mathrm{Pij} = \frac{\mathrm{Xij}}{\sum_{i=1}^{m} Xij} \qquad j = 1, \ldots, n \qquad (1)$$ Normalization of data in the matrix

$$\mathrm{Ej} = -\mathrm{k} \sum_{i=1}^{m} Pij \times Ln\, Pij \qquad i = 1,2, \ldots, m \qquad (2)$$ Entropy values

$$\mathrm{k} = \frac{1}{\mathrm{Ln}\, m^{\circ}} \qquad (3)$$ Coefficient of entropy

$$\mathrm{dj} = 1 - \mathrm{Ej} \qquad (4)$$ Distance of entropy

$$\mathrm{Wje} = \frac{\mathrm{dj}}{\sum dj} \qquad (5)$$

To normalize existing data, calculation of entropy values, the distance between indicators and weights of them were employed formulas of 1 to 5 in the ES weighing procedure. The symbols of Xij, m°, and dj are the values of the matrix of data, the number of alternatives and distance of entropy respectively.

2.2. Ranking systems

As mentioned above seven MCDM models were applied to classify alternatives of research. The ARAS model firstly introduced as an advanced format of the SAW model in 2010. As we know the SAW model denotes the values of ranks after doing a simple normalization and introducing the vector of weights inside the rows of alternatives. The word ARAS implied on integrated ratio assessment for ranking alternatives containing various criteria in a decision matrix. Employing the ARAS model like many multivariate models is looking for the pathways to select the best response and possible solution. This model resembles other MCDM models and also is comparable with TOPSIS, VIKOR, WASPAS and SAW in simplicity. The values of weights are different for ARAS and SAW models but with no difference between ranking values. The WASPAS model aggregated the sum of weights and weighted products to release one united rank for the alternative in its designed equation (Karande et al., 2016; Yazdani-Chamzini, 2013).

The CODAS model sustained to rank alternatives pertains to combined distance assessment and it has been introduced in 2016. The decision matrix composed for this model contains an optional criterion matrix deduces a compromise response regarding the Euclidean and Taxicab distances. The Euclidean distance also is part of the framework of the TOPSIS model posed by 1981. By the definition, the main structure of the TOPSIS model underpins a trend of geometric distances as a minimum expansion from a positive ideal solution and the minimum propinquity to the negative ideal solution. The MABAC and MARCOS models are newly developed MCDM models in this regard. The framework of MABAC configured based on the implication of the distance of the criterion function of each of the appeared alternatives from the approximate border area (Ecer et al., 2019; Ghorabaee et al., 2016; Pamucar et al., 2018). The equations associated with defined MCDM models have been described in the following next step.

2.2.1. TOPSIS Method

$$\mathrm{pij} = \frac{\mathrm{Xij}}{\sqrt{\sum_{i=1}^{m}(\mathrm{Xij})^2}} \quad (6)$$ Normalization of data in the matrix

$$\mathrm{V} = \mathrm{pij} \times \mathrm{Wj} \quad (7)$$ Vector of weights

$$\mathrm{A}+= \{(\max \mathrm{Vij}|\mathrm{j} \in \mathrm{J}), (\min \mathrm{Vij}|\mathrm{j} \in \mathrm{j}')|\mathrm{i} = 1,2,\ldots,\mathrm{m}\} = \quad (8)$$ Determination of positive solution

$$= \{V_1^+, V_2^+,..V_j^+, V_n^+\}$$

$$\mathrm{A}-= \{(\min \mathrm{Vij}|\mathrm{j} \in \mathrm{J}), (\max \mathrm{Vij}|\mathrm{j} \in \mathrm{j}')|\mathrm{i} = 1,2,\ldots,\mathrm{m}\} = \quad (9)$$ Determination of negative solution

$$= \{V_1^-, V_2^-,..V_j^-, V_n^-\}$$

$$\mathrm{di}+= \left\{\sum_{j=1}^{n}(\mathrm{Vij} - \mathrm{Vj}+)\right)^2 \}^{0.5} ; \mathrm{i}, = 1,2,3,\ldots\mathrm{m} \quad (10)$$ Euclidean distance of positive solution

$$\mathrm{di}-= \left\{\sum_{j=1}^{n}(\mathrm{Vij} - \mathrm{Vj}-)\right)^2 \}^{0.5} ; \mathrm{i}, = 1,2,3,\ldots\mathrm{m} \quad (11)$$ Euclidean distance of negative solution

$$\mathrm{cli}+= \frac{\mathrm{di}-}{\mathrm{di}(+) + (\mathrm{di}-)} \quad \mathrm{i} = 1,2,3,4,5,6 \quad (12)$$ The values of ranks

2.2.2. ARAS model

$$\mathrm{pij} = \frac{\mathrm{Xij}}{\sum_{i=1}^{m}\mathrm{Xij}} \quad (13)$$ Normalization of data in the matrix

$$\mathrm{V} = \mathrm{pij} \times \mathrm{Wj}, \quad \mathrm{i} = \mathrm{o},\mathrm{m} \quad (14)$$ Vector of weights

$$\mathrm{Si} = \sum_{j=1}^{n} \text{normalized values of Xij}, \quad \mathrm{i} = \mathrm{o},\mathrm{m} \quad (15)$$ Summation of normalized values

$$\mathrm{Ki} = \frac{\mathrm{Si}}{\mathrm{S.}} ; \quad \mathrm{i} = \mathrm{o},\mathrm{m} \quad (16)$$ Calculation of utility degree

2.2.3. SAW model

$$\mathrm{Pij} = \frac{\mathrm{Xij}}{\sum_{i=1}^{n}\mathrm{Xij}} \quad \mathrm{i} = \Gamma,\mathrm{m}; \ \mathrm{j} = \Gamma,\mathrm{n} \quad (17)$$ Normalization of data in the matrix

$D = \frac{Xij \,.\, Wj}{\sum_{i=1}^{n} Xij} \qquad i = \Gamma, m; \;\; j = \Gamma, n$	(18)	Normalizing, weighing and calculating the values

2.2.4. WASPAS Model

$pij = \frac{Xij}{Max\ Xij}$	(19)	Normalization of data in the matrix
$Qi(1) = \sum_{j=1}^{n} pij\ Wj$	(20)	Computation of the relative importance of the alternatives in the role of a vector
$Qi(2) = \prod_{j=1}^{n} (pij)^{wj}$	(21)	Computation of the relative importance of the alternatives
$Qi = ƛQi(1) + (1 - ƛ)Qi(2), \qquad ƛ = 0, \ldots, 1$	(22)	Calculating the values of ranks, λ =0.5

2.2.5. CODAS model

$pij = \frac{Xij}{\sum_{i=1}^{m} Xij}$	(23)	Normalization of data in the matrix
$V = pij \ \times Wj$	(24)	Vector of weights
$nsj = \min rij$	(25)	Determination of the minimum rij
$Ei = \sum_{j=1}^{m}((rij - nsj)^{2})^{0.5}$	(26)	Determination of the Euclidian distances
$Ti = \sum_{j=1}^{m} \mid rij - nsj \mid$	(27)	Determination of the Taxicab distances
$Ra = [hik]n \times n$	(28)	Compose the relative assessment matrix
$hik = (Ei - Ek) + (\psi(Ei - Ek) \ \times (Ti - Tk))$	(29)	Determination of Euclidean distance (t = 0.02)
$Hi = \sum_{k=1}^{n} hik$	(30)	Determination of the values of ranks

2.2.6. MARCOS model

$AI = \min xij \text{ if } j \in B \text{ and } \max xij \text{ if } j \in C$	(31)	AI solutions
$I = \max xij \text{ if } j \in B \text{ and } \min xij \text{ if } j \in C$	(32)	I solutions
$pij = \frac{Xij}{Xai} \qquad \text{if} \in C$	(33)	Normalization of data in the matrix
$V = pij \ \times wj$	(34)	Vector of weights
$Ki- = \frac{Bi}{Saai} \qquad si = 1,2, \ldots m$	(35)	Utility degree identification
$Ki+ = \frac{Bi}{Sai}$	(36)	Utility degree identification
$Ci = \sum_{i=1}^{n} V$	(37)	Summation of NW values of alternatives along with AI and I
$f(Ki) = \frac{(Ki+) + (Ki-)}{1 + \frac{1 - f(Ki+)}{f(Ki+)} + \frac{1 - f(Ki-)}{f(Ki-)}}$	(38)	Determination of the utility function of alternatives to release ranks

$$f(Ki-) = \frac{(Ki+)}{(Ki+) + (Ki-)}$$	(39)	Determination of the utility function of alternatives associated with AI
$$f(Ki+) = \frac{(Ki-)}{(Ki+) + (Ki-)}$$	(40)	Determination of the utility function of alternatives associated with I

2.2.7. MABAC model

$$Xij = \frac{Xij - (\text{minimum } Xij+)}{(\max Xij+) - (\text{minimum } Xij-)} \quad \text{if } Xij \in B$$	(41)	Normalization of data in the matrix
$$V = (Xij + 1).Wj$$	(42)	Vector of weights
$$gj = \left(\prod_{i=1}^{m} V\right)^{1/m}, i = 1, m; j = 1, n$$	(43)	Determination of approximate border area matrix
$$Qi = \sum_{j=1}^{n} (V - gj)$$	(44)	Ranking of options via the sum of the distance of options of the border approximate areas

In the above equations (Vj+), (Vj-), S·, n, rij, Xai, Ki^-, Ki^+, gi and ∏ are the quantity of NW value in each column of matrix of data (positive solution), the quantity of NW value in each column (negative solution), the greatest NW value in the rows of alternatives, number of criteria, minimum quantity of NW values in column of alternatives, the greatest values in the columns of matrix of data, division between sum of NW values in matrix of data to sum of minimum NW values in matrix, division between sum of NW values in matrix of data to sum of maximum NW values in matrix, geomean the column of NW alternatives and the result of multiplying numbers respectively. This requires explaining that to calculate the Euclidian and Taxicab distances in equation 29 the numbers obtained in the column of the matrix are subtracted from the distances and t is applied as a coefficient to the part of the formula. Then the sum of the total numbers obtained for the alternatives determines the final ranking (or Hi in equation 30) (Karande et al., 2016; Yazdani-Chamzini, 2013).

3. Results and discussion

Plasmas are advanced facilities in the culminating biocompatibility and generating environmentally friendly products with a long lifespan. The CVD is a method for producing nanostructured commodities and forming coatings on the substrates. In this practice, the precursors evaporate and enter into the reactor consequently undergo surface adsorption to form a solid film on the substrate. Solid films can be formed as amorphous, polycrystalline or monocrystalline schemes. The CVD process consists of five steps such as (1) Reaction gases entering the reactor (2) The penetration of gases through a boundary layer (3) Contacting the gases with the underlying surface (4) Perform a deposition operation on the subsurface (5) Infiltration of reaction by-products through the boundary layer (Jonidi et al., 2013). The growth rate is not sensitive to the flow rate of the input materials. Therefore, this criterion was ignored to select by the present study. But the flow rate has an exponential relationship with rising the temperature. Due to the reduction of initial feed, the growth rate on the substrate surface decreases as the growth temperature raises (Jonidi et al., 2013). Similar changes take place in the growth mechanism of systems containing constant temperature and variable pressures. Therefore, both parameters of temperature and pressure are important criteria to run and operate the plasma CVD reactors. The liquid or solid precursors enter the gas through a boiling evaporator, then the produced gas is driven into the reactor. The liquid precursors are easier to utilize than solid. Because the heat transfer and the available surface area of the solid are less than that of the liquid. Using CVD technique can create a variety of nanostructures such as quantum dots, ceramic nanostructures, carbides, carbon nanotubes, highly diverse layers, and semiconductors, metal coatings, and generation of layers with organic and inorganic compounds in crystalline or glass forms and having desirable properties and even pure diamonds generation. So, the quality plays the main role in the selection of the best diamond CVD reactor. That is why quality selected as an important criterion and key factor. One of the advantages of employing the direct exploitation of gaseous products containing the by-products can be noticed by the fact that they can easily be separated from the main products (Khachatryan et al., 2008; Purushothaman et al., 2011). Table 1 offers some chemical kinetic reactions for selectivity of CH_4 and H_2 conversion as other prominent criteria in this regard. However, these reactions are not limited to only 28 interactions so experimentally there are more reactions for CH_4 and other species in the CVD reactor. Other precursors also follow similar chemical kinetic with radicals of H°. But it is very complex when a mixture of gaseous compounds introduces into reactors. Figures 2.1 and 2.2 show the modern CVD techniques and their illustrated reactors.

Table 1. Chemical kinetic reactions for conversion of CH_4 (Zhang et al 2014)

No	Reaction
1	CH_4=CH_3+H
2	CH_4+H= CH_3+H_2
3	CH_3+H= CH_2+H_2
4	CH_2+H= CH+H_2
5	CH_2+H_2= CH_3+H
6	CH_3+CH_2= C_2H_4+H
7	CH_3+CH_3= CH_4+CH_2
8	CH_3+CH_3= C_2H_5+H
9	H+H+H_2= H_2+H_2
10	CH_3+H_2= CH_4+H
11	CH_3+CH_3= C_2H_5+H
12	C_2H_5+H= C_2H_4+H_2
13	C_2H_5 = C_2H_4+H
14	C_2H_4+H= C_2H_3+H_2
15	C_2H_4+CH_3= C_2H_3+CH_4
16	C_2H_4+H_2= C_2H_2+H_2+H_2
17	C_2H_4+H_2= C_2H_3+H+H_2
18	C_2H_3+H= C_2H_2+H_2
19	C_2H_2+H= C_2H_3
20	CH_2+CH_3= C_2H_4+H
21	CH+H= C+H_2
22	C+CH_3= C_2H_2+H
23	CH+C_2H_2= C_3H_2+H
24	C_3H_2+H= C_3H_3
25	C_2H+H_2= C_2H_2+H
26	CH_3+H_2= CH_4+H
27	C_2H_4+C_2H_3= C_4H_6+H
28	CH_3+H_2= CH_2+H+H_2

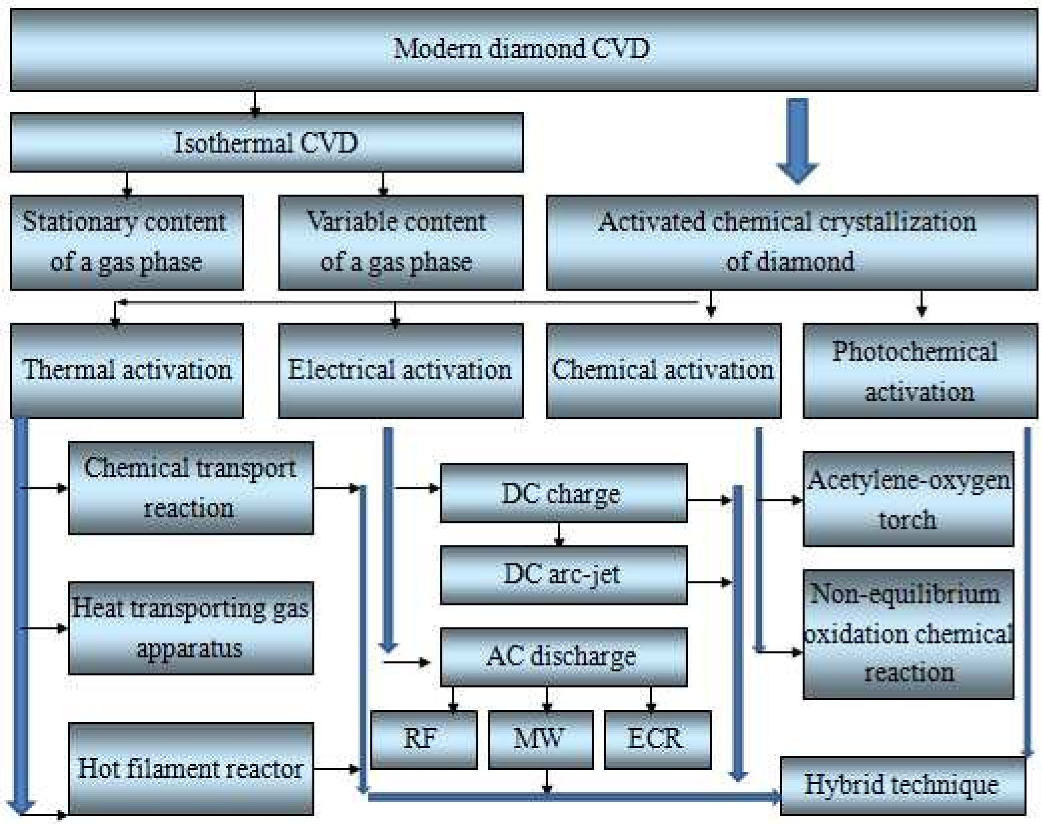
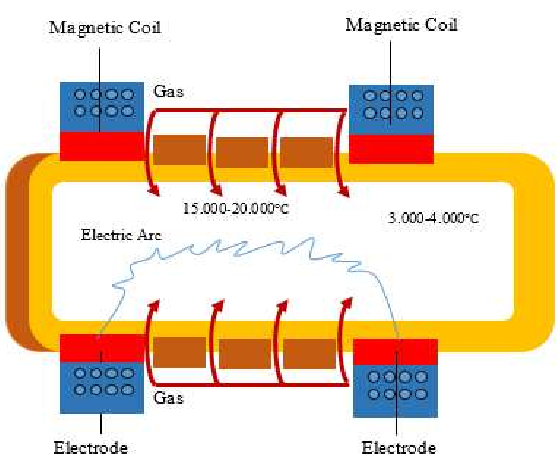
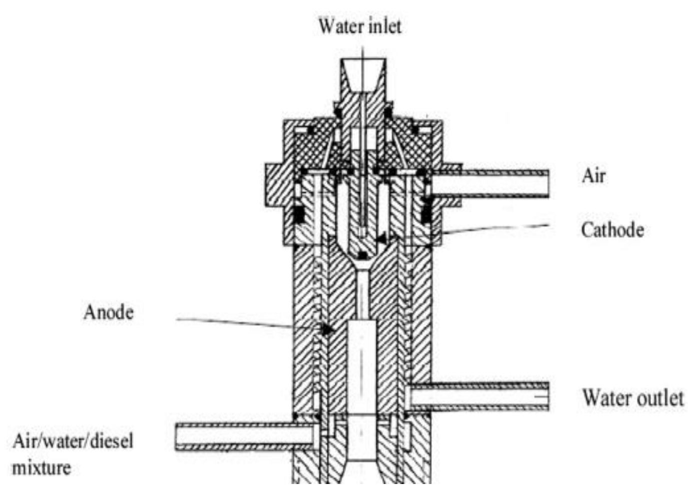


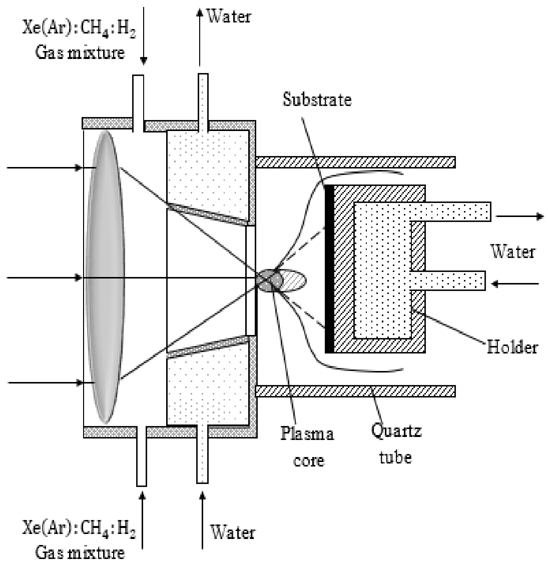
Figure 2.1. The modern diamond CVD



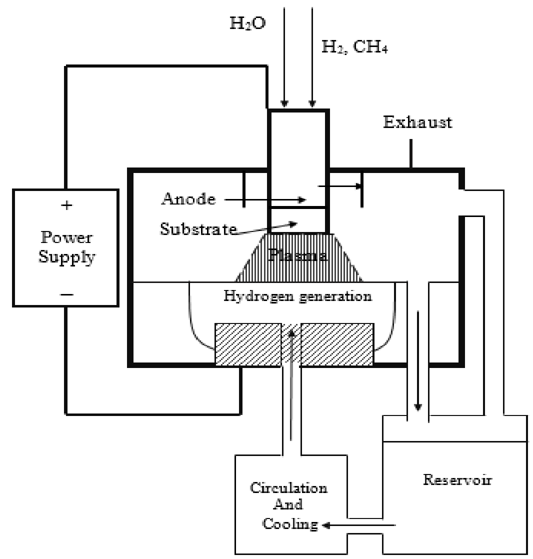
(a) Ac to Arc transition plasma



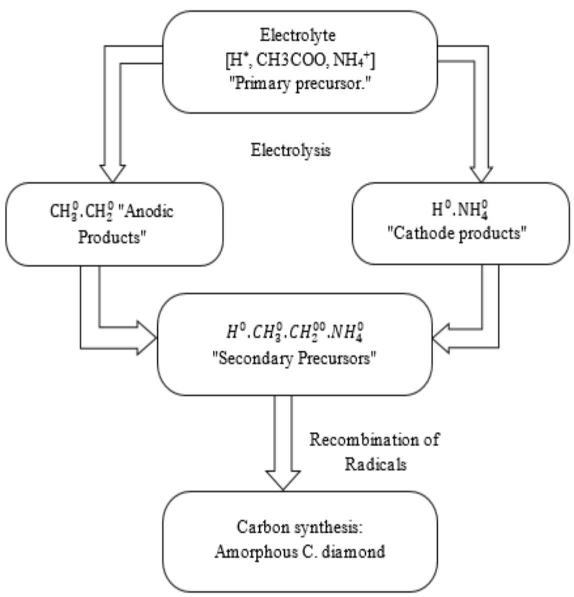
(b) Plasmatron



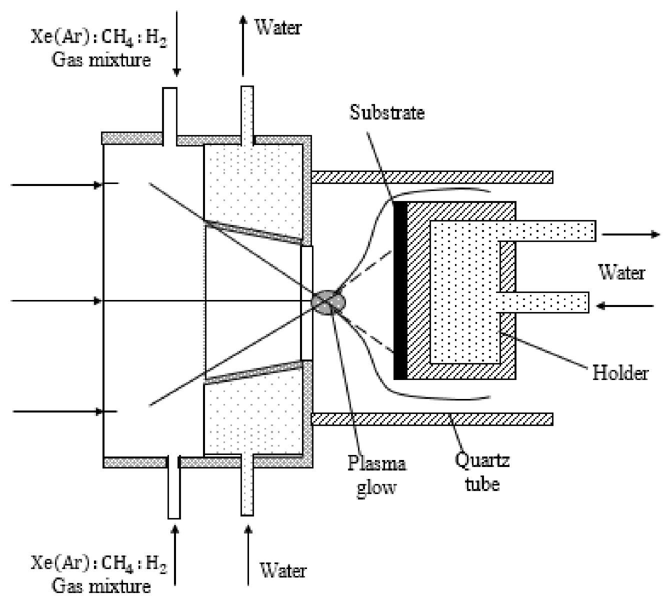
© CO_2 optical laser Plasmatron



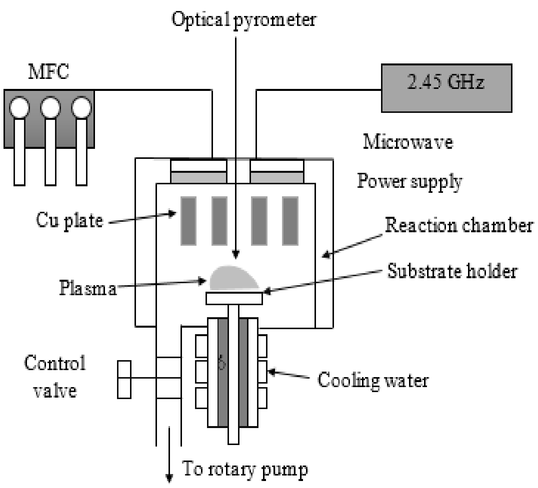
(d) DC plasma CVD



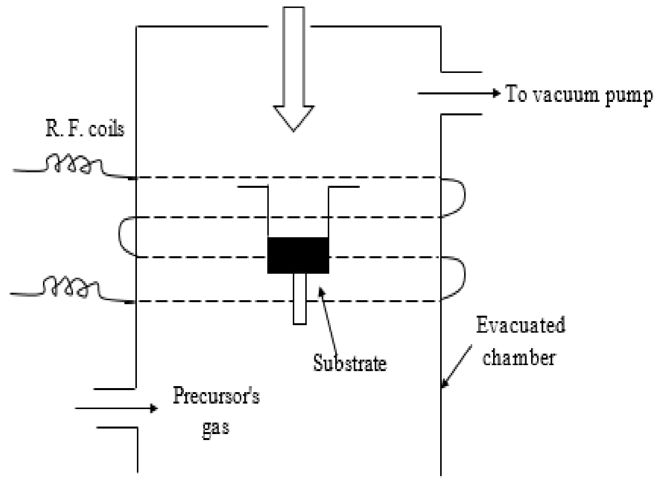
(e) CVD procedure equipped to anodic oxidation



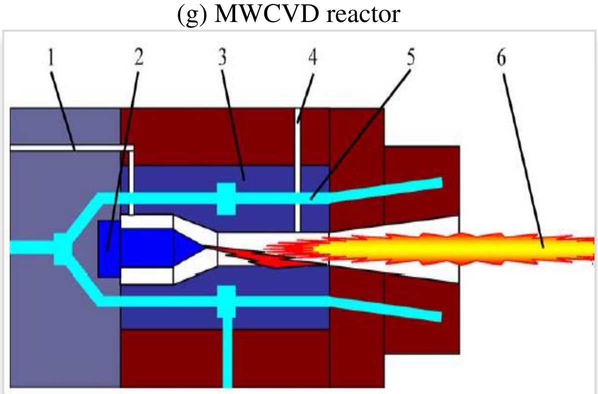
(f) Glow discharge CVD reactor



(g) MWCVD reactor



(h) RFCVD plasma



(I) Schematic of a flame: 1- gas inlet; 2- cathode; 3- anode; 4- power injection inlet; 5- cooling system; 6- Acetylene-Oxygen torch

Figure 2.2. The modern diamond CVD reactors

To explain Figure 2.2 the brief definition used to declare the advantages and drawbacks of plasma CVD reactors such as (a) AC plasma reactor is identified through existing small potential between the electrodes and low-density currents. The electrodes sustain sparks inside the reactor with low voltages depend on the type of feedstock entered into the chamber. To handle and confine the electric charge, particle dissipation and current density of induced charge are used magnetic coils attached to the reactor walls. The advantages associated with employing the AC plasma reactor for deposition aim are recognized to be the potential for smaller installations, a wide choice of reactants, appropriate chemical reactivity and current consumed (Takikawa and Tanoue 2007).

(b) Plasmatron as a reformer receded lots of drawbacks and got more popularity because of rapid start-up, minimum operational and technical outlays in pilot plant scale, intangible pollution distribution, centralized H_2 generation, low power requirement, simple scale-up, compactness, efficient reformation, simple power generator (Unnisa and Hassanpour 2017).

(c) The optical laser-plasma reactor contains high energy input, high-density excited species, short pulse dissipation with high deposition rate and quite good uniformity in direct CVD process (Marczak et al 2014). There are some scale-up and configuration difficulties for integrated reactors with partial oxidation.

(d) Dc reactor included electrodes that take the electric current from an enhanced voltage supplier with low-pressure ambient. Exploiting the DCCVD plasma for direct deposition operation containing a disc-shaped glass cylinder with two electrodes upon plates encountered to ion falling deficiency, high voltage power generator, low performance, and poor quality. To recede the above-named difficulties utilized accommodation of substrate on the cathode electrode with some variations in both current density and gas pressure along with pulsed DC discharge (Suzuki et al., 1999).

(e) The electrolysis containing a CVD reactor equipped to anodic oxidation electrode is part of the AC reactor with the same pros and cons.

(f) The glow discharge regime is a range of current between the arc and dark discharges. The dark discharge or Townsend regime is commenced from 10^{-10} (saturation regime) to 10^{-5} A (Corona) while arc discharge is started from 10 (glow to arc transition) to upper than 10000 A (hot arc). Generally, the glow discharge in a low-pressure gas reactor seems to be a simple practice to acquire the electric field ionization and generates slightly high and effective deposition in direct CVD operation. Handling the glow to arc transition is a simple process by operators. The appropriate electrodes configuration is a suitable way to compensate for the energy losses by thermal conduction. Also, the glow plasma reactor efficiently operates for a combination of gases due to a strong electrical discharge (Zhang et al 2014).

(g) The MW plasma reactors are exploited as open, resonance and closed structures with slightly high powers. The striking behavior of MW is a constraint factor but it can be reduced or removed by applying a variety of appropriate generators (Sun et al 2016).

(h) RF discharges are characterized by the electrode-less reactors or coils contain local power density lower than that of a DC plasma with low plasma loss, efficient operation, with a simple framework, high source geometry, good uniformity properties, low electron density, and ion temperature. It is an intermediate system between thermal and non-thermal discharges, environmentally much cleaner than mechanical and wet chemical processes with a fast processing trend. The disadvantages of using an RF plasma reactor is allocated to descend local thermodynamic equilibrium, reaction collisions with variations in pressure (Denes and Manolache, 2004).

(I) the flame includes a high degree combustion facilities equipped to anode and cathode electrodes and substrate surface to deposition aim. The advantages and drawbacks of this reactor devoted to less flicker production, stable operation, appropriate handling, and lower refractory wear, power demand with minimum load resistance and electrode erosion and current-carrying/cooling restrictions respectively (Denes and Manolache, 2004).

The information associated with the initial screening of evaluator teams for the DDRs including input and output materials stream along with energy consumed is promising assessments for future expansion in this regard. A study conducted by the corresponding author investigated DDRs using the SAW model supported by the fuzzy set theory that resulted in the classification of plasma gasification reactors (Hassanpour 2018). Through this study, the author fortified the study to make a strong decision using traditional to novel MCDM systems. To conduct DDO by direct gasification process via HFP, DC, AC, MW, Flame, Laser, Glow, and Plasmatron panoplied to deposition reactor was identified a list of prominent criteria in 14 cases such as Quality (C_1), (0.1089), H_2 selectivity (C_2), (0.1041), CH_4 (or another precursor) conversion rate (C_3), (0.1041), growth rate (C_4), (0.0898), temperature (C_5), (0.0836), pressure (C_6), (0.0836), power (C_7), (0.0659), technology resource (C_8), (0.0616), equipment provision possibility (C_9), (0.0573), technical standards (C_{10}), (0.0532), implementation limitations (C_{11}), (0.0515), safety (C_{12}), (0.0510), renewable energy utilization (C_{13}), (0.0445), cost (C_{14}), (0.0409) that were weighted based on a strong literature review from recent publications.

Therefore, the selection of some criteria (such as C_7-C_{14}) was accomplished based on the above-named advantages and disadvantages of plasma CVD reactors. The criterion of cost comprised the economic aspects of operation and construction outlays of plasma reactors. Safety has a certain definition in this regard, the score assigned for the criteria took into consideration the reactors holding electrodes and electrodes less configuration of plasma reactors about run up the electric current and temperature rising risks so the values of 1 to 7 determined for reactors. This discussion has held back the description of some DD methods such as bias-enhanced nucleation, synthesis of detonation diamonds, ion implantation, high pressure, and high-temperature diamond synthesis in this paper. Table 2 included a DM matrix to prioritize the plasma reactors.

Table 2. DM matrix

Indicator/ technology	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}
HFP	7	7	7	7	7	1	2	6	7	7	1	6	6	7
DC	2	6	6	2	7	1	3	5	7	7	6	4	6	7
AC	6	6	6	6	7	1	3	5	7	7	6	4	6	7
MW	7	7	7	7	7	1	2	6	7	7	1	6	6	7
Flame	3	5	5	7	7	1	1	4	7	7	1	4	6	4
Laser	7	7	7	7	7	1	1	6	7	7	1	6	6	7
Glow	6	7	7	6	7	1	3	6	7	7	4	4	6	7
Plasmatron	6	7	7	6	7	1	2	7	1	7	1	6	6	7

Source: (Hassanpour 2018)

By Table 3, it was denoted the ranks for plasma reactors in seven MCDM systems along with introducing special vectors of each model. Using above-named equations resulted in the below findings after normalization, calculation of the values of weights and some especial calculations depend on each model and their equations individually.

Table 3. Ranking systems developed for plasma reactors

Technology	TOPSIS	ARAS	SAW	CODAS	WASPAS	MARCOS	MABAC
HFP	3	3	3	3	3	2	1
DC	6	6	6	5	6	6	6
AC	1	2	2	1	2	3	5
MW	3	3	3	3	3	2	1
Flame	7	7	7	7	7	7	7
Laser	4	4	4	4	4	4	3
Glow	2	1	1	2	1	1	2
Plasmatron	5	5	5	6	5	5	4

The obtained findings in Table 3 were presented high consistency among seven MCDM models. Table 2 was used as a source of data acquired in this step or the values of the weights of criteria in the ES weights calculation procedure. Therefore, the obtained Wje collected to compose Table 4. Table 4 displays the values of weights based on the ES procedure described by equations 1 to 5.

Table 4. The values of weights based on ES procedure

Criteria	E	dj=1-Ej	Wje	$\sum dj$	K
C_1	0.9695	0.0304	0.0998	0.3051	0.4808
C_2	0.9970	0.0029	0.0097		
C_3	0.9970	0.0029	0.0097		
C_4	0.9787	0.0212	0.0695		
C5	1	0	0		
C_6	1	0	0		
C_7	0.9651	0.0348	0.1142		
C_8	0.9942	0.0057	0.0188		
C_9	0.9642	0.0357	0.1172		
C_{10}	1	0	0		
C_{11}	0.8447	0.1552	0.5087		
C_{12}	0.9903	0.0096	0.0317		
C_{13}	1	0	0		
C_{14}	0.9938	0.0061	0.0202		

In the following steps, the values of the weights released via ES procedure dilated the way towards ranks appearance by conducting the values in an especial vector into the normalized matrix of data of Table 2. Data were undergone the same procedure with the previous step to assort the plasma reactors. So, Table 5 comprises the emerged classification in this regard. By the way, high consistency also was observed in the acquired findings in Table 5.

Table 5. Ranking systems developed for plasma reactors

Technology	TOPSIS	ARAS	SAW	CODAS	WASPAS	MARCOS	MABAC
HFP	4	4	4	4	4	4	4
DC	2	2	2	2	2	2	2
AC	1	1	1	1	1	1	1
MW	4	4	4	4	4	4	4
Flame	6	7	7	6	6	7	7
Laser	5	5	5	5	5	5	5
Glow	3	3	3	3	3	3	3
Plasmatron	7	6	6	7	7	6	6

The values of weights developed in ES procedure and extracted from the own study were come through the comparison method by statistical tests. It has emerged a dramatic rise in the value of weight allocated to C_{11} up to

0.5087. This means that by the presence of the positive and negative criteria in selecting the best reactor for the diamond CVD operation, the highest interfering factor is assigned to the criterion of implementation constraints. Figure 3 displays the comparison of both Wje with the Wj.

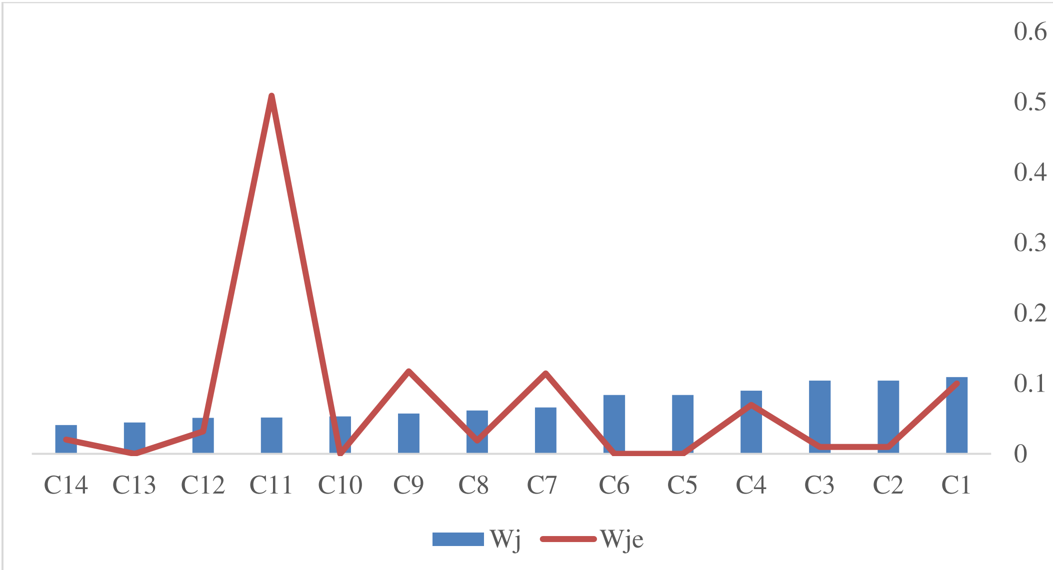


Figure 3. The comparison of both weighing systems of Wje and Wj

According to the pair samples correlations, it has come into view a correlation with propinquity of -0.200 between Wje and Wj with no significant difference between them. Also, the t-test was evinced no significant difference between both weighing systems.

This part of the study kept proceeding with considering this assumption that the criteria can encompass the same significance (Table 2). Therefore, the criteria were taken the same values up to 0.0715 individually. Table 6 shows the findings of equal weighing in seven ranking models.

Table 6. Ranking systems developed for plasma reactors

Technology	TOPSIS	ARAS	SAW	CODAS	WASPAS	MARCOS	MABAC
HFP	4	3	3	4	3	3	1
DC	3	4	4	2	5	6	6
AC	2	1	1	1	2	2	5
MW	4	3	3	4	3	3	1
Flame	7	7	7	7	7	7	7
Laser	5	5	5	5	4	4	3
Glow	1	2	2	3	1	1	2
Plasmatron	6	6	6	6	6	5	4

Taking into consideration the values of the weights expanded in seven MCDM models encompassing three different kinds of weighting systems attracted attention towards collecting the results in a figure. Therefore, Figure 4 lays out the findings together to illustrate the results for the easiest presenting way. In Figure 4 the symbols (L), (S) and € joined to titles of ranking models introduce the type of weighting system integrated to MCDM models such as a weighing system based on a literature review (or own study), ES and equal weighting respectively. In Figure 4 the highest values of weights devoted to the ranking system of WASPAS. Figure 5 also presents the sequence chart for the same data.

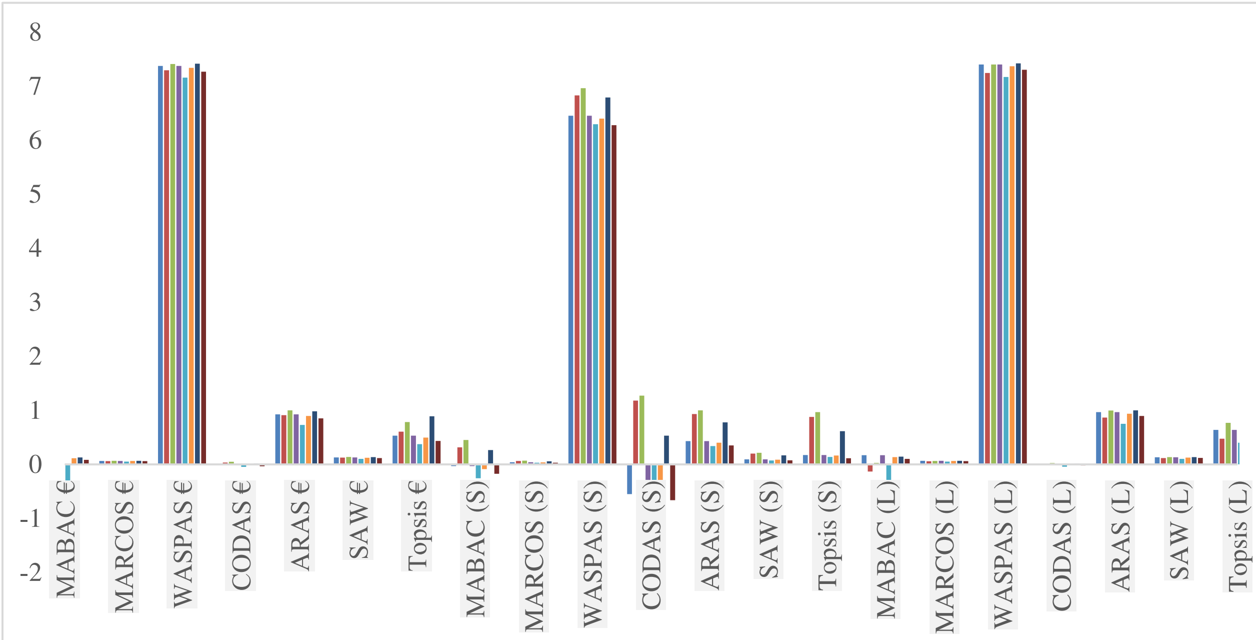


Figure 4. The values of weights of plasma reactors in ranking systems

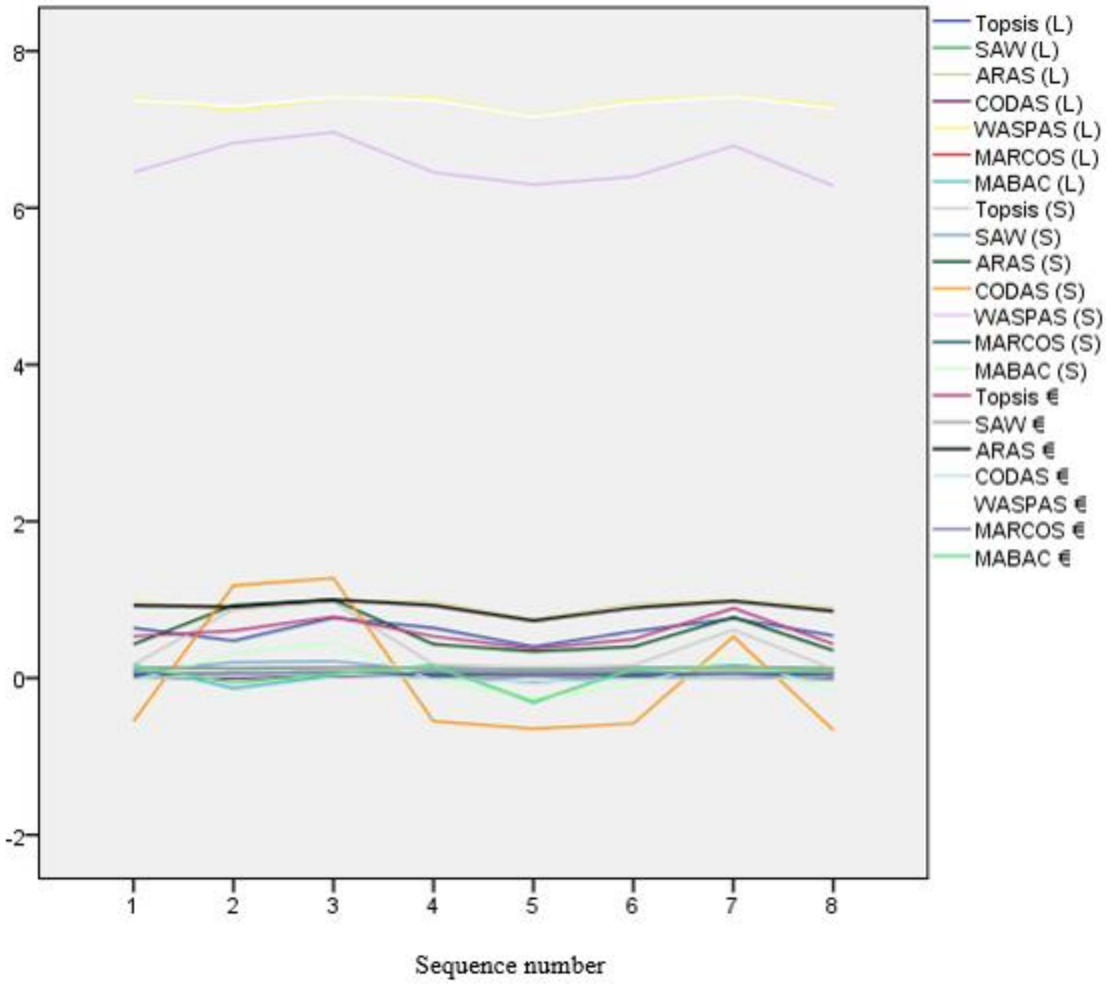


Figure 5. Sequence chart for values of weights in MCDM models

The sequence diagram typically displays interactions and interplays between various classes of scenarios to perform the functionality of the scenario where they are graphically passing through development stages. The distribution of the values of weights in MCDM models has emerged in straight and linear approaches and high overlapping in comparison with each other. The linear expansion also proceeded in parallel formats mostly (Ecer et al., 2019).

The SA was accomplished to validate the findings and results of the present study by the following that has been described. There is no significant difference among 210 weights values of 7 MCDM models with 3 various types of weighting systems applied according to t-test analysis. The α coefficient had revealed good reliability for the mentioned values of weights approximately 0.862. With regard to this fact that α is defined as $\alpha \geq 0.9$ (excellent), $0.8 \leq \alpha < 0.9$ (good), $0.7 \leq \alpha < 0.8$ (acceptable), $0.6 \leq \alpha < 0.7$ (questionable), $0.5 \leq \alpha < 0.6$ (poor), $\alpha < 0.5$ (unacceptable) (Prosperi et al., 2019). The Spearman correlation test was performed to find the coincidence between the values of the weights of ranking systems. It was distinguished as the highest correlation and coincidence or conformance among 7 MCDM models by number 1 in Table 7.

Table 7. The correlation coefficient comparison among the values of weights in MCDM models

Spearman test; correlation coefficient sig (2-tailed).
Correlation is significant at the 0.01 level (2-tailed).
Correlation is significant at the 0.05 level (2-tailed).

	SAW (L)	ARAS (L)	CODAS (L)	WASPAS (L)	MARCOS (L)	MABAC (L)	TOPSIS (L)
SAW (L)	1	1	0.952	1	.0928	0.639	.0976
ARAS (L)	1	1	0.952	1	0.928	.0639	.0976

CODAS (L)	0.952	0.952	1	0.952	0.831	.0518	0.976
WASPAS (L)	1	1	0.952	1	0.928	.0639	0.976
MARCOS (L)	0.928	0.928	0.831	0.928	1	.0855	.0855
MABAC (L)	0.639	0.639	0.518	0.639	0.855	1	0.566
TOPSIS (L)	0.976	0.976	0.976	0.976	0.855	0.566	1
	MABAC (S)	MARCOS (S)	WASPAS (S)	CODAS (S)	ARAS (S)	SAW (S)	TOPSIS (S)
MABAC (S)	1	1	0.976	0.976	1	1	0.976
MARCOS (S)	1	1	0.976	0.976	1	1	0.976
WASPAS (S)	0.976	0.976	1	1	0.976	0.976	1
CODAS (S)	0.976	0.976	1	1	0.976	0.976	1
ARAS (S)	1	1	0.976	0.976	1	1	0.976
SAW (S)	1	1	0.976	0.976	1	1	0.976
TOPSIS (S)	0.976	0.976	1	1	0.976	0.976	1
	MABAC €	MARCOS €	WASPAS €	CODAS €	ARAS €	SAW €	TOPSIS €
MABAC €	1	0.639	0.590	0.084	0.446	0.445	0.253
MARCOS €	0.639	1	0.976	0.590	0.904	0.904	0.759
WASPAS €	0.590	0.976	1	0.711	0.952	0.952	0.855
CODAS €	0.084	0.590	0.711	1	0.855	0.855	0.928
ARAS €	0.446	0.904	0.952	0.855	1	1	0.904
SAW €	0.4456	0.904	0.952	0.855	1	1	0.904
TOPSIS €	0.253	0.759	0.855	0.928	0.904	0.904	1

According to Table 7, full compliance was denoted by the values of 1 and having looked at the remaining values were identified the highest coincidence among existing values. Also, the highest compliance was obtained by the weighing system of ES according to the findings via spearman test; correlation coefficient sig (2-tailed) around 0.976-1 among seven MCDM models in Table 7. The equal weighing system had shown the lowest correlation for the TOPSIS-MABAC about 0.253 and it was found around 0.518 for the MABAC-CODAS via the third weighing system.

The sustainable development of OPEC countries evaluated by Ecer et al., (2019) besetting 41 indicators along with 3 dimensions and 10 factors via a strong literature review extracted from valuable and scientific databases. The findings came through the combined compromise solution model and compared with other MCDM models such as WASPAS, MABAC, CODAS, and VIKOR taking into account the same significance for the criteria. The precision and accuracy of findings validated by an escalated correlation of approximately 0.97 among 5 MCDM models. To find the most proper industrial robot and microclimate in an office used 5×5 and 6×14 for criteria × alternatives using the CODAS model supported with the values of criteria weights obtained by expert's opinions respectively. Then, the results passed the way towards the vicinity of MCDM models of WASPAS, COPRAS, TOPSIS, VIKOR, and EDAS to verify the achievements. The SA by Spearman's rank correlation coefficient manifested around 0.01 to 1 for 15 values released (Ghorabaee et al 2016). The power generation technology selection comprising lots of criteria and alternatives in 68 scenarios scrutinized the novel LNN pairwise-CODAS model by Pamucar et al (2018) in Libya. The accuracy and validity of the PW-CODAS model investigated based on the values obtained from TOPSIS, VIKOR, MABAC, MAIRCA models and Spearman coefficient. To find the equipment of flexible manufacturing systems exploited a matrix of 8 × 8 for alternatives × criteria and ES as a weighing system. The ARAS, COPRAS, Spearman’s rank correlation coefficient and Kendall’s coefficient of concordance employed as comparison tests to verify and evaluate the sensitivity of models (Chatterjee and Chakraborty, 2014). To assess the reverse logistics systems that are employed to culminate the organization business excellence applied the fuzzy complex proportional and COPRAS, COPRAS-G models as methods of comparison, precision and accuracy for the findings (including a matrix of (7 × 16 for criteria × alternatives)) to present a high validity along with SWARA in an automotive industry (Zarbakhshnia et al., 2018). Sremac et al (2018) evaluated the ten logistics providers of companies participating in transport the dangerous commodities via SWARA (weighing system) and WASPAS for 8 significant criteria and validated by both Rough SWARA and Rough Dombi aggregator methods. The SA carried out using Rough SAW, Rough EDAS, Rough MABAC, and Rough TOPSIS and Spearman’s correlation coefficient (for the mentioned models ranged from 0.927-0.977). To select healthcare waste treatment technology encompassing 4 disposal practices aligned for a matrix of 5 significant criteria along with 19 sub-criteria. The data passed through the hesitant fuzzy linguistic for taking the values of weights. The MCDM models of MAIRCA, MABAC, VIKOR, and TOPSIS assigned to rank and compare the findings and get a strong decision in the technology selection (Adar and Delice 2019). Identifying the best renewable energy project (solar radiation, wind, hydropower geothermal energies, photosynthetically fixed energy) taken into consideration the COPRAS model supported with analytical hierarchy process to release the weights for criteria. To verify the obtained results taken into account the MCDM models such as VIKOR, SAW, ARAS and TOPSIS to investigate the accuracy and precision of the employed model. More validation of models achieved via Spearman's rank correlation coefficients among four mentioned models up to 0.994, 0.885, 0.994 and 0.994 respectively (Yazdani-Chamzini, 2013). The robot selection difficulties led to the use of 6 various kinds of MCDM models and results compared with local and global weight stability intervals set and enacted in the SA (Karande et al., 2016). In the strategic project portfolio selection has done a strong literature review to select the most important criteria (34 cases) and assigned the MABAC, DM trial and evaluation laboratory model to rank and weigh the alternatives and criteria respectively. Then, the findings underwent validation steps relied on some other models such as Interval-valued Intuitionistic Fuzzy-MABAC, TOPSIS-Grey, and Grey-VIKOR in 10 scenarios as a SA. So, the ranking remained constant for all scenarios and fortified the stability in models (Debnath et al 2017). The findings of the current study present and sound in full agreement and compliance with the formerly mentioned studies in terms of SA, the number of models employed and the validity of obtained and calculated values.

4. Conclusion

The current research leaped and stipulated to change the attitudes towards waste materials management in receding the traditional methods and pervade and sought valuable technologies to make up high value-added products. The MCDM models employed were allocated from traditional to newly introduced methods in the DM process. The literature review done by the present study underpins the vast application of plasma reactors during the last 20 years to now as well as the great guide to denote the table of DM or matrix of data. However, bearing in mind this fact that selecting the best plasma reactor for DD is not very easy but DM models and systems really dilated the channels to make up the brains and surmount difficulties raised. Also, DM systems were manifested utmost propinquity in findings so it resulted in a classification of highly qualified plasma reactors in this regard. Also, the current way is able to handle the solid and liquid forms of waste materials introduced into the DDRs. The selected plasma reactors can be exploited to DDO in low to high voltages (like AC to AC corona, AC arc, gliding arc, AC hot jet, etc) depend on the type of waste in direct and complete gasification operations. Additionally, the findings confirmed a high consistency among seven MCDM models with good reliability and proper interactions. Also, the highest compliance emerged by the weighing system of ES among 7 MCDM models with introducing the C_{11} that holds the highest weight and constraint. With regard to findings, the best-selected reactors can be introduced both reactors of AC and DC with the highest correlation coefficient in the ES weighing system. Also, the AC reactor placed the first priority in all weighing systems. For future studies suggestions, all inventory of input and output materials and energy streams can be assessed by evaluator teams in the project identification plans. The screening steps of project identification can be taken into consideration the initial data as either raw data or shifted on currency values to demystify the efficiency of industrial projects via the data envelopment analysis models and newly developed and outlined DM models. Also, future researches orientation can proceed and deal with economic estimation and sustainability of DDRs in industrial dimensions.

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Figures

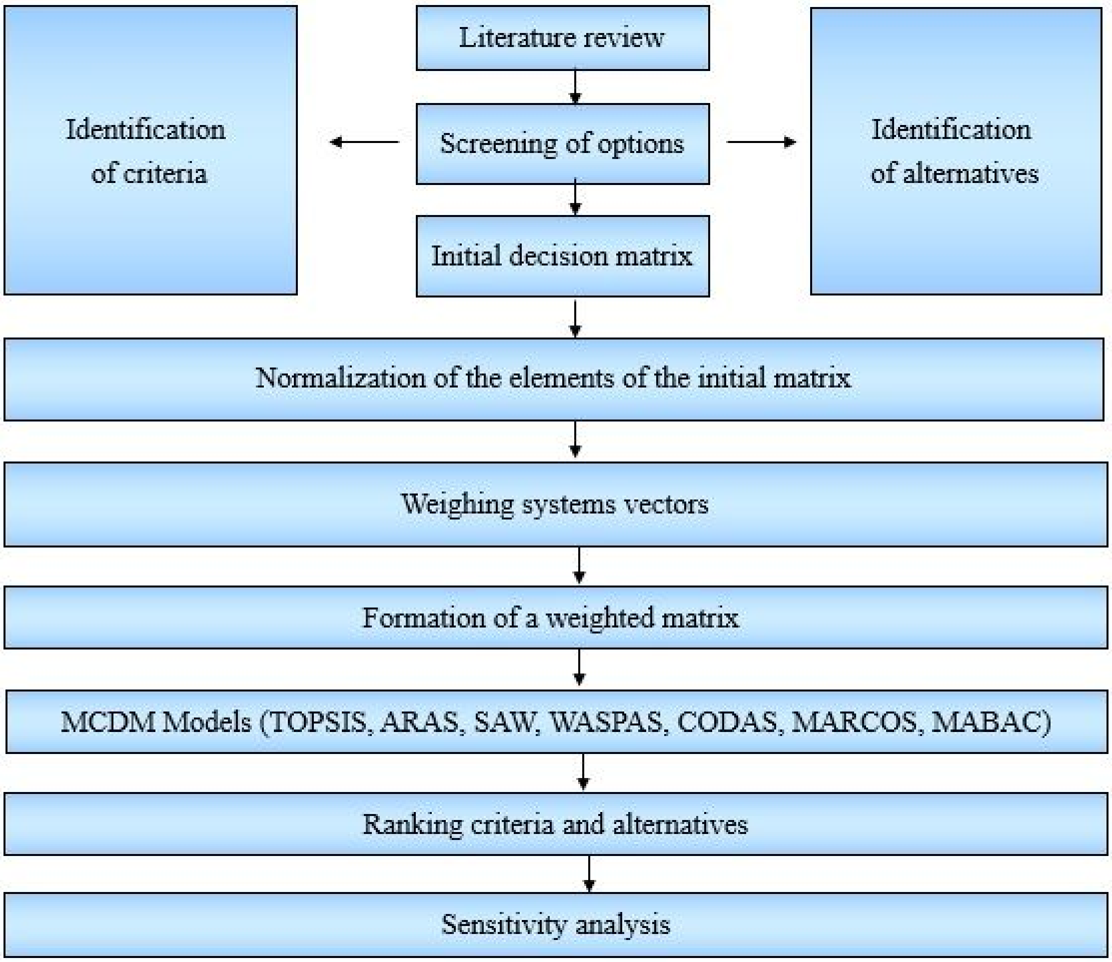

Figure 1

Flow-diagram of followed work

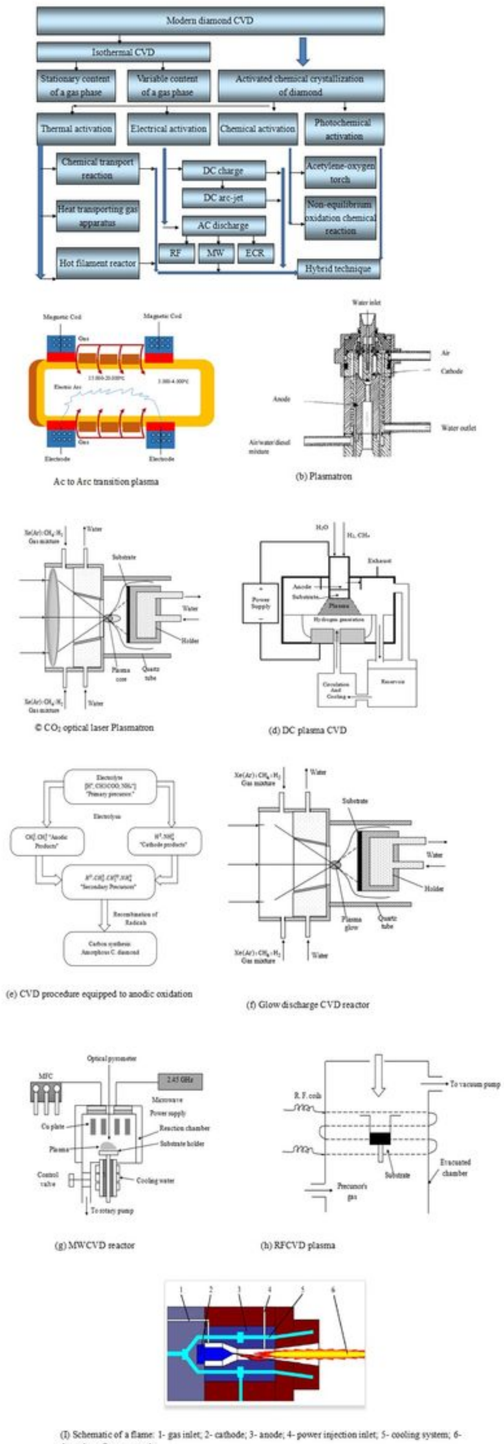

Figure 2

2.1. The modern diamond CVD. 2.2. The modern diamond CVD reactors

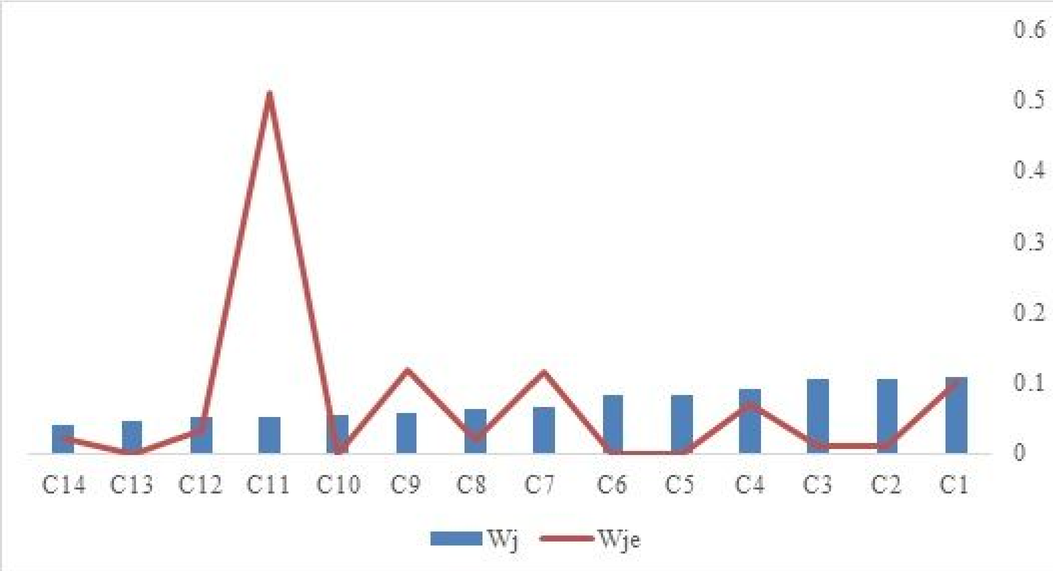

Figure 3

The comparison of both weighing systems of Wje and Wj

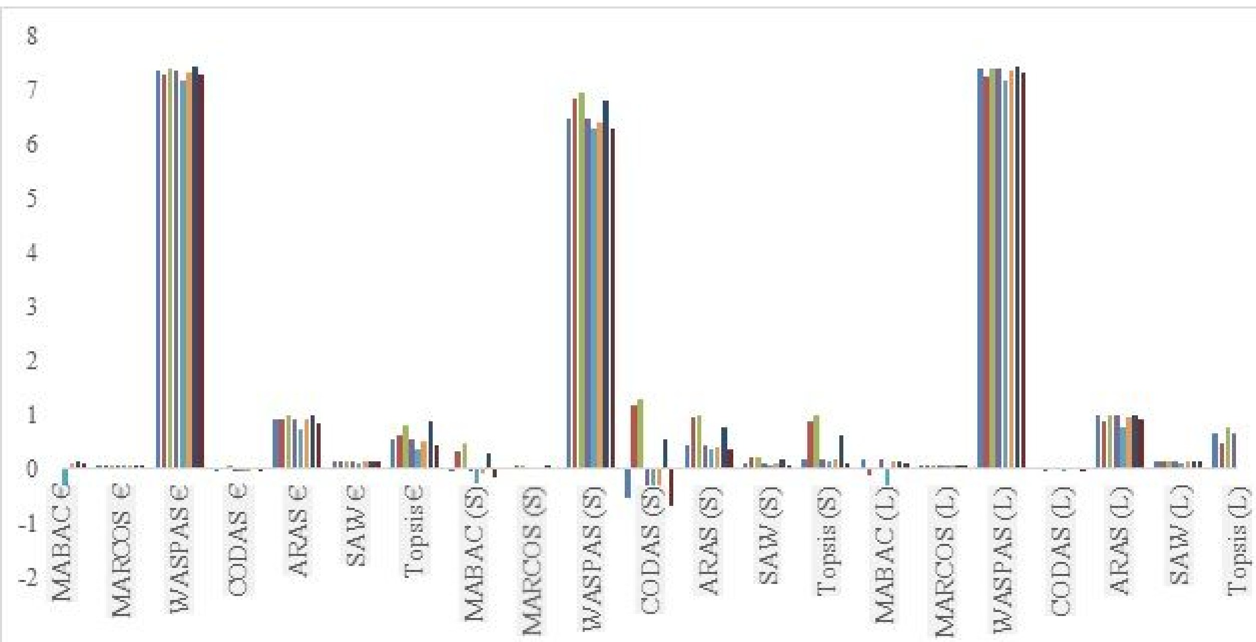

Figure 4

The values of weights of plasma reactors in ranking systems

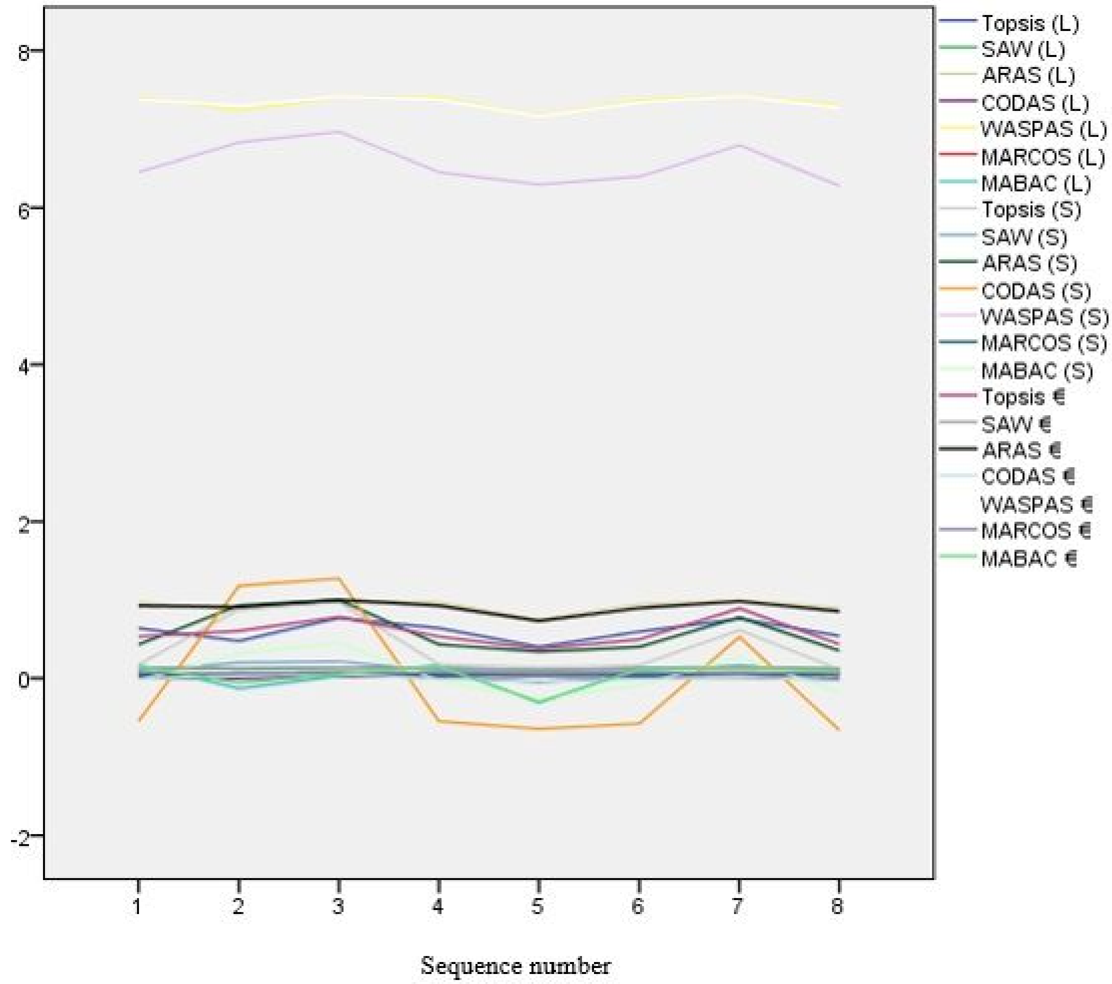

Figure 5

Sequence chart for values of weights in MCDM models

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