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Highlights

- Maxwell Fractional Model
- Mineral Flotation Overall Performance
- Effect on PV Module Performance
- Fractional Model in SAOS Experiments

Discovering Thoughts, Inventing Future

VOLUME 17 ISSUE 3 VERSION 1.0

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The Mineral Flotation Overall Performance Increase by the Improvement of Recycling

By A. Alouani, A. Arbaoui & K. Benkhouja

University Chouaib Doukkali

Introduction- The use of flotation process for the mineral enrichment is increasing to satisfy the client and to match his evolving requirements. The consumption mode of reagent and energies greatly impacts the global cost of mineral enrichment by flotation, and is a determinant factor in the overall performance.

To improve the quality of products, we developed new wash and flotation processes of minerals. Their enrichment knows a big development and arouses a particular interest, which is motivated by the increasing product's demand and by the need to handle the enrichment of minerals that cannot be done by the conventional treatment processes.

The use of these processes on an industrial scale and its integration in the installations and the factories achieved within the framework of mining industries allowed to:

- Rationalize the mineral deposits exploitation and to increase their durations
- Value all the minerals
- Improve the productivity
- Extend the deposits life expectancy in exploitation
- Produce marketable and diverted qualities of minerals
- Ensure the integration of the various mineral deposits exploitation in the mining industries development project based on the sustainable development.

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The use of flotation process for the mineral enrichment is increasing to satisfy the client and to match his evolving requirements. The consumption mode of reagent and energies greatly impacts the global cost of mineral enrichment by flotation, and is a determinant factor in the overall performance.

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- Ensure the integration of the various mineral deposits exploitation in the mining industries development project based on the sustainable development.

Ores valorization during all the value chain follows an integrated industrial process since the extraction of the rock, beneficiation, and transportation until the industrial valorization.

The results obtained on the industrial scale are conclusive, viable and confirm the results obtained in laboratories and on pilots scale.

Using these new processes leads to:

- Very low grade beneficiation
- Improvement of mineral recovery
- Production of high ores quality
- Experience is capitalized and integrated in the mining industries projects under the sustainable development framework

In order to improve the flotation process overall performance, several flow recycling case studies were considered. The reduction of the recycling ratio increases the specific consumption of Flotation reagents, however its progressive increment reduces the need for reagents up to an optimal level. Moreover, any increase results in an accumulation of fine particles in the circuits, which causes saturation and a reduction of the production capacity in the Flotation unit.

According to the "AA" curve below, the industrial optimization led to a remarkable reduction of the specific consumptions for the same raw product profile and for the same level of the production capacity.

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Mineral beneficiation by flotation

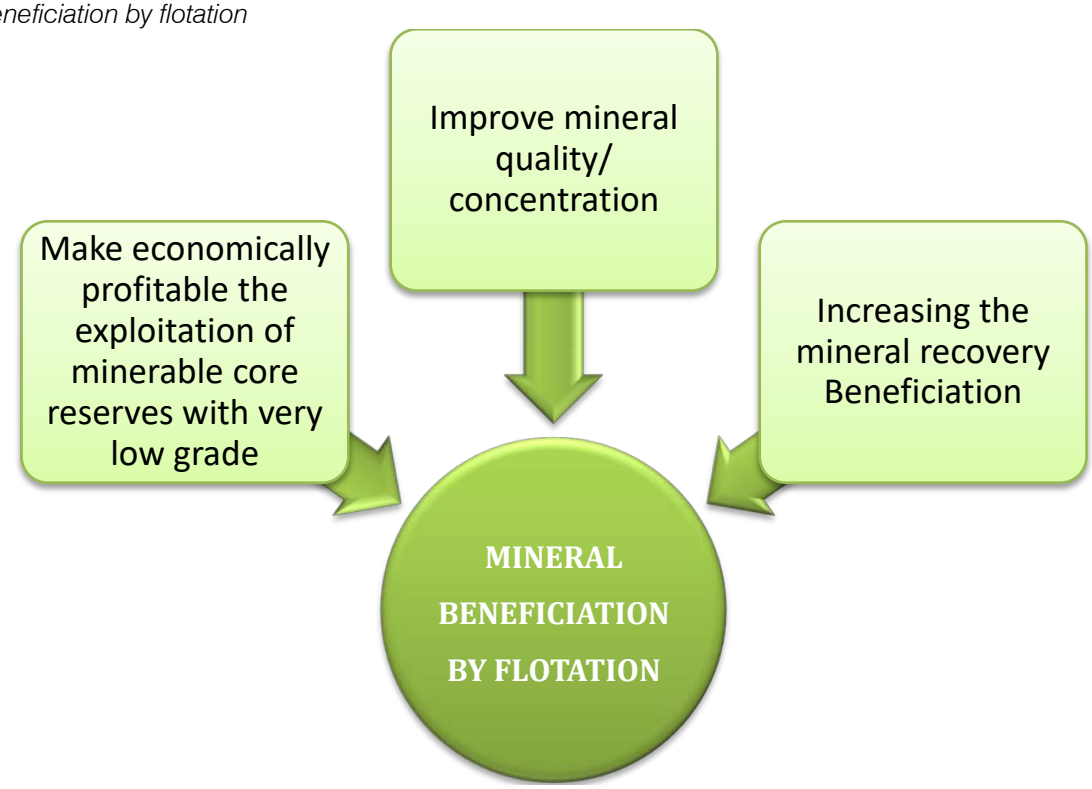

Fig. 1: Mineral beneficiation by flotation

Steps to develop new flotation process

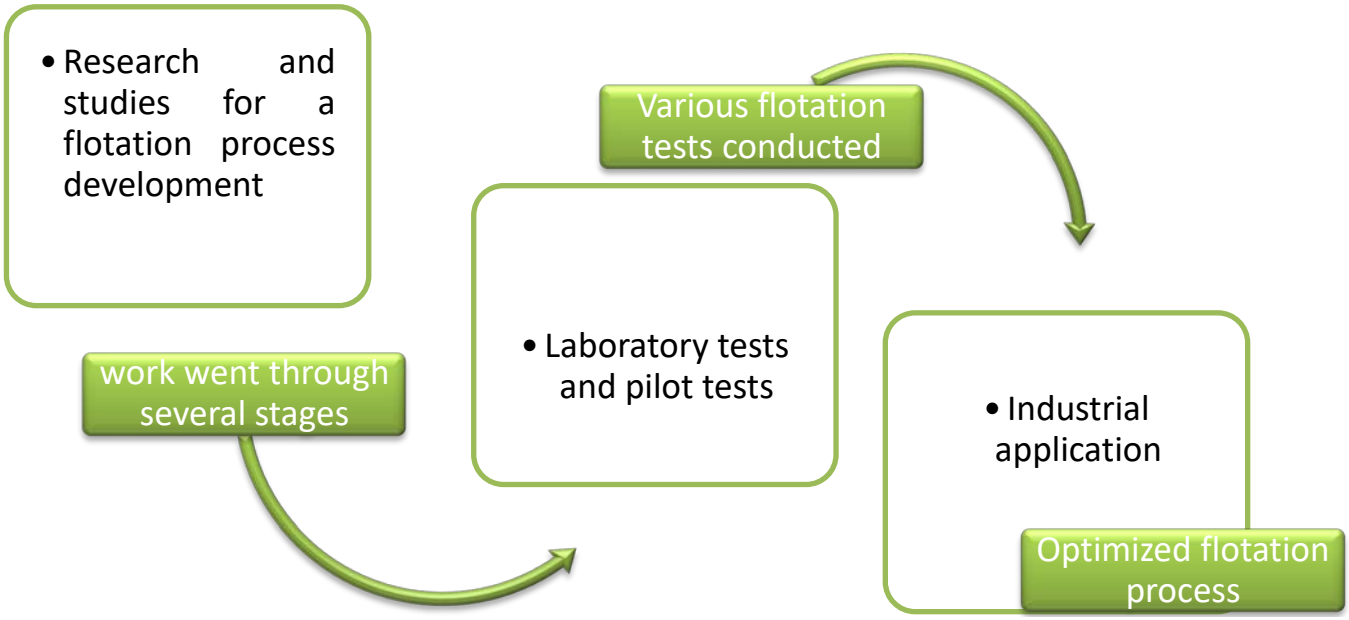

Fig. 2: Steps to develop new flotation process

- Laboratory tests are carried out in small flotation with minimal unit capacity.
- The tests are focused on the determination of operating parameters and the choice of flotation reagents.
- Adjust the order of reagents concentration.
- Determine the stay time of different process phases.

After the laboratory tests, come the tests on pilot scale phase. These ones are needed to confirm the results obtained in the laboratory and assess the extrapolation effects parameters on pilot scale. This leads to the determination of stabilization and process optimization parameters and several recycling flow cases.

Preparation of process tender

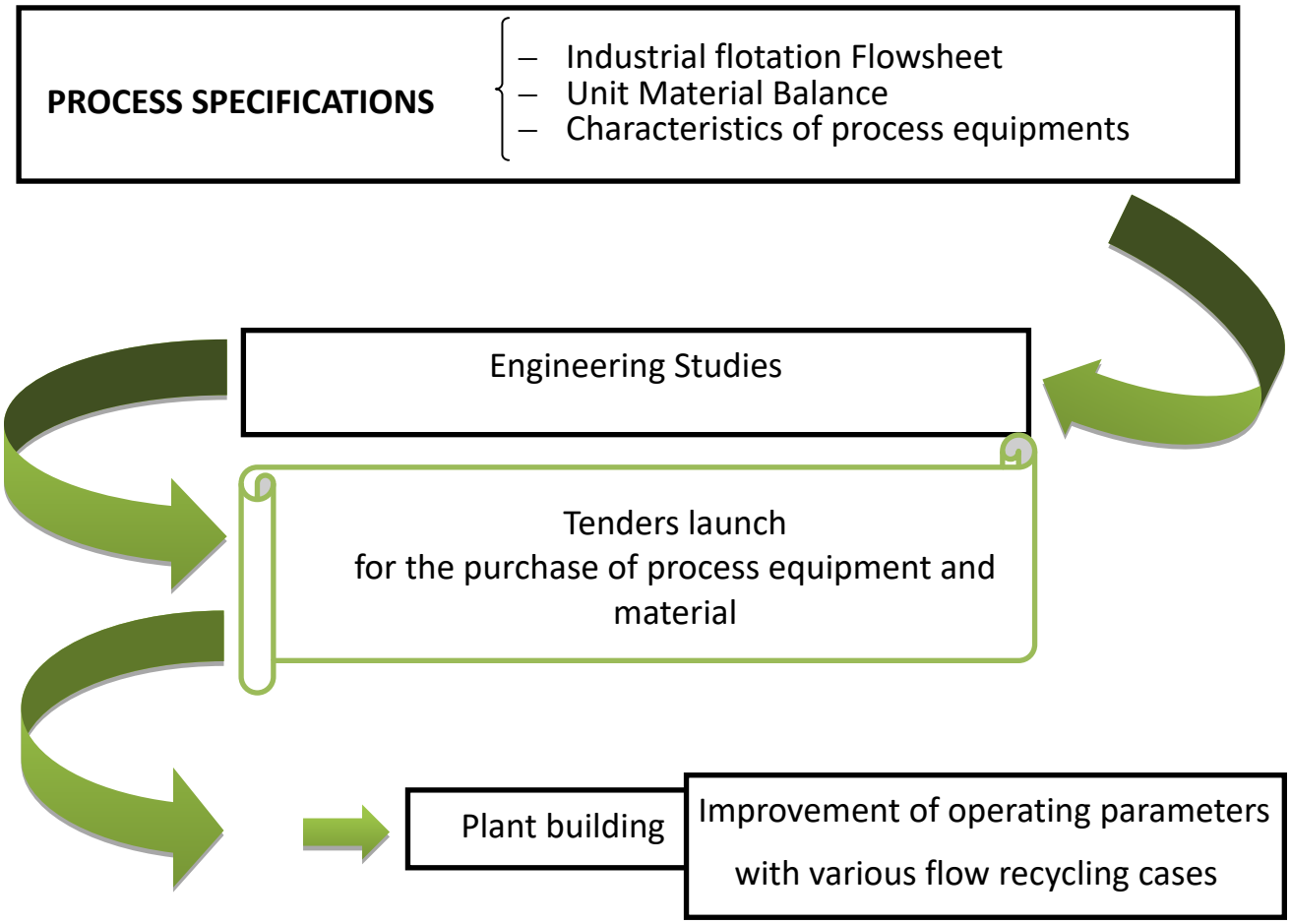

Fig. 3: Preparation of process tender

The optimization is based on the process model of mineral enrichment by washing flotation with a calibration on the experimental results and the industrial units' returns of experiments.

Vigilance points are to observe, especially the recycling impact on the accumulation of fine particles and circuits' saturation, which leads to an optimal point of recycling flows.

The optimization of these recycling flows leads to the following results:

- Reduction of fresh water consumption and therefore a sustainable water resources management.
- Decreased wastewater volumes.
- Maximum recovery of unused reagents retained in the industrial unit wastewater.

Starting from a simplified flow sheet of the elaborated process

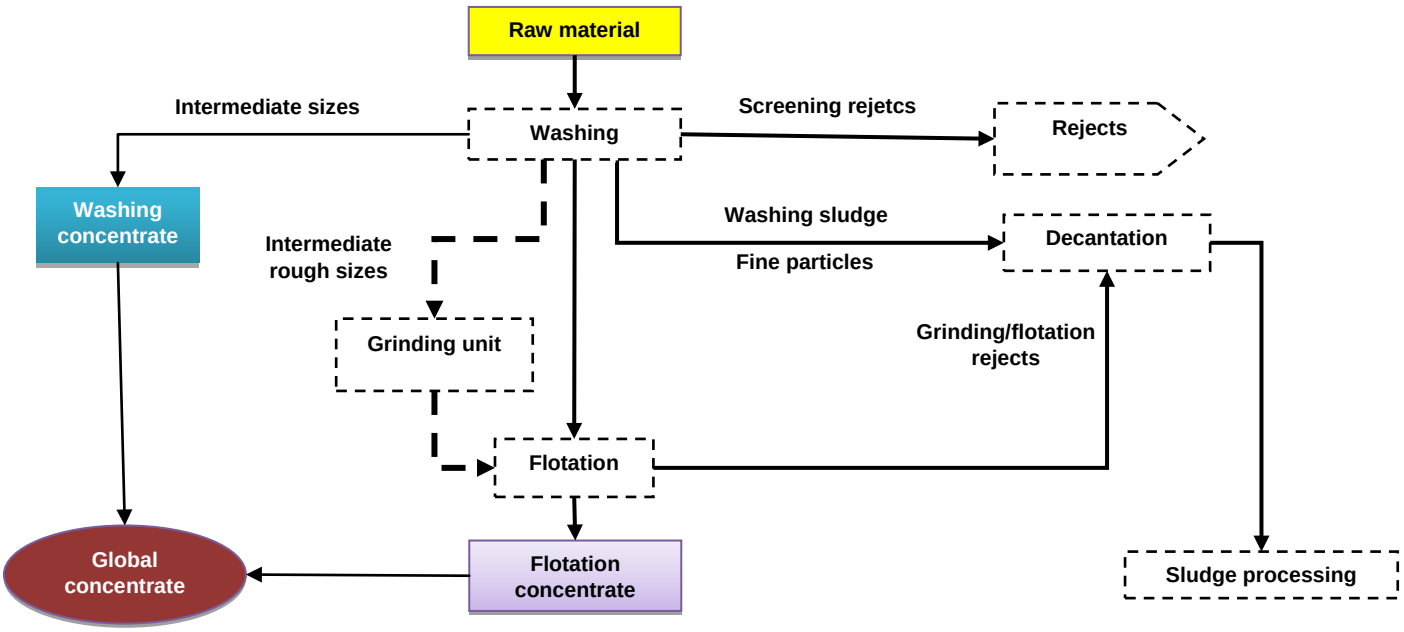

Fig. 4: Simplified flow sheet of mineral washing flotation

The optimization is based on the identified influence parameters

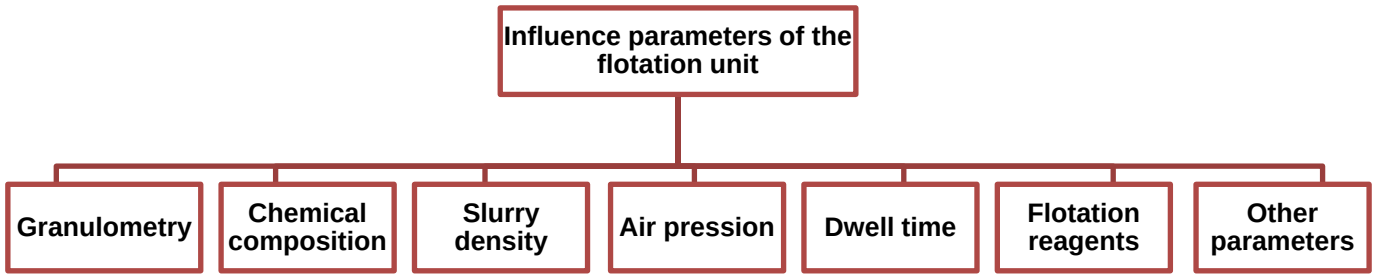

Fig. 5: Influence parameters of the flotation unit

Flotation process phases

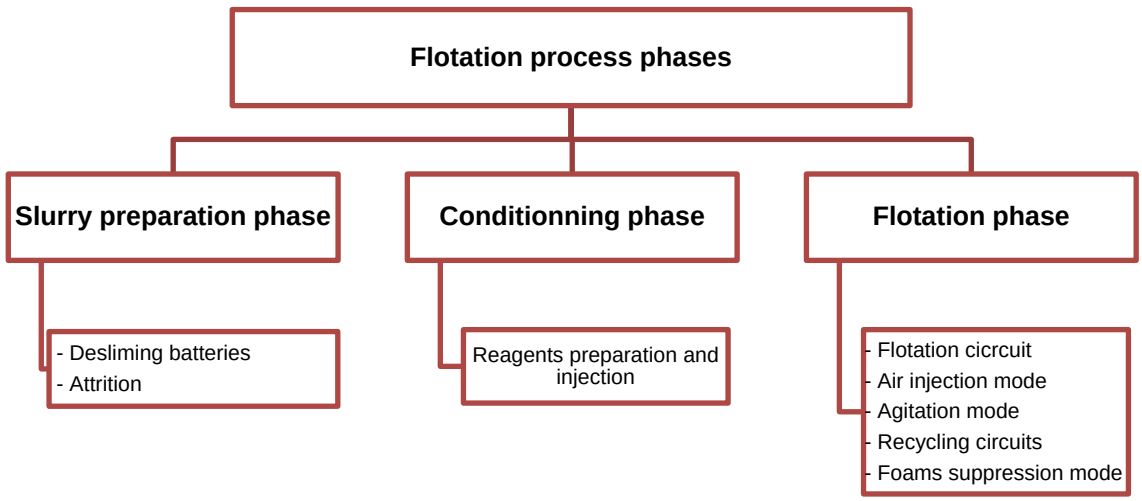

Fig. 6: Flotation process phases

The curve "AA" below is based on the optimization test result which helps determine the optimum recycling point (optimal operating point).This resolves the dilemma of "increasing the recycling flow in order to recuperate a bigger quantity of reagents. This process will ultimately lead to a bigger saturation of the circuits which can lead to a capacity decrease".

This is more efficient with the use of foam flotation because the generation of abundant foam is generally quite a challenge spread in the mining industry.

There are many ways of foam flotation, here are some identified:

- Breaking foams by high pressure water
- Additional mechanical breaking by pumping
- Optimization of flow and breaking circuits recycling
- Hydrocycloning and storage foams in intermediary basins before evacuation

II. Conclusion

- The results obtained are aligned with the ones from the AA curve
- The results obtained on the industrial scale are conclusive, viable and confirm the results obtained in laboratories and pilots scale
- Using these new processes leads to:
  - Very low grade beneficiation
  - Improvement of mineral recovery
  - Production of high quality mineral
  - Reduction in the reagents consumption

Reduction of the recycling ratio increases the specific consumption of Flotation reagents, how ever its progressive increment reduces the need for reagents up to an optimal level. Moreover, any increase results in an accumulation of fine particles in the circuits, which causes saturation and a reduction of the production capacity in the Flotation unit.

According to the "AA" curve above, the industrial optimization led to a remarkable reduction of the specific consumptions for the same raw product profile and for the same level of the production capacity.

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Performance Evaluation of a Trigeneration System with Micro Gas Turbine Engine (MICTRIGEN) based on Exergy Analysis

By Ozgur Balli

Abstract- This study presents some developed energetic and exergetic assessment indicators to analyze the exergetic performance evaluation of a trigeneration system with a micro gas turbine engine (MICTRIGEN) fueled by natural gas. The energy efficiency, electrical to heating ratio, electrical to cooling ratio, cooling factor and heating factor are determined to be 66.67%, 2.062, 2.857, 0.419 and 0.581, respectively. On the other hand, the exergy efficiency, improved exergy efficiency, fuel exergy depletion ratio, productivity lack ratio, exergetic improvement potential, waste exergy improvement potential ratio, fuel exergy improvement potential ratio, waste exergy cost rate, environmental effect factor, exergetic sustainability index, sustainable efficiency factor and ecological effect factor of the system are estimated to be 38.42%, 48.55%, 61.58%, 160.28%, 133.69 kW, 33.88%, 20.86%, 1.144×10^{-3} kW/$, 1.603, 0.624, 1.624 and 2.603, respectively.

Keywords: trigeneration, micro gas turbine engine, exergy analysis, energetic performance paramaters, exergetic performance indicators.

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Based on the exergy, the electrical to heating ratio, electrical to cooling ratio, cooling factor, and heating factor are found to be 38.42%, 13.231, 53.328, 0.199 and 0.801, respectively. Performance indicators show that system owners and researchers focus on the combustion chamber, heat exchanger, water pump, and absorption chiller to improve the exergetic efficiency values of these components. Additionally, these parameters help us to measure environmental/ ecological impacts and sustainability of system.

Keywords: trigeneration, micro gas turbine engine, exergy analysis, energetic performance paramaters, exergetic performance indicators.

Nomenclature

AC	air compressor
ACh	absorption chiller
c	specific heat capacity (kJ/kg.K)
CC	combustion chamber
CF	cooling factor
e	specific energy (kJ/kg)
$\dot{E}$	energy rate(kW)
Eco EFF	ecological effect factor (-)
ECR	electrical to cooling ratio
EEF	environmental effect factor (-)
EHR	electrical to heating ratio
$\dot{E}x$	exergy rate (kW)
$\dot{E}xIP$	exergetic improvement potential (kW)
$ExSI$	exergetic sustainability index (-)
FRI	fuel ratio indicator (%)
FExDR	fuel exergy depletion ratio (%)
FExIPR	fuel exergy improvement potential ratio (%)
h	specific entalphy (kJ/kg)
HE	heat exchanger
HF	heating factor
G	generator
GT	gas turbine
GTMS	gas turbine mechanical shaft
LHV	lower heating value of fuel (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
MICTRIGEN	trigeneration system with micro gas turbine engine
P	pressure (kPa)
PLR	productivity lack ratio (%)
PRI	product ratio indicator (%)
R	universal gas constant (kJ/kg-K)
REC	recuperator
RExIPR	relative exergetic improvement potential ratio (%)
RWExCR	relative waste exergy cost rate (%)
RWExR	relative waste exergy rate (%)
RWExIPR	relative waste exergy improvement potential ratio (%)
s	specific entrophy (kJ/kg-K)
SEF	sustainable efficiency factor (-)
SP	selling price ($)
$\dot{Q}$	heat rate (kW)
T	temperature (K)
$\dot{W}$	work rate or power rate(kW)
WExCR	waste exergy cost rate (kW/$)
WP	water pump

Greek Letters

ε	specific exergy (kJ/kg)
γ	fuel exery grade function
η	energy efficiency (%)
ψ	exergy efficiency (%)
Ψ	improved exergy efficiency (%)

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Subscripts

a	air
AC	air compressor
ACh	absorption chiller
CC	combustion chamber
ch	chemical
cool	cooling energy/exergy
D	destruction
elect	electrical energy/exergy
en	energy
ex	exergy
F	fuel
heat	cooling energy/exergy
g	combustion gas
G	generator
GT	gas turbine
GTMS	gas turbine mechanical shaft
HE	heat exchanger
in	input
j	location
k	the *k*'th component
kn	kinetic
L	losses
MICTRIGEN	trigeneration system with micro gas turbine engine
out	output
P	pressure
ph	physical
Pr	product
pt	potential
REC	recuperator
T	temperature
WEx	waste exergy
WP	water pump
0	dead (environment or reference) state

I. Introduction

The world energy utilization is quickly increasing at a worrying rate. This has already upraised concerns over potential supply problems, lessening of energy resources and expediting environmental impacts (ozone layer depletion, global warming, climate change, etc.). The global expending pattern in buildings energy using, both residential and commercial, has rised steadily; coming to figures between 20% and 40% in developed countries. In fact, it has gone beyond the other major sectors, namely, industrial and transportation. Key reasons associating to this increasing figure include: (i) growth in population; (ii) greater requirement for building services; (iii) the necessity for better comfort levels; and (iv) longer duration of residers consumed time inside buildings. Without a doubt, the upraising trend in energy demand will continue into the future [1]. For this reason, enhancing energy efficiency in energy conversion systems is today a main aim for global energy policy makers. Suitable way is to optimize the use of energy delivered from the fossil fuels by designing more energy-efficient power systems [2]. In this respect, high-efficiency trigeneration systems are gaining more attention. [3]

There are many advantages of trigeneration systems, involving higher system efficiency, lessened greenhouse gas emissions, short transmission lines, decreased thermal losses and waste heat, discounted operating cost, miniaturized distribution units, multiple generation options, raised reliability, and fewer grid failure [4]. The primary mover is a important part of a trigeneration plant and the making its selection is very important. The dominant primary movers are internal combustion engines, external combustion engines (e.g. Stirling engines), gas turbines, steam turbines, micro-turbines, and fuel cells. [4-5]

In the open literature, some studies have examined to evaluate the energy and exergy performance of the trigeneration systems, to assess the economical and exergoeconomic performance of the trigeneration systems, and to determine the optimal operating strategies of trigeneration systems based on different prime movers. Balli et al. [6, 7] evaluated the thermodynamic and thermo economic performance of a trigeneration system with a rated output power of 6.5 MW gas-diesel engine integrated with an absorption chiller. The results of this study can be beneficial to change the components that have low thermodynamic efficiencies and large exergy consumptions, allowing to regulate the sale price of the products and to review the plant's economic policy. Additionally, Acıkkalp et al. [8, 9] investigated the advanced exergy and advanced exergoeconomic performance of the same trigeneration system. The exergy destruction rate and investment cost rate were divided into four components: endogenous, exogenous, avoidable and unavoidable. The results indicated that the components of trigeneration system had strong relationships with each other since the endogenous exergy destruction of the components was smaller than exegenous exergy destruction. Wang et al. [10] examined a trigeneration system with an 6.5 kWe-hydrogen fueled engine whose losses heats, discarded from exhausts and engine cooling system, are used for household purpose (hot and cooling water). Their study indicated that the hydrogen is a very interesting fuel that gives permission performing equal or better performance to the conventional diesel fuel in terms of energetic performance and near zero carbon emissions. Thus, the authors highlighted the tremendous potential fuel savings and large reductions in greenhouse gas emissions per. Lin et al. [11] studied and realized a trigeneration system based on 9.5 kW-a small-scale diesel engine coupled with both a heat recovery system and absorption cooler. The experimental results pointed that if the engine load was over 50%, the exhaust gases were hot enough to run the absorption refrigerator

allowing very low temperature. Smilarly, Jannnelli et al. [12] analyzed a small-size trigeneration system with a 20 kW Lombardini diesel engine and a double effect water-LiBr absorption chiller by applying the available operating data. This combined system has been configured to produce both hot water and cooled water, by recuperating heat from the engine exhaust gasses. Rey et al. [13] examined the performance of micro-trigeneration system with a Honda Internal Combustion Engine (ICE) and validated the model with test data. They pointed out that this system is a well-chosen one for using a stand-alone system in buildings to produce electricity, heating and cooling. For an office building in Hong Kong, the performance of three types of trigeneration systems, driven by ICEs, are investigated and compared with a conventional chiller powered by the grid electricity [14]. The results indicated that the total yearly electricity demand from the building is decreased by 10.4% for the natural gas-fueled engine. For an ICE-based trigeneration system, two different operational strategies are researched and compared by Santo [15]. The energy utilization factor (energy efficiency) was estimated to be between 65% and 81% while the exergy efficiency was obtained to be between 35% and 38.4%. In an experimental investigation, Angrisani et al. [16] suggested a micro trigeneration system with a natural gas–fueled ICE coupled with an absorption cooling unit. They reported that, the system produced 5.4 kW-electrical power besides providing a considerable reduction of greenhouse gas emissions.,- Another experimental investigation of a micro-trigeneration system with a diesel engine coupled to an absorption chiller is examined by Khatri et al. [17]. The thermal efficiency of the system was calculated to be 86.2% and the reduction on the CO2 emissions was found to be 60.71%.

Micro gas turbines in available and in development are described as gas turbines with electrical power capacity ranges between 30 and 350 kW. Micro gas turbines alike large gas turbines can be used in power generation, cogeneration and trigeneration applications. Micro gas turbines are able to operate on variety of fuels, including natural gas, sour gases and liquid fuels such as gasoline, kerosene and diesel fuel/distillate heating oil [18, 19]. Bruno et al. [20] conducted the integration of four micro turbines (in the range 30-100 kW-electrical power) with a double effect direct-fired absorption chiller. The authors examined the effect of the post-combustion level on the trigeneration performance and defined the working conditions that permitted getting the maximum efficiency. The results showed that a directly driven absorption chiller with a post-combustion system can familiarise advantages with respect to the more conventional single effect hot water system in terms of higher coefficient of performance (COP) and flexibility. This is due to the decoupling between the electricity and the chilled water production. Ho et al. [21] studied a cogeneration system with a Capstone microturbine (30 kW) integrated with - a single effect - absorption chiller. The results of this study presented that the electric efficiency was obtained to be 21% and the overall system efficiency was determined to be 46%. Huicochea et al. [22] evaulated the performance of a tigeneration system based on a double effect absorption chiller driven by the exhaust gas of a 30 kW-microturbine. The reducing tendency of all performance parameters (i.e. COP and electric efficiency) with the increase of ambient temperature was shown. The results indicated that the suggested system for the co-production of electric, cooling and heating powers based on the micro turbine technology represents an attractive solution in the fields of the distributed generation. However, Thu et al. [23] investigated the energy and exergy performance of a 65 kWe-CNG fueled micro turbine enegine coupled with 112 kW-waste heat recovery system. The results showed that the combustor was responsible for approximately 70% of the total exergy destruction. The energy efficiency of the system varied from 15.7% at 25% load to 28.95% at full load operation while the exergy efficiency was found to be around 30.4% at full load operation. On the other hand, Ming et al. [24] analyzed a natural gas-fired micro turbine trigeneration system with absorption chiller at Tongji University, China. The maximum energy efficiency of system was estimated to be 80% in the winter, depending on power output, and 65% in the summer. Finally, Chen et al. [25] examined the behavior and performance of a small-scale gas turbine (1747 kW-electrical power) with a double effect chiller and a heat exchanger during the off-design operation. The estimated efficiency of the gas turbine ranged from 27 at full load to 11% at partial load, while the COP increased slightly with the decreasing of the load level of the trigeneration system. Thus, the performance breakdown of the system was due to the bad performance of the gas turbine under the off-design conditions.

Some researchers also investigated the performance of the biomass-fueled trigeneration systems. Wang et al. [26] analyzed a biomass trigeneration system that involves a biomass gasifier, a heat pipe heat exchanger for recovering waste heat from product gas, an internal combustion engine to produce electricity, an absorption chiller/heater for cooling and heating, and a heat exchanger to produce domestic hot water. Operational flows were represented in three work conditions: summer, winter, and the transitional seasons. Energy and exergy analyses were evaluated for different operational flows. The energy efficiencies were obtained to be 50.00% for summer season, 37.77% for winter season, and 36.95% for transitional season while the exergy efficiencies were calculated to be 6.23% for summer season, 12.51% for winter season, and 13.79% for transitional season, respectively. Waste

analyses of energy and exergy indicated that the largest exergy destruction occured in the gasification system, which accounts for more than 70% of the total waste exergy rate. Annual performance indicated that the suggested biomass-fueled trigeneration system lessened biomass consumption by 4% compared with the non-use of a heat recovery system for high-temperature product gases. Huang et al. [27] carried out the technical and economic modelling and performance analysis of biofuel fired trigeneration systems equipped with energy storage for remote households. To adapt the dynamic energy demand for electricity, heating and cooling, both electrical and thermal energy storage devices were integrated to balance larger load changes. Technical performance, the emissions from the system, and the impacts of electrical and thermal energy storages had been examined. Finally, an economic evaluation of the systems was analyzed It was obtained that the internal combustion engine (ICE) based trigeneration and/or combined heat and power (CHP) system was more suitable for heat to electricity ratio value below 1.5 for a household. The biomass boiler and Stirling engine based system was also beneficial for heat to electricity energy demand ratio lying between 3 and 3.4. Parise et al. [28] analyzed the performance of a trigeneration system with a biofuel-driven compression ignition engine as the prime mover. They reported a reduction of around 50% and 95% in primary energy consumption and CO2 emissions, respectively. Furthermore Wang et al. [29] examined the energy, environmental and economic evaluation of four different trigeneration systems driven by ICE applied for a remote island. All energy demands for the investigated island were covered by the trigeneration system without the assistance of electric grid. These systems were assesmend in terms of primary energy saving ratio, carbon dioxide emission saving ratio and annualized life cycle cost. The results indicated that all trigeneration system was superior to the conventional system. It was observed that the trigeneration system with a double-effect absorption chiller offered a better option compored with a single-effect absorbtion chiller.

Recently, some research works have been devoted to analyze trigeneration systems with fuel cell prime movers. Al-Sulaiman et al. [30] suggested a trigeneration system based on a solid oxide fuel cell (SOFC) and Organic Rankine Cycle (ORC) coupled with an absorption chiller and conducted the energy analysis of the system. The results indicated a trigeneration efficiency of 74%, cooling cogeneration efficiency of 57% and heating cogeneration efficiency of 71%. Energy, exergy and exergoeconomic assessments for a novel trigeneration system based on a SOFC coupled to an absorption refrigeration system were examined by Chitsaz et al. [31] and Ranjbar et al. [32]. They reported the maximum energy and exergy efficiency values of the system were obatained to be 79% and 47% for, respectively. However, Ma et al. [33] suggested a SOFC trigeneration system with ammonia-water waste heat recovery cycle. The possible energy efficiency was obtained to be 80% and more under the specified conditions. On the other hand, Tippawan et al. [34] researched the energy and exergy performances of a trigeneration system with an ethanol-fueled SOFC integrated with an absorption chiller. They concluded that the trigeneration plant gained 32% gain in efficiency compared to the conventional power cycle. Another SOFC-trigeneration system with LiBr/H2O absorption refrigeration cycle and fueled by coke oven gas was analyzed by Zhao et al. [35]. They reported that overall trigeneration efficiency was estimated to be approximately 90%. On the other hand, Wang et al. [36] investigated a novel micro trigeneration system combined a direct flame fuel cell, a boiler and an absorption chiller for residential applications. The electricity efficiency of the system was lower than 20% while cogeneration efficiency reached above 90%. It was noted that the electric efficiency of the microtobuler SOFC stack-trigeneration was estimated to be around 30% that this better value was acquired by improving the SOFC materials.

In addition to the above mentioned trigeneration systems, other technologies are introduced in the literature to serve as prime movers for trigeneration applications. These technologies consist of: steam turbine and Organic Rankine Cycle (ORC)-based trigeneration systems, solar energy driven technologies, biomass-driven trigeneration systems, Stirling engine-based trigeneration systems and systems with multiple prime movers. For a novel ORC-based trigeneration system producing power, pure water, cooling and heating, Mehr et al. [37] reported that the maximum thermal and exergy efficiencies of 89.2% and 43.05%, respectively. Boyaghchi and Heidarnejad [38] examined a micro solar-energy based trigeneration system integrated with an ORC for summer and winter seasons. They concluded that the thermal and exergy efficiencies and the product cost rate are 23.66%, 9.51% and 5114.5 $/year, respectively. Al-Sulaiman et al. [39] assessed a trigeneration system with parabolic trough solar collectors combined with ORC. The maximum energy efficiency of the system was calculated to be 94% in the trinegeneration mode operation. Design, simulation and optimization of a small trigeneration plant supplied by geothermal and solar energies, with a 6 kW micro-ORC and a 30 kW-single effect LiBr/H2O chiller is presented by Buonomano et al. [40]. For a solar energy based trigeneration system with flat-plate solar collectors, a multiobjective optimization is conducted by Wang et al. [41] using genetic algorithm for power mode, combined heat and power mode and combined cooling and power mode. Zare [42] studied a comparative thermodynamic analysis and optimization for two different designs of

geothermal energy-based trigeneration systems. The two considered systems were an organic Rankine cycle and a Kalina cycle for power generation units. Additionally, A LiBr/water absorption chiller and a water heater coupled to the Organic Rankine and Kalina cycles were used for cooling and heating loads. The maximum exergy efficiency values of the Kalina cycle-based system and the ORC-based system were accounted to be 50.36% and 46.51%. These results indicated that Kalina cycle-based system was more efficient. On the other hand, Fontalvo et al [43] proposed and modeled a trigeneration system powered by Rankine cycle using an ammonia-water mixture with an absorption refrigeration cycle. It was found that the absorber, the boiler and the turbine were the sources of greatest exergy destruction. Furhermore, Chua et al. [44] examined different trigeneration systems integrated with renewable to serve an electrically isolated island in Singapore. A wide variety prime mover was analyzed at altering levels of renewable energy insertion: micro turbines, solar photovoltaics, solar Stirling dish, fuell cells, and biomass power generation with absorption cooling. Primary energy was reduced for each case, and high renewable penetration (40%) corresponed to the potential reduction in CO2 emissions, but the increased capital costs in this case resulted in a net projected economic loss.

The main goal and orginality of this study is to evaulate the exergetic performance of a micro gas turbine engine trigeneration system (*MICTRIGEN*) installed in Turkey with the exergy analysis methodology for the first time according to the best of the author's knowledge.

II. System Description

a) General description of the MICTRIGEN

A schematic of the investigated micro gas turbine trigeneration (*MICTRIGEN*) system is given in Figure 1. This system consists of an air compressor (*AC*), a combustion chamber (*CC*), a gas turbine (*GT*), a gas turbine mechanical shaft (*GTMS*), a recuperator (*REC*), an electrical generator (*G*), a heat exchanger (*HE*), a water pump (*WP*) and an absorption chiller (ACh). The *MICTRIGEN* system produces 225 kW-net electrical power rates, 109.1 kW-net heating energy rates and 78.76 kW-net cooling energy rates. The *MICTRIGEN* consumes 0.01258 kg/s-natural gas while the mass flow of air is 1.4544 kg/s. The mass flow rates of the hot and chilled water are measured to be 1.3 kg/s and 3.75 kg/s. The pressure and temperature values of hot water inletting at the *HE* are 323.15 K and 1025kPa while the pressure and temperature values of hot water outleting the *HE* are 363.15 K and 1000kPa, respectively. On the other hand, the pressure and temperature values of hot water at hot section outlet of the *Ach* are measured to be 343.15 K and 950 kPa. However, the cold water flows in the *ACh* with 285.15 K and 300 kPa when it discarges from the *ACh* with 280.15 K and 275 kPa, respectively. The selling price (*SP*) of the system is estimated to be 345000 $ (USA).

b) Assumptions made

In this study, the assumptions made are listed below:

- The MICTRIGEN system operates in a steady-state and steady flow.
- The principle of ideal-gas mixture is applied for the air and combustion gaseous.
- The combustion reaction is complete.
- The fuel injected to combustion chamber is the natural gas. The low heating value (LHV) of natural gas is assumed to be 49234.5kJ/kg.
- The compressor and the gas turbine considered are reckoned as adiabatic.
- The changes in the kinetic energy, the kinetic exergy, the potential energy and the potential exergy within the engine are assumed to be negligible.
- The temperature and the pressure of the dead (environmental) state are measured to be 298.15 K and 101.33 kPa, respectively.
- The air-to-fuel mass ratio is equal to 105.61.

c) Combustion balance, specific heat capacity of emissions and air

The air is composed of nitrogen 77.48%, oxygen 20.59%, carbon dioxide 0.03% and water vapour 1.90%. There are very small amount of argon, carbon monoxide, etc., in the air, which are neglected in this study. The pressured air mixed with fuel and burned in the combustion chamber to enable stable burning and the air-to-fuel ratio is to be at appropriate level. To have completed burning of fuel and to decrease the temperature, the air-to-fuel ratio in the combustion chamber is always higher than stoichiometric ratio. Because of this, there is a significant amount of oxygen within the combustion gases. When Air-Fuel Ratio is 105.61, the general combustion reaction equation is found to be:

$$\left(0.9334CH_4 + 0.00211C_2H_6 + 0.00029C_3H_8 + 0.00012C_4H_{10} + 0.06408N_2\right) + 62.1733\begin{pmatrix} 0.7448N_2 + \\ 0.2059O_2 + \\ 0.0003CO_2 + \\ 0.019H_2O \end{pmatrix} \rightarrow 0.9576CO_2 + 3.0574H_2O + 10.9244O_2 + 48.4922N_2 \quad (1)$$

After combustion reaction, the mass compositions of combustion gases are obtained to be 2.38% CO_2, 2.99% H_2O, 19.50% O_2 and 75.13% N_2. The specific heat capacity of the combustion gaseous can be written in the following form:

$$c_{P,g}(T) = 0.995904 + \frac{0.008608}{10^2}T + \frac{0.017167}{10^5}T^2 - \frac{0.070978}{10^9}T^3 \quad (2)$$

The ideal gas constant value of combustion gases was estimated to be $0.291942\,kJ(kg-K)^{-1}$. The specific heat capacity of air is a function of temperature is given as follows [45]:

$$c_{P,a}(T) = 1.04841 - \left(\frac{3.83719T}{10^4}\right) + \left(\frac{9.45378T^2}{10^7}\right) - \left(\frac{5.49031T^3}{10^{10}}\right) + \left(\frac{7.92981T^4}{10^{14}}\right) \quad (3)$$

where the temperature is evaluated in *K*.

III. Methodology

a) Mass, energy and exergy balance equations

Mass, energy and exergy balances for each component of a system under steady state conditions can be written as follows [46]:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (4)$$

$$\dot{Q} - \dot{W} = \sum \dot{m}_{out} e_{out} - \sum \dot{m}_{in} e_{in} \quad (5)$$

$$\sum \left(1 - \frac{T_o}{T_j}\right)\dot{Q}_j - \dot{W} = \sum \dot{m}_{out}\varepsilon_{out} - \sum \dot{m}_{in}\varepsilon_{in} + \dot{E}x_D \quad (6)$$

where $\dot{m}$ is the mass flow rate, e is the specific energy, $\dot{Q}_j$ is the heat transfer rate through the boundary at temperature T_j at location *j*, $\dot{W}$ is the work rate, ε is the specific exergy, and $\dot{E}x_D$ is the exergy destruction rate.

In the absence of nuclear, magnetism, electricity and surface tension effects in the thermal systems, the total specific energy and exergy can be determined from [6, 18, 26]:

$$\sum e = e_{kn} + e_{pt} + e_{ph} + e_{ch} \quad (7)$$

$$\sum \varepsilon = \varepsilon_{kn} + \varepsilon_{pt} + \varepsilon_{ph} + \varepsilon_{ch} \quad (8)$$

Where subscripts of kn, pt, ph and ch denote the kinetic, potential, physical and chemical, respectively. In this study, the changes in the kinetic energy/exergy and potential energy/exergy within the *MIGTRIGEN* were assumed to be negligible.

The specific physical energy for air, combustion gases and water may be written as [6, 18]:

$$e_{ph} = c_P T - c_{P,o} T_o \quad (9)$$

$$e_{ph} = h - h_o \quad (10)$$

The specific physical exergy is claculatde from th following equations [18, 26, 47]:

$$\varepsilon_{ph} = c_{P(T)}\left[T - T_o - T_o \ln\left(\frac{T}{T_o}\right)\right] + RT_o \ln\left(\frac{P}{P_o}\right) \quad (11)$$

$$\varepsilon_{ph} = h - h_o - T_o(s - s_o) \quad (12)$$

The specific chemical energy and exergy of gaseous hydrocarbon fuels $(C_a H_b)$ on a unit mass can be determined as follows [18, 47, 48]:

$$e_{ch} = LHV \quad (13)$$

$$\varepsilon_{ch} = \gamma_F . LHV \quad (14)$$

$$\gamma_F \cong 1.033 + 0.0169\frac{b}{a} - \frac{0.0698}{a} \quad (15)$$

where γ_F denotes the fuel exergy grade function that is estimated to be 1.0308 fornatural gas. However, energy rate and exergy rate is calculated by [18]:

$$\dot{E} = \dot{m}e \quad (16)$$

$$\dot{E}x = \dot{m}\varepsilon \quad (17)$$

b) Performance evaluation metrics

i. Energetic performance parameters

Evaluating the trigeneration system's efficiency is important and requires the use of suitable indicators. The overall energy efficiency of the MIGTRIGEN is defined as the ratio of total useful energy output (electrical, heating and cooling) to the total fuel energy input and can be expressed as [49-51]:

$$\eta_{MICTRIGEN} = \frac{\dot{E}_{elect} + \dot{E}_{heat} + \dot{E}_{cool}}{\dot{E}_F} \quad (18)$$

Additionally, several performance indicators are were suggested to evaluate the energetic performance of the trigeneration system by Al-Sulaiman et al. [51] and Maraver et al. [52]. These are given as follows:

The electrical to heating ratio based on energy [51]:

$$EHR_{en,MICTRIGEN} = \frac{\dot{E}_{elect}}{\dot{E}_{heat}} \quad (19)$$

The electrical to cooling ratio based on energy [51]:

$$ECR_{en,MICTRIGEN} = \frac{\dot{E}_{elect}}{\dot{E}_{cool}} \quad (20)$$

The cooling factor based on energy [52]:

$$CF_{en,MICTRIGEN} = \frac{\dot{E}_{cool}}{\dot{E}_{cool} + \dot{E}_{heat}} \quad (21)$$

The heating factor based on energy:

$$HF_{en,MICTRIGEN} = \frac{\dot{E}_{heat}}{\dot{E}_{cool} + \dot{E}_{heat}} \quad (22)$$

ii. *Exergetic performance parameters*

Some useful assessment parameters based on the exergy methodology were offered by Balli [53]. These are given as follows:

- *Exergetic efficiency* (ψ)*:* The ψ is calculated by the ratio of the sum of the outlet flows as product exergy to the sum of the inlet flows as fuel exergy. It can be estimated as follows:

$$\psi = \frac{\dot{E}x_{\Pr}}{\dot{E}x_F} = 1 - \frac{\dot{E}x_{WEx}}{\dot{E}x_F} \quad (23)$$

For the MICTRIGEN system, the product exergy rate is obtained from:

$$\dot{E}x_{\Pr,MICTRIGEN} = \dot{W}_{elect} + \dot{E}x_{heat} + \dot{E}x_{cool} \quad (24)$$

- *Relative waste exergy ratio (RWExR):* The *RWExR* is determined by the ratio of the waste exergy rate of k'th component to total waste exergy rate of the system. It is accounted by;

$$RWExR = \frac{\dot{E}x_{WEx,k}}{\dot{E}x_{WEx,MICTRIGEN}} \quad (25)$$

For the MICTRIGEN system, the total waste exergy rate is estimated by:

$$\dot{E}x_{WEx,MICRTRIGEN} = \dot{E}x_{F,MICTRIGEN} - \dot{E}x_{\Pr,MICTRIGEN} = \sum \dot{E}x_D + \sum \dot{E}x_L \quad (26)$$

- *Fuel exergy depletion ratio (FExDR):* The *FExDR* can be defined as the ratio of the waste exergy rate of the k'th component to the fuel exergy rate supplied in the system. It is formulated as follows:

$$FExDR = \frac{\dot{E}x_{WEx,k}}{\dot{E}x_{F,MICTRIGEN}} \quad (27)$$

- *Productivity lack ratio (PLR):* The *PLR* can be identified as the ratio of the waste exergy rate of the k'th component to the product exergy rate of the MICTRIGEN. It is formulated as follows:

$$PLR = \frac{\dot{E}x_{WE,k}}{\dot{E}x_{\Pr,MICTRIGEN}} \quad (28)$$

- *Product ratio indicator(PRI):* The *PRI* is calculated by dividing the product exergy rate of the k'th component to the product exergy rate (*Pr*) of the MICTRIGEN as follows;

$$PRI = \frac{\dot{E}x_{\Pr,k}}{\dot{E}x_{\Pr,MICTRIGEN}} \quad (29)$$

- *Fuel ratio indicator(FRI):* The *FRI* is estimated by dividing the fuel exergy rate of the k'th component to the total fuel exergy rate of the MICTRIGEN as follows;

$$FRI = \frac{\dot{E}x_{F,k}}{\dot{E}x_{F,MICTRIGEN}} \quad (30)$$

- *Exergetic improvement potential (ExIP):* The maximum improvement in the exergy efficiency for a process or a system can be achieved when the exergy consumption (losses and destruction) minimized. Consequently, it is useful to employ the concept of an "exergetic improvement potential" when analyzing different processes and systems.

The *ExIP*is written as follows;

$$\dot{E}xIP = (1-\psi)\dot{E}x_{WEx} \quad (31)$$

- *Relative exergetic improvement potential ratio (RExIPR):* The *RExIPR* is defined as the ratio of the exergetic improvement potential of k'th component to the total exergetic improvement potential of all components. This parameter indicates that which compenent within a system provides the maximum improvement when it is changed or improved. The *RExIPR* is obtained from;

$$RExIPR = \frac{\dot{E}xIP_k}{\dot{E}xIP_{MICTRIGEN}} \text{ (n= number of components)} \quad (32)$$

- *Waste exergy improvement potential ratio (WExIPR)*: The *WExIPR* is obtained from the ratio of the exergetic improvement potential of k'th component to the waste exergy rate of k'th component. High value of exergetic destruction improvement ratio demonstrates that exergetic improvement potential rate for a component occurs in high level. The *WExIPR* is calculated from:

$$WExIPR = \frac{\dot{E}xIP_k}{\dot{E}x_{WEx,k}} \quad (33)$$

- *Fuel exergy improvement potential ratio (FExIPR)*: The *FExIPR* is presented as the ratio of the exergetic improvement potential rate of k'th component to the total fuel exergy of the system. It is found from:

$$FExIPR = \frac{\dot{E}xIP_k}{\dot{E}x_{F,MICTRIGEN}} \quad (34)$$

- *Improved exergetic efficiency* (Ψ): If an exergetic improvement is realized in a component, the fuel exergy rate required for a component decreases for constant production and the exergy efficiency of the component increases. This new value of exergetic efficiency can be named as the improved exergetic efficiency. The Ψ is calculated as flows:

For the components:

$$\Psi_k = \frac{\dot{E}x_{\Pr,k}}{\dot{E}x_{F,k} - \dot{E}xIP_k} \quad (35)$$

Fort the MICTRIGEN system:

$$\Psi_{MICTRIGEN} = \frac{\dot{E}x_{\Pr,MICTRIGEN}}{\dot{E}x_{F,MICTRIGEN} - \dot{E}xIP_{MICTRIGEN}} \quad (36)$$

- *Waste exergy cost rate (WExCR):* Exergy consumption (losses and destruction) creates an extra monetary lost during a production. A system with lower exergy consumption has more useful product exergy and subsequently more potential to do work. A less efficient system has low useful product exergy and less potential to do work. The loss in production potential can be represented as a cost rate. The *WExCR*is the ratio of the waste exergy rate of k'th component to the selling price of the system. It can be taken from;

$$WExCR_k = \frac{\dot{E}x_{WEx,k}}{SP_{MICTRIGEN}} \quad (37)$$

- *Relative waste exergy cost rate (RWExCR):* The *RWExCR* is the ratio of the waste exergy cost rate of k'th component to the total waste exergy cost rate within the system. This paremeter indicates that which component of the system is more effective in the waste exergy cost rate. The *RWExCR* is estimated by:

$$RWExCR_k = \frac{WExCR_k}{WExCR_{MICTRIGEN}} \quad (38)$$

- *Environmental effect factor (EEF):* One of the sustainability indicators is the environmental effect factor which is calculated the ratio of fuel waste exergy ratio to the exergy efficiency. Environmental impact factor indicates whether or not it damages the environment because of its unusable waste exergy output, losses and exergy destruction. The *EEF* can be counted by;

$$EEF = \frac{FWExR}{\psi} \quad (39)$$

- *Exergetic sustainability index (ExSI)*: Exergetic sustainability index is vital parameter among exergetic sustainability indicators to assess the system's sustainability level. Its function of environmental effect factor can be found out by ratio of 1 to the environmental effect factor. The range of this index is between 0 and ∞. The higher efficiency means low exergy destruction ratio and low environmental effect factor as a result higher exergetic sustainability index. Exergy clearly helps determine efficiency improvements and reductions in thermodynamic losses attributable to a process. Measures to increase exergy efficiency can reduce environmental impact by reducing exergy losses. Within the scope of exergy methods, such activities lead to increased exergy efficiency and reduced exergy consumption (both waste exergy emissions and internal exergy destructions). The *ExSI* is figured out from;

$$ExSI = \frac{1}{EEF} \quad (40)$$

- *Sustainable efficiency factor (SEF):* If a process or system uses low amount fuel or energy for the desired production, it is said that this process or system has high exergetic efficiency value as well as high sustainability level because low emissions are emitted to the environment. An increasing in the exergetic efficiency results a rising in the sustainability level of the system. Consuquently, the sustainable efficiency factor can be used as a sustaianability assessment parameter and the *SEF* is picked up as follows;

$$SEF = \frac{1}{1-\psi} \quad (41)$$

- *Ecological effect factor (EcoEF):* The $EcoEF$ of the k'th component is estimated from following equation;

$$EcoEF = \frac{\dot{E}x_F}{\dot{E}x_{\Pr}} = \frac{1}{\psi} \quad (42)$$

Above-mentioned assessment parameters, the relations between eqn. (19) and eqn. (22) can be written with the exergy terms as the following:

The electrical to heating ratio based on exergy:

$$EHR_{ex,MICTRIGEN} = \frac{\dot{E}x_{elect}}{\dot{E}x_{heat}} \quad (43)$$

The electrical to cooling ratio based on exergy:

$$ECR_{ex,MICTRIGEN} = \frac{\dot{E}x_{elect}}{\dot{E}x_{cool}} \quad (44)$$

The cooling factor based on exergy:

$$CF_{ex,MICTRIGEN} = \frac{\dot{E}x_{cool}}{\dot{E}x_{cool} + \dot{E}x_{heat}} \quad (45)$$

The heating factor based on exergy:

$$HF_{ex,MICTRIGEN} = \frac{Ex_{heat}}{\dot{E}x_{cool} + \dot{E}x_{heat}} \quad (46)$$

IV. Results and Discussion

In this study, the performance assesments of a trigeneration system with micro gas turbine engine (MICTRIGEN) is evaluated by the energy and exergy analyses methodology.

a) Energetic performance evaluation of the MICTRIGEN

The MICTRIGEN system produces 225 kW-net electrical power rates $(\dot{W}_{14})$, 109.1 kW-net heating energy rates $(\dot{E}_{19})$ and 78.76 kW-net cooling energy rates $(\dot{E}_{22})$ at maximum operation mode while the system consumes 619.374 kW-fuel energy rates $(\dot{E}_4)$. According to these data, the energy efficiency (η), the electrical to heating ratio (EHR_{en}), the electrical to cooling ratio (ECR_{en}), the cooling factor (CF_{en}) and the heating factor (HF_{en}) are determined to be 66.67%, 2.062, 2.857, 0.419 and 0.581, respectively. If the MICTRIGEN system is only operated to produce the electrical power, the prime mover energy efficiency of the system is calculated to be 36.33%. This value indicates that the energy efficiency of the trigeneration system is approximately double (1.845) of the energy efficiency of the simple cycle. The typical prime mover and overall energy efficiency performances of a micro turbine cogeneration system were given as 18-27% and 65-75%, repectively [54]. According to this data, the prime mover and overall energy efficiency values of the investigated trigeneration system is superior to reference values.

b) Exergetic performance evaluation of the MICTRIGEN

The *MICTRIGEN* system consumes 640.87 kW-fuel exergy rates $(\dot{E}x_4)$ in order to produce 246.23 kW-product exergy rates that are 225 kW-net electrical power rates $(\dot{W}_{14})$, 17.01 kW-net heating exergy rates $(\dot{E}x_{19})$ and 4.22 kW-net cooling exergy rates $(\dot{E}x_{22})$ at maximum operation mode. According to these data, the exergy efficiency (ψ), the electrical to heating ratio (EHR_{ex}), the electrical to cooling ratio (ECR_{ex}), the cooling factor (CF_{ex}) and the heating factor (HF_{ex}) are found to be 38.42%, 13.231, 53.328, 0.199 and 0.801, respectively. The 640.87 kW- fuel exergy rates can be divided into 246.23 kW-product exergy rates and 394.64 kW-waste exergy rates. In other words, the 38.42% of fuel exergy rate can be converted to useable product exergy rate while the 61.58% of fuel exergy creates the waste exergy rate. However, the net electrical power is the 91.38% of product exergy rate when the net heating exergy rate is the 6.91% of product exergy rate and the cooling exergy rate is the 1.71% product exergy rate. The percent combinations of fuel exergy, waste exergy and product exergy are illustrated in Fig.2.

The exergetic balance equations (eqn. no: 47-62) of the *MICTRIGEN* system and its main components (*AC, CC, GT, GTMS, REC, G, HE, WP* and*ACh)* are listed in Table 1. On the other hand, thermodynamic cycle data of the MICTRIGEN system under actual operating conditions are given in Table 2 for maximum operation mode. Using the data in Table 2, exergy analysis is conducted to assess the exergetic performance of the *MICTRIGEN* and its main components. The obtained values of the performance indicators are listed in Table 3. The main findings of the exergetic analysis are summarized as follows:

- The exergy efficiency values of the *AC, CC, GT, GTMS, G, REC, HE, WP* and*ACh* are obtained to be 89.09%, 60.66%, 98.39%, 97.50%, 97.71%, 94.11%, 40.96%, 25.51%, and 36.77%, respectively. The maximum exergy destruction rate is calculated to be 252.15 kW in the combustion chamber (*CC)* with 60.66% exergetic efficiency hence the combustion processes exhibit very high thermodynamic inefficiencies caused by chemical reaction, heat transfer, friction, and mixing. On the other hand, the maxiumum exergetic improvement potential (99.21 kW) will be realized by improving energy efficiency of component and/or using new design combustion chamber (high temperature resistance material, laminar and uniform flow, etc.) The waste exergy rate and the exergetic improvement potential rate of the system components are shown in the Fig.3.

- The exergy efficiency of all componetscan be increased if some technological improvements are developed and applied. The real and improved exergy efficiency values of engine componets are illustrated in Fig.4. Fig.4 indicates that effects of improvement scan be seen as an exergy efficiency increasing with 11.10% in the *CC*, 21.92% in the *HE*, 24.49% in the *ACh*, 31.80% in the *WP* and 19.13% in the *MICTRIGEN* system.
- The *WP* has the best value of relative waste exergy ratio with 0.15% while the *CC* has the worst value with 63.89%. These values show that the maximum exergy destruction rate occurs in the *CC* between the engine components.
- The maximum fuel exergy depletion take place in the *CC* with 39.34 % even as the minimum fuel exergy depletion occurs within the *WP* with 0.09%. Total fuel exergy depletion ratio of the system is calculated to be 61.58%. However, the productivity lack ratio is obtained to be the maximum value with 102.49% within the *CC* since the ***CC*** has the maxiumum product exergy rate between the components. On the other hand, Total productivity lack ratio of the *MICTRIGEN* is obtained to be 160.28%. Fuel exergy depletion ratio (*FExDR*) and productivity lack ratio (*PLR*) of the *MICTRIGEN* and its components are exhibited in Fig.5.
- The product ratio (*PRI*) and fuel ratio indicators (*FRI*) are illustrated in Fig.6. Between the comoponents, the *GT* has the maximum *PRI* with 205.32% while the *CC* has the maximum *FRI* with 100.0%.
- Between the components, the waste exergy improvement potential ratio (*WExIPR*) is estimated to be 74.49% for the *WP* that is a maximum value while the fuel exergy improvement potential ratio (*FExIPR*) is accaunted to be 15.89% for the *CC* that is a maximum value. For the *MICTRIGEN* system, the *WExIPR* and *FExIPR* are found to be 33.88% and 20.86%, respectively. The values of the *WExIPR* and *FExIPR* are indicated in Fig.7.
- The waste exergy cost rate (*WExCR*) values of components are given in Fig.8. The maximum *WExCR* is calculated to be 0.731×10^{-3} kW/$ for the *CC*. On the other hand, the maximum relative waste exergy cost ratio (*RWExCR*) is estimated to be 63.89% for the *CC* between the components.
- The enviromental effect factor (*EEF*) and ecological effect factor(*EcoEF*) values of the components are illustrated in Fig.9. Fig.9 points that the *CC* has the maximum *EEF* value with 0.649while the *WP* has the highest *EcoEF*value with 3.920. On the other words, the *EEF* values indicate that the *CC* has the highest exergy destruction rate when the *EcoEF* values show that the *WP* has the lowest exergy efficiency.
- The highest value of *ESI* instructs that the component has the lowest environmental effect factor. Between the components, the *WP* has the highest value of the exergetic sustainability index (*ESI*) with 274.36 because the *WP* has the lowest *EEF* value with 0.004. The *ESI* values of the *MICTRIGEN* and its components are demonstrated in the Fig. 10.
- The sustainable efficiency factors (*SEF*) of the *MICTRIGEN* and its components are given in Fig.11. The maximum *SEF*value is calculated to be 62.18 for the *GT* in good agreement with the exergy efficiency value of the *GT*.

Addition to above mentioned results, the exergetic performance indicator values of the whole *MICTRIGEN* are indicated in Fig.12. The ψ, Ψ, *FExDR, PLR, WExIPR, FEXIPR, WExC, EEF, ExSI, SEF,* and *EcoEF* values of the whole *MIGTRIGEN* are determined to be 38.42%, 48.55%, 61.58%, 160.28%, 33.38%, 20.86%, 1.144×10^{-3} kW/$, 1.603, 0.624, 1,624, and 2.603, respectively. The exergetic improvement potential (*ExIP*) of the *MICTRIGEN* are estimated by two methods. Possible *ExIP* value is obtained from the sum of all components' *ExIP* values. Possible *ExIP* value of the system is accounted to be 133.69 kW. The other method is theoretical and it is estimated from eqn.(31). The theoretical *ExIP* value is found to be 243.02 kW. It is impossible to get the theoretical *ExIP* value hence the sum of the total *ExIP* value (133.69 kW) of all components and the exergy rate (11.03 kW) of emitted exhaust gases to environment is lower than the theoretical *ExIP* value (243.02 kW).

V. Conclusions

This study presents some developed energetic and exergetic assessment indicators to analyze the exergetic performance evaluation of a trigeneration system with a micro gas turbine engine (*MICTRIGEN*) fueled by natural gas. These parameters help the system designers, owners and researchers to measure the cost rate, the environmental/ecological impacts and the sustainable development. This work aims to create a layout of the possibilities and advantages that exergetic performance analysis offers to the trigeneration systems.

The energy efficiency, the electrical to heating ratio, the electrical to cooling ratio, the cooling factor and the heating factor are determined to be 66.67%, 2.062, 2.857, 0.419 and 0.581, respectively.

The component level exergy analysis indicates that the components of the *CC, HE, WP* and *ACh* have the unfavourable values of exergetic performance parameters. Because of these, the above-mentioned components are selected to be bad factors for the *MICTRIGEN*. All exergetic performance indicators show that the system designer, owner and researchers focus on the components of the *CC, HE, WP* and *ACh* to

improve the exergetic efficiency values of these components.

The exergy efficiency, improved exergy efficiency, fuel exergy depletion ratio, productivity lack ratio, exergetic improvement potential, waste exergy improvement potential ratio, fuel exergy improvement potential ratio, waste exergy cost rate, environmental effect factor, exergetic sustainability index, sustainable efficiency factor and ecological effect factor of the *MICTRIGEN* system are estimated to be 38.42%, 48.55%, 61.58%, 160.28%, 133.69 kW, 33.88%, 20.86%, $1.144x10^{-3}$ kW/$, 1.603, 0.624, 1.624 and 2.603, respectively. Furthermore, the electrical to heating ratio, the electrical to cooling ratio, the cooling factor and the heating factor based on the exergy are found to be 38.42%, 13.231, 53.328, 0.199 and 0.801, respectively.

The recommended exergetic performance parameters in this study can be benefical to analyze the exergetic performance evaluation of the similar systems and to determine the sustainability levels of these systems.

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Figure Captions

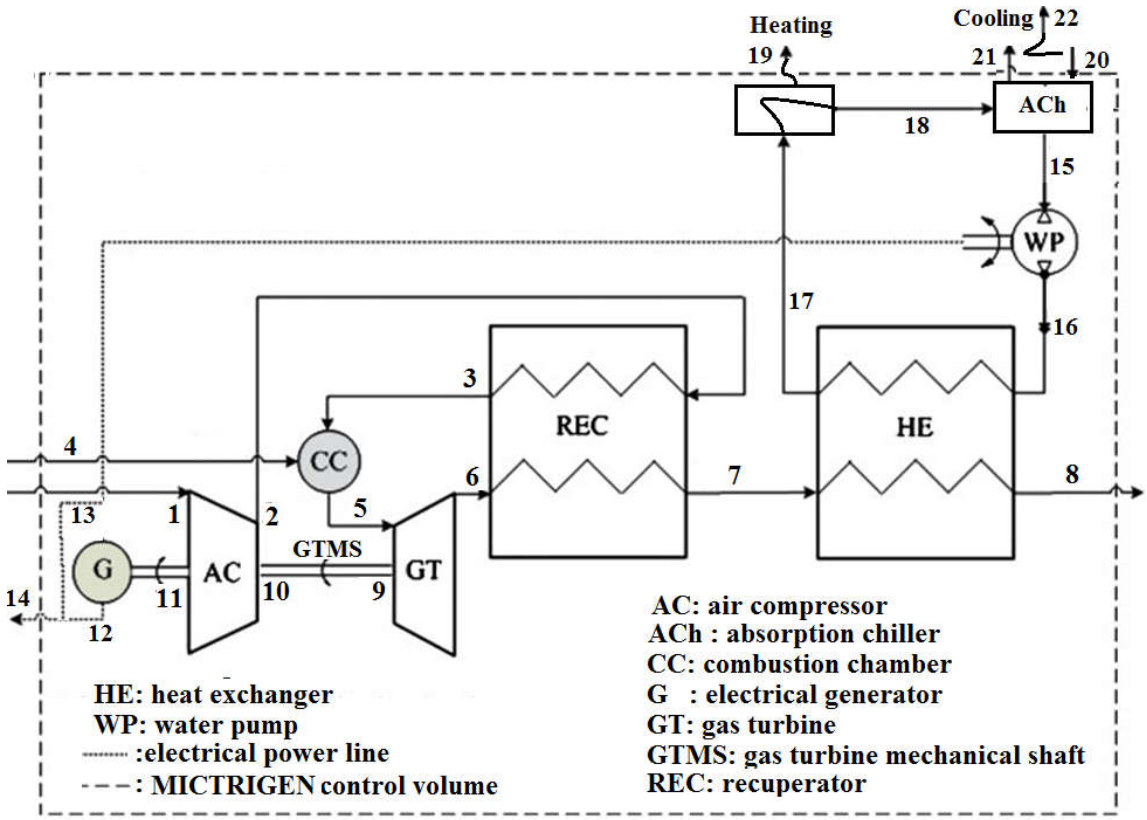

Fig. 1: A schematic of the investigated MICTRIGEN.

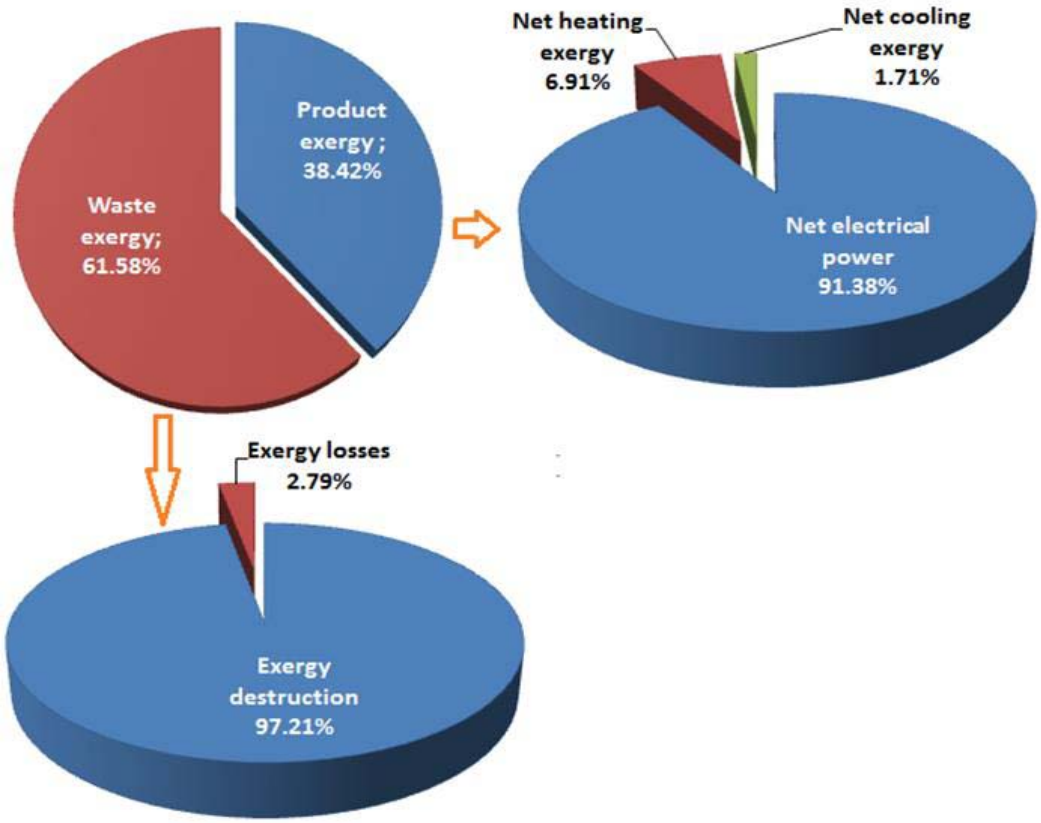

Fig. 2: The percent combinations of fuel exergy rate, waste exergy rate and product exergy rate.

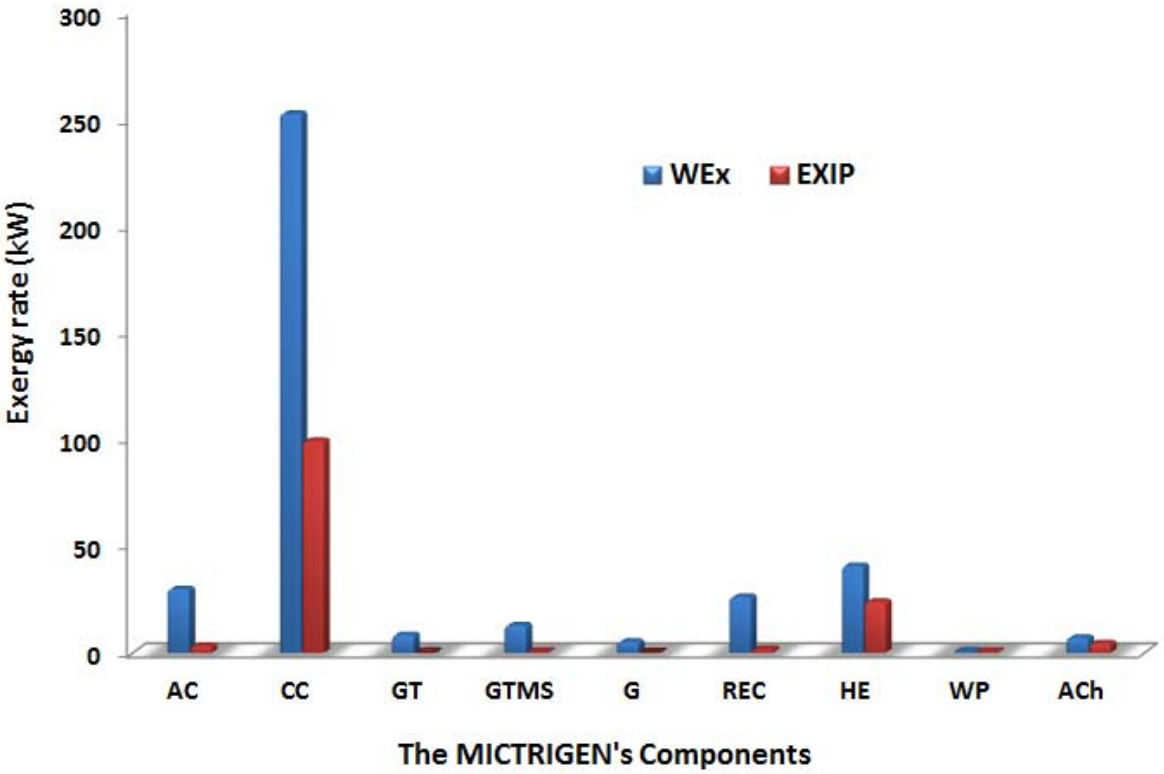

Fig. 3: The waste exergy rate and the exergetic improvement potential rate of the system components.

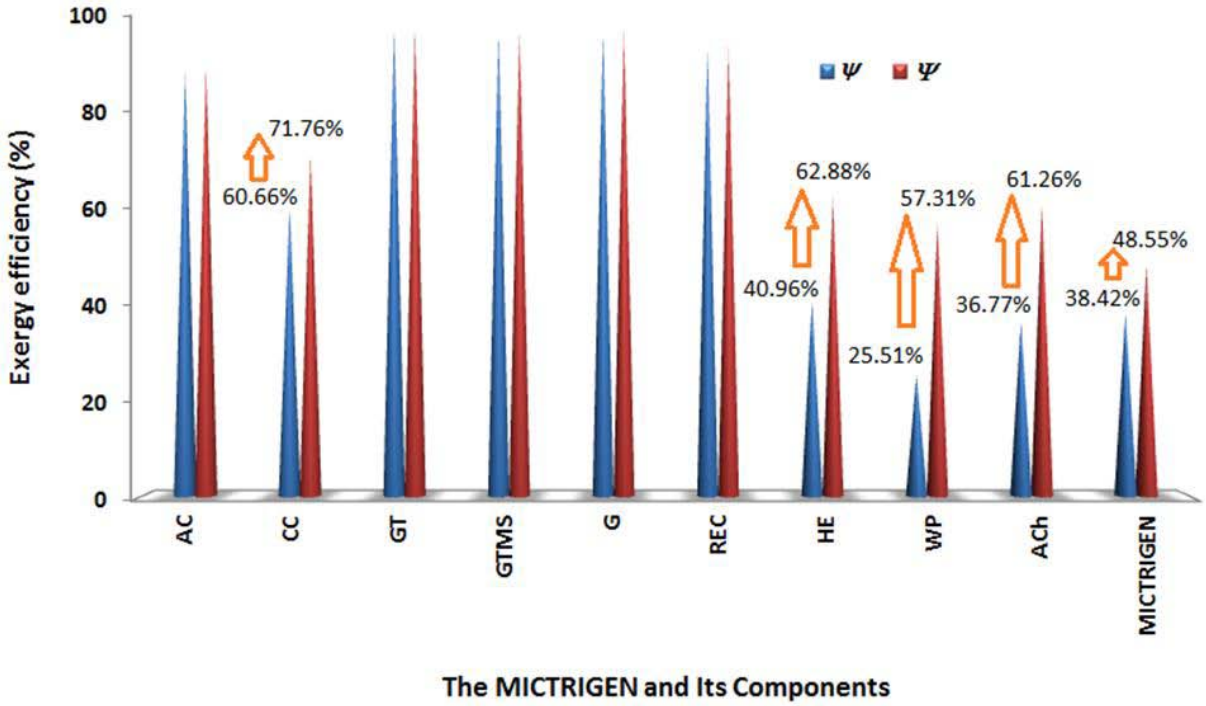

Fig. 4: The real and improved exergy efficiency values of the MIGTRIGEN and its componets.

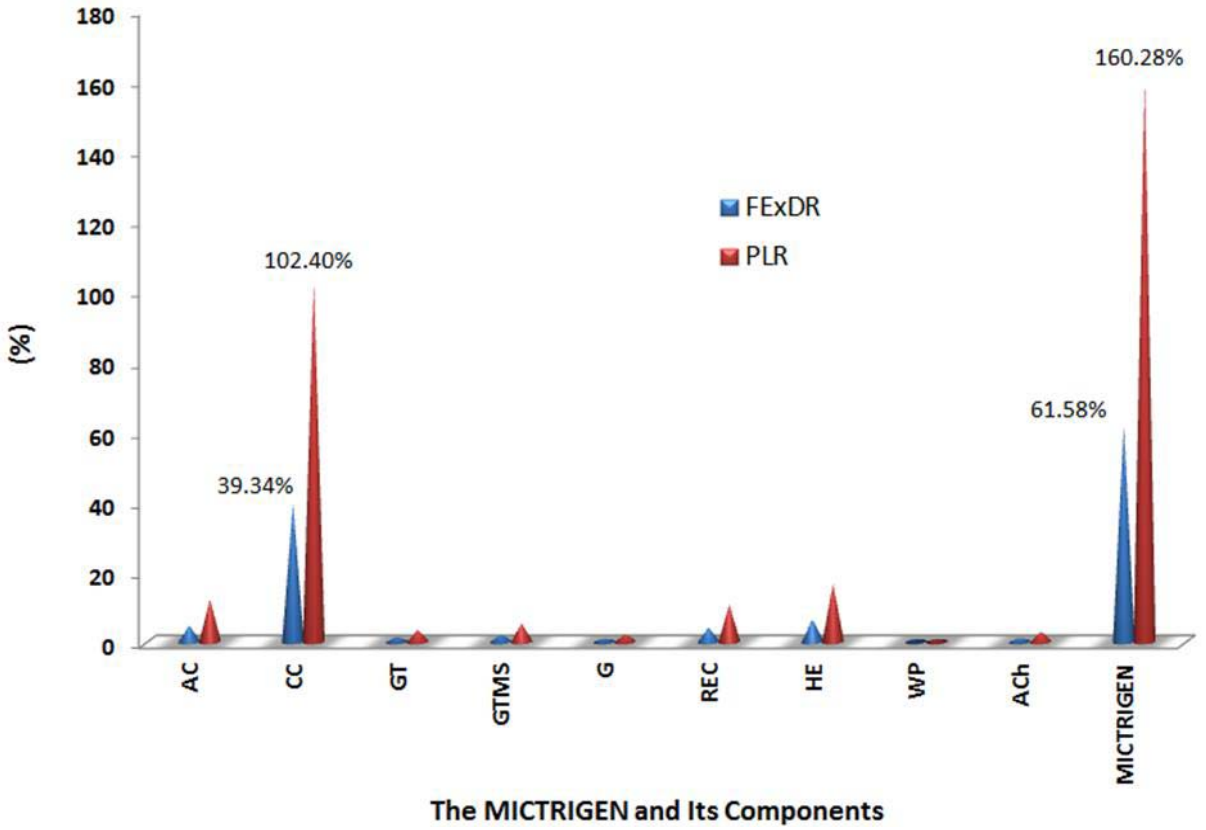

Fig. 5: Fuel exergy depletion ratio and productivity lack ratio of the *MICTRIGEN* and its components.

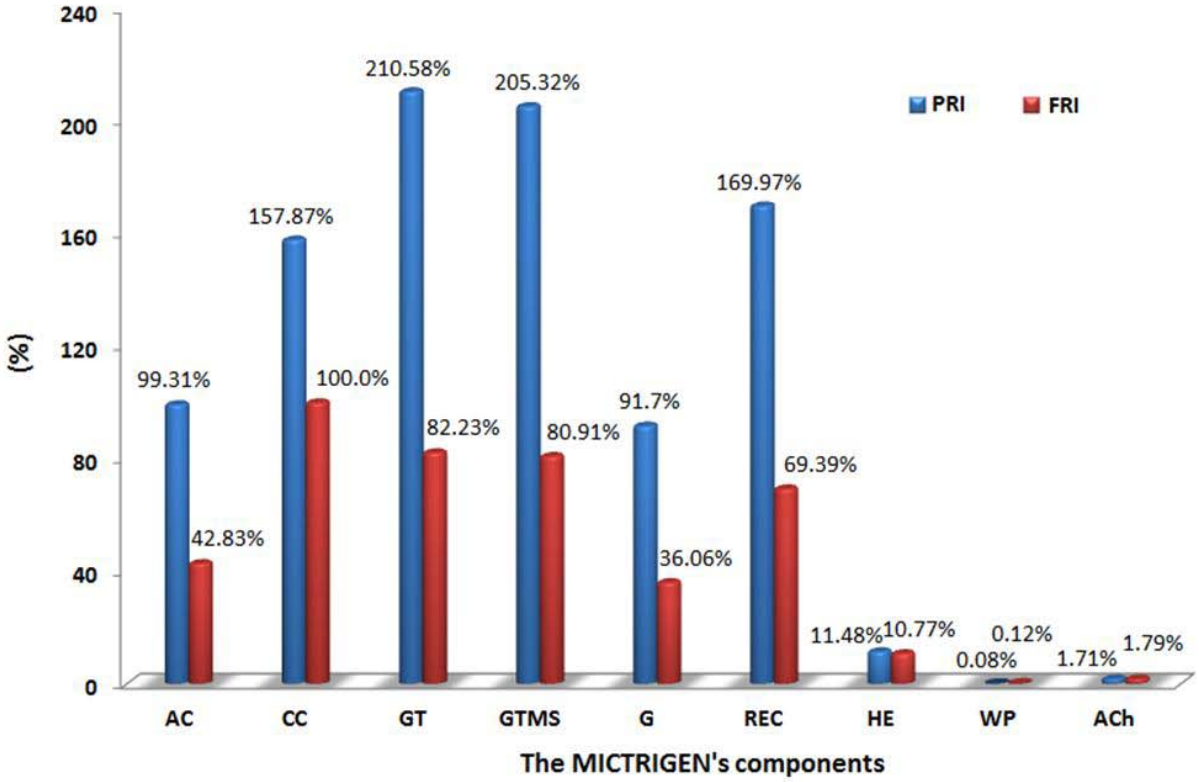

Fig. 6: The product ratio and fuel ratio indicators of the system components.

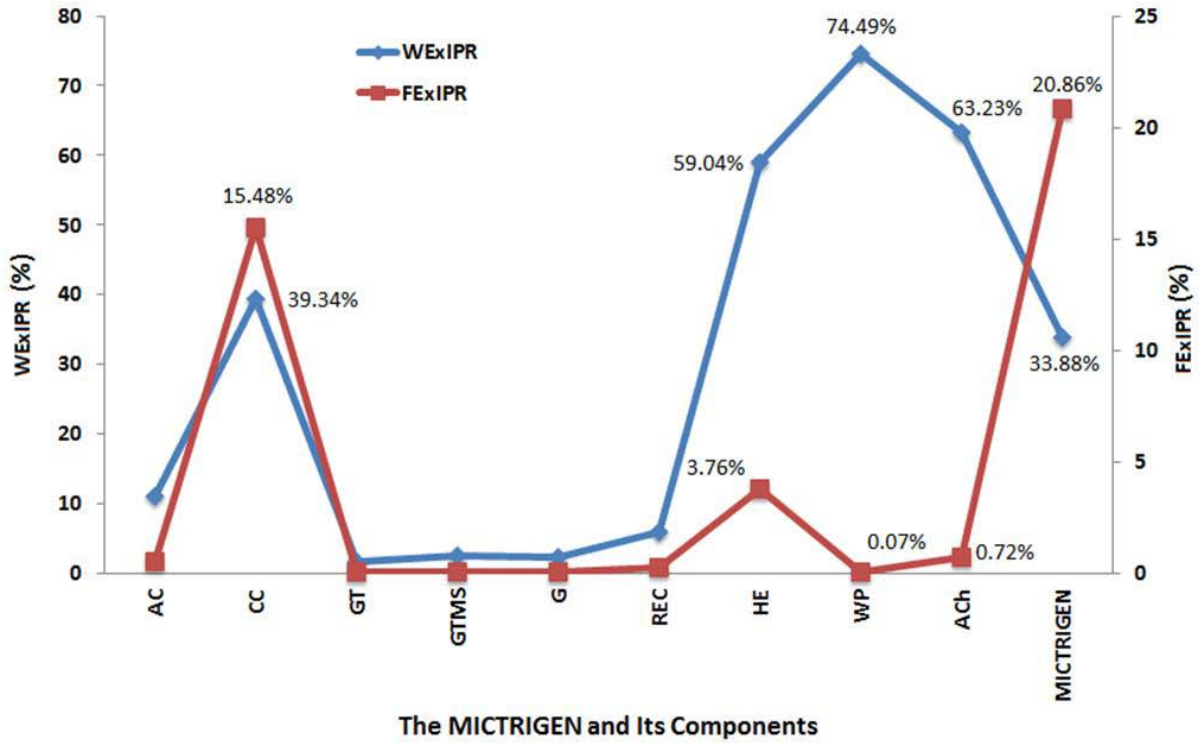

Fig. 7: The waste exergy and fuel exergy improvement potential ratios of the MIGTRIGEN and its components.

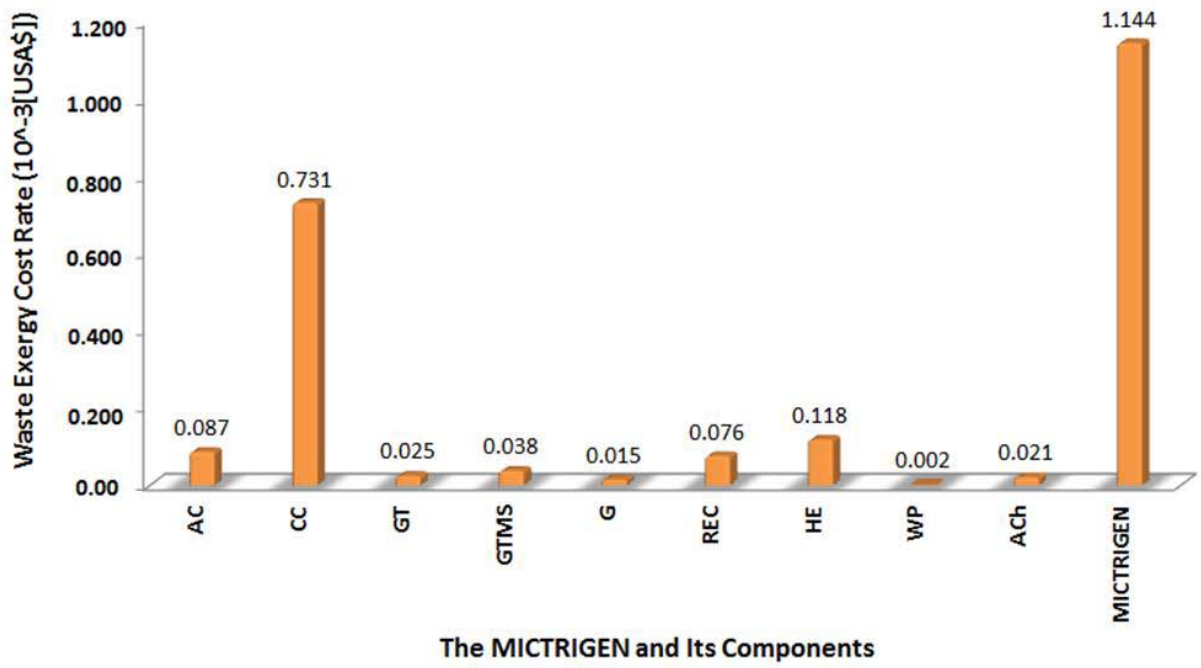

Fig. 8: The waste exergy cost rate values of the MIGTRIGEN and its components.

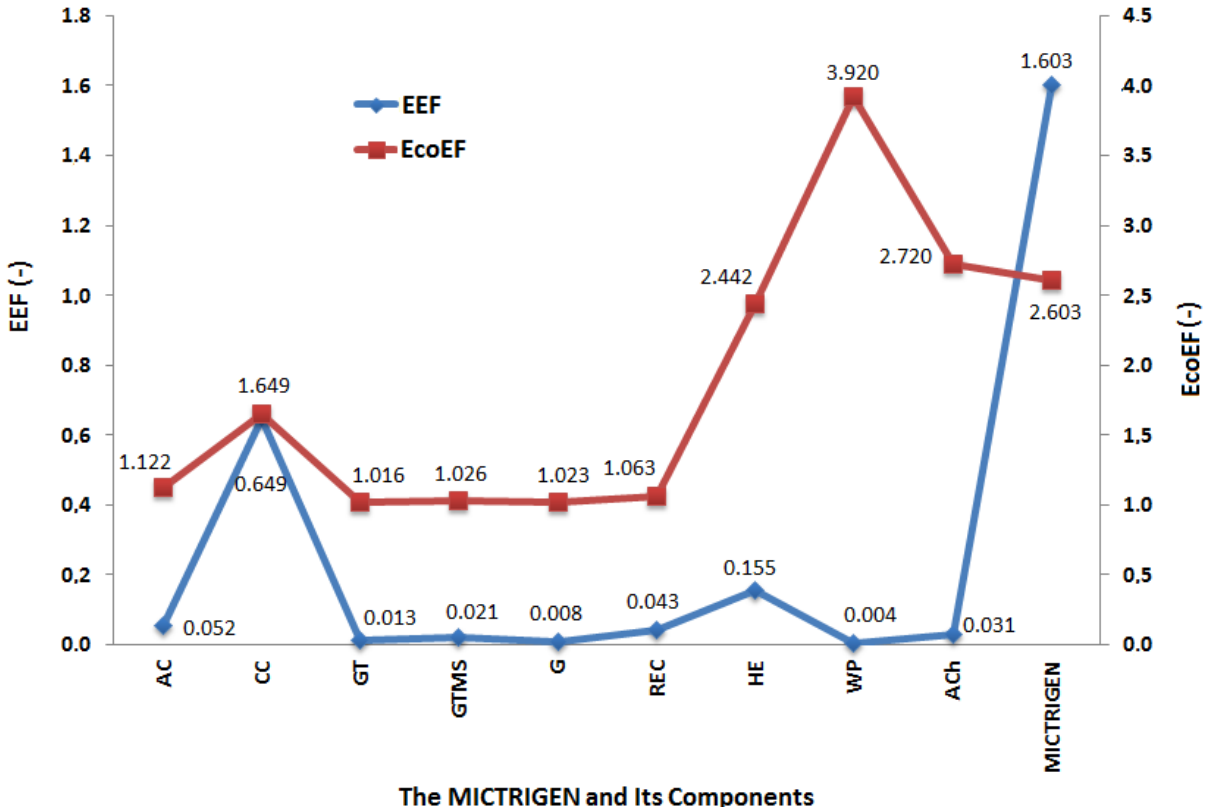

Fig. 9: The enviromental effect factor and ecological effect factor values of the MIGTRIGEN and its components.

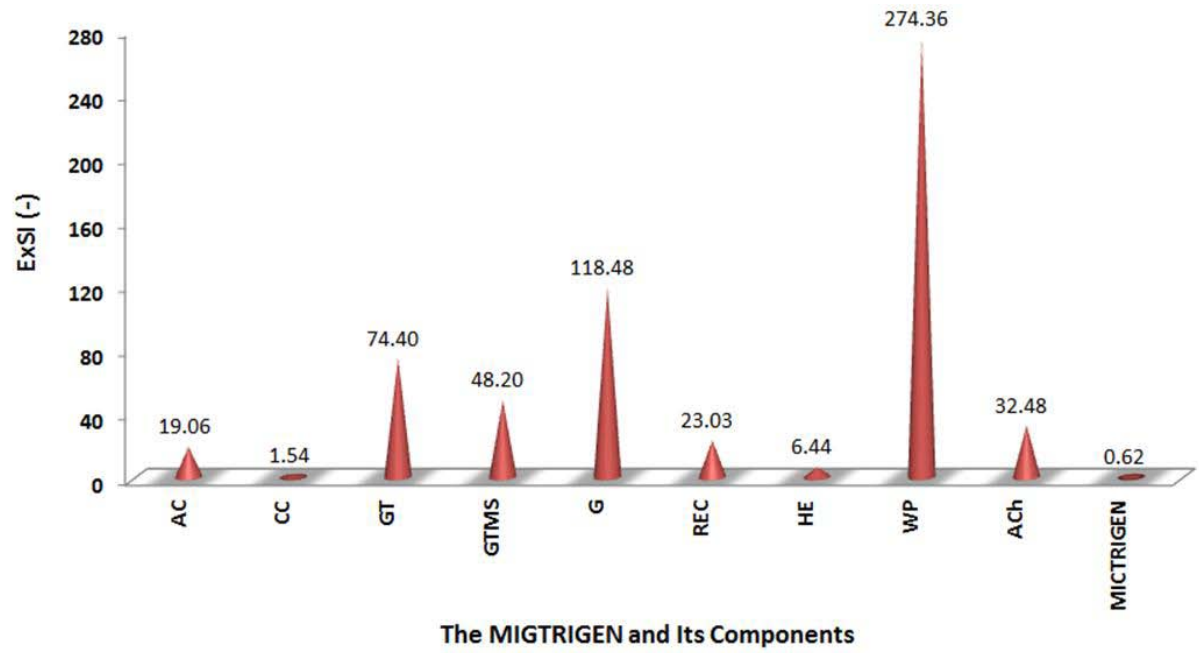

Fig. 10: The exergetic sustainability index values of the *MICTRIGEN* and its components.

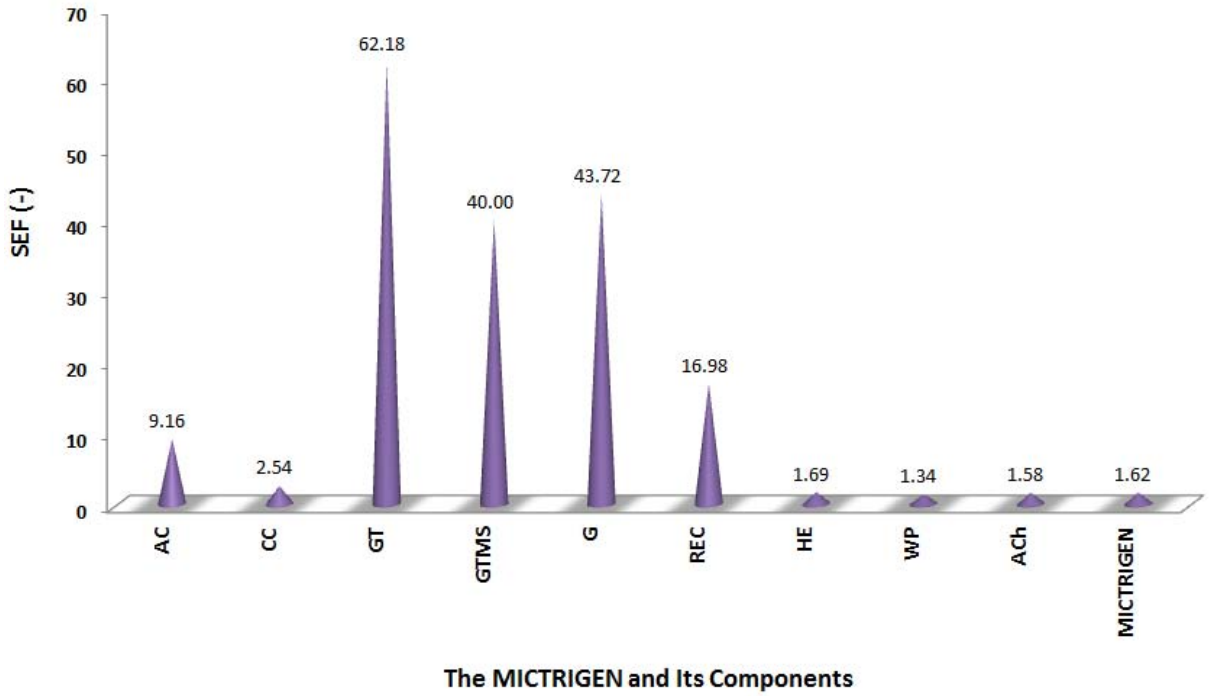

Fig. 11: The sustainable efficiency factors of the *MICTRIGEN* and its components.

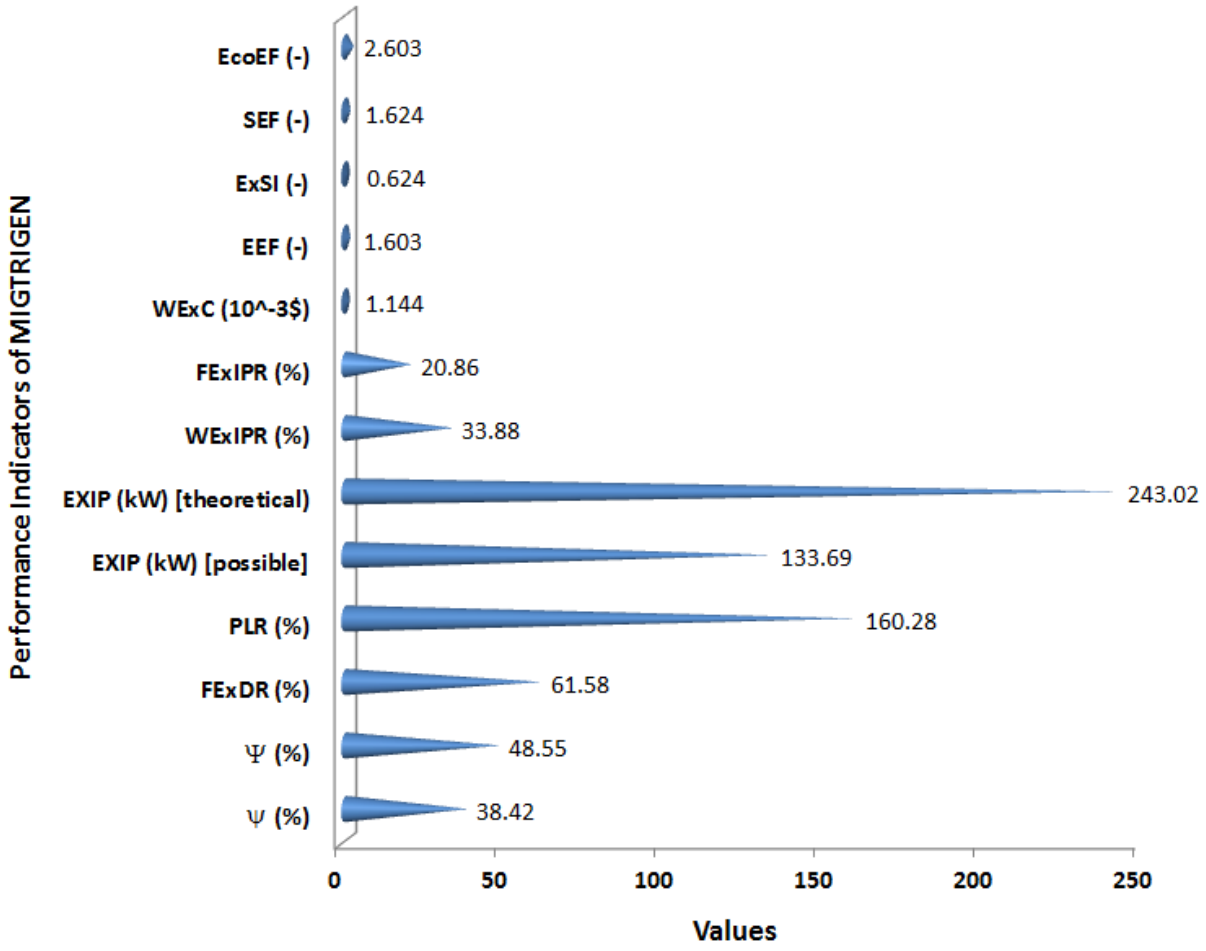

Fig.12: The exergetic performance indicator values of the whole *MICTRIGEN*.

Table Captions

Table 1: The exergetic balance equations of the *MICTRIGEN* system and its main components

Components	Fuel	Product	Waste exergy rate (destruction and losses)	Eqn. No.
AC	$\dot{W}_{10}-\dot{W}_{13}$	$\dot{E}x_2-\dot{E}x_1$	$\dot{E}x_{WEx,AC}=\dot{E}x_{D,AC}=\left(\dot{W}_{10}-\dot{W}_{11}\right)-\left(\dot{E}x_2-\dot{E}x_1\right)$	(47)
CC	$\dot{E}x_4$	$\dot{E}x_5-\dot{E}x_3$	$\dot{E}x_{WEx,CC}=\dot{E}x_{D,CC}=\dot{E}x_4-\left(\dot{E}x_5-\dot{E}x_3\right)$	(48)
GT	$\dot{E}x_6-\dot{E}x_5$	$\dot{W}_9$	$\dot{E}x_{WEx,GT}=\dot{E}x_{D,GT}=\left(\dot{E}x_6-\dot{E}x_5\right)-\dot{W}_9$	(49)
GTMS	$\dot{W}_9$	$\dot{W}_{10}$	$\dot{E}x_{WEx,GTMS}=\dot{E}x_{D,GTMS}=\dot{W}_9-\dot{W}_{10}$	(50)
G	$\dot{W}_{11}$	$\dot{W}_{12}$	$\dot{E}x_{WEx,G}=\dot{E}x_{D,G}=\dot{W}_{11}-\dot{W}_{12}$	(51)
REC	$\dot{E}x_6-\dot{E}x_7$	$\dot{E}x_3-\dot{E}x_2$	$\dot{E}x_{WEx,REC}=\dot{E}x_{D,REC}=\left(\dot{E}x_6-\dot{E}x_7\right)-\left(\dot{E}x_3-\dot{E}x_2\right)$	(52)
HE	$\dot{E}x_7-\dot{E}x_8$	$\dot{E}x_{17}-\dot{E}x_{16}$	$\dot{E}x_{WEx,HE}=\dot{E}x_{D,HE}=\left(\dot{E}x_7-\dot{E}x_8\right)-\left(\dot{E}x_{17}-\dot{E}x_{16}\right)$	(53)
WP	$\dot{W}_{13}$	$\dot{E}x_{16}-\dot{E}x_{15}$	$\dot{E}x_{WEx,WP}=\dot{E}x_{D,WP}=\dot{W}_{13}-\left(\dot{E}x_{16}-\dot{E}x_{115}\right)$	(54)
ACh	$\dot{E}x_{18}-\dot{E}x_{15}$	$\left\|\dot{E}x_{21}-\dot{E}x_{20}\right\|$	$\dot{E}x_{WEx,ACh}=\dot{E}x_{D,ACh}=\left(\dot{E}x_{18}-\dot{E}x_{15}\right)-\left(\left\|\dot{E}x_{21}-\dot{E}x_{20}\right\|\right)$	(55)
MICTRIGEN	$\dot{E}x_4$	$\dot{W}_{14}+E\dot{x}_{19}+E\dot{x}_{22}$	$\dot{E}x_{WEx,MICTRIGEN}=E\dot{x}_4-\left(\dot{W}_{14}+E\dot{x}_{19}+E\dot{x}_{22}\right)$	(56)
			$\dot{E}x_{19,heating}=E\dot{x}_{17}-E\dot{x}_{18}$	(57)
			$\dot{E}x_{22,cooling}=\left\|E\dot{x}_{21}-E\dot{x}_{20}\right\|$	(58)
	Auxiliary equations		$\dot{E}x_{WEx,MICTRIGEN}=E\dot{x}_L-\sum E\dot{x}_D$	(59)
			$E\dot{x}_L=E\dot{x}_8$	(60)
			$\sum E\dot{x}_D=E\dot{x}_{D,AC}+E\dot{x}_{D,CC}+E\dot{x}_{D,GT}+E\dot{x}_{D,GTMS}+E\dot{x}_G+E\dot{x}_{D,REC}+E\dot{x}_{D,HE}+E\dot{x}_{D,WP}+E\dot{x}_{D,ACh}$	(61)
			$\dot{W}_{12}=\dot{W}_{13}+\dot{W}_{14}$	(62)

Table 2: Thermodynamic cycle data of the MICTRIGEN system under actual operating conditions

State no.	Fluid type/work	$\dot{m}$ (kgs^{-1})	T (K)	P (kPa)	c_P $(kJ(kg-K)^{-1})$	h / LHV $(kJkg^{-1})$	s $(kJ(kg-K)^{-1})$	$\dot{E}$ (kW)	$\dot{E}x$ (kW)
0	Air	0	298.15	101.33	1.00412			0.00	0.00
0'	Water	0	298.15	101.33		104.93	0.367	0.00	0.00
1	Air	1.4544	298.15	101.33	1.00412			0.00	0.00
2	Air	1.4544	476.25	455.96	1.02486			274.46	244.52
3	Air	1.4544	928.35	449.12	1.12657			1085.67	663.02
4	Fuel	0.01258	298.15	202.75				619.37	640.87
5	Combustion gases	1.46698	1193.15	442.39	1.22244			1700.49	1051.74
6	Combustion gases	1.46698	944.15	105.90	1.17047			1181.98	524.75
7	Combustion gases	1.46698	502.15	104.20	1.07343			351.56	80.06
8	Combustion gases	1.46698	363.15	102.53	1.04640			118.27	11.03
9	Mechanical power							518.51	518.51
10	Mechanical power							505.55	505.55
11	Mechanical power							231.09	231.09
12	Electrical power							225.80	225.80
13	Electrical power							0.80	0.80
14	Net electrical power							225.00	225.00
15	Hot water	1.300	323.150	900.00		210.102	0.703	136.72	6.42
16	Hot water	1.300	323.250	1025.00		210.627	0.705	137.41	6.62
17	Hot water	1.300	363.150	1000.00		377.688	1.192	354.59	34.90
18	Hot water	1.300	343.150	950.00		293.769	0.954	245.49	17.89
19	Net heating energy/ exergy rate							109.10	17.01
20	Chilled water	3.750	285.150	300.00		50.699	0.181	-203.37	5.30
21	Chilled water	3.750	280.150	275.00		29.696	0.106	-282.13	9.52
22	Net cooling energy/exergy							78.76	4.22

Table 3: The exergetic performance indicator values of the MIGTRIGEN's components

Components	$\dot{E}x_F$ (kW)	$\dot{E}x_{\mathrm{Pr}}$ (kW)	$\dot{E}x_{WEx}$ (kW)	ψ $(\%)$	*RWExR* $(\%)$	*FExDR* $(\%)$	*PLR* $(\%)$	*ExIP* (kW)	Ψ $(\%)$	*WExIPR* $(\%)$
AC	274.46	244.52	29.95	89.09	7.59	4.67	12.16	3.27	90.16	10.91
CC	640.87	388.72	252.15	60.66	63.89	39.34	102.40	99.21	71.76	39.34
GT	526.99	518.51	8.48	98.39	2.15	1.32	3.44	0.14	98.42	1.61
GTMS	518.51	505.55	12.96	97.50	3.28	2.02	5.26	0.32	97.56	2.50
G	231.09	225.80	5.29	97.71	1.34	0.82	2.15	0.12	97.76	2.29
REC	444.69	418.50	26.19	94.11	6.64	4.09	10.63	1.54	94.44	5.89
HE	69.04	28.28	40.76	40.96	10.33	6.36	16.55	24.07	62.88	59.04
WP	0.80	0.20	0.60	25.51	0.15	0.09	0.24	0.44	57.31	74.49
ACh	11.47	4.22	7.26	36.77	1.84	1.13	2.95	4.59	61.26	63.23

Components	*RExIPR* $(\%)$	*FExIPR* $(\%)$	*PRI* $(\%)$	*FRI* $(\%)$	*WExC* $(10^{-3}\$)$	*RWExCR* $(\%)$	*EEF* $(-)$	*ExSI* $(-)$	*SEF* $(-)$	*EcoEF* $(-)$
AC	2.444	0.510	99.31	42.83	0.087	7.589	0.052	19.064	9.165	1.122
CC	74.204	15.480	157.87	100.00	0.731	63.892	0.649	1.542	2.542	1.649
GT	0.102	0.021	210.58	82.23	0.025	2.148	0.013	74.402	62.181	1.016
GTMS	0.242	0.051	205.32	80.91	0.038	3.285	0.021	48.203	40.000	1.026
G	0.090	0.019	91.70	36.06	0.015	1.339	0.008	118.484	43.723	1.023
REC	1.153	0.241	169.97	69.39	0.076	6.635	0.043	23.032	16.982	1.063
HE	18.000	3.755	11.48	10.77	0.118	10.328	0.155	6.440	1.694	2.442
WP	0.332	0.069	0.08	0.12	0.002	0.151	0.004	274.359	1.342	3.920
ACh	3.431	0.716	1.71	1.79	0.021	1.838	0.031	32.481	1.582	2.720

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Modelling Two Different Disperse Polystyrene with Maxwell Fractional Model in SAOS Experiments

By Bruno Manuel Ribeiro Alves
University of Minho

Abstract- The purpose of this work is to perform two adjustments of different disperse polystyrene using the technique of Alves (Alves, 2017) with the data present on Farias (Farias, 2009), data belonging to a group of eminent researchers. It is seen that the adjustments are of good quality for a polystyrene anionic polymerised and with an inferior quality for a free-radical polymerised polystyrene. It leads to a possible correlation with the polydispersity index and the quality of adjustment performed with Maxwell fractional model.

It is concluded in this work that Maxwell fractional model is able to describe the behaviour when Mw/Mn is closer to 1 but the same is not completely valid for polydispersity index of 1.44.

Keywords: Maxwell fractional model; viscoelastic fluid; SAOS experiments; polystyrene; wolfram mathematica 10; non-linear regression; polydispersity index.

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I. Introduction

The purpose of this work is to perform two adjustments using the technique of Alves (Alves, 2017) with the data present in Farias (Farias, 2009) that belongs to a group of eminent researchers.

On this work is checked a possible correlation of the polydispersity index with the chain branching thanks to the realisation of adjustments of SAOS dynamic polystyrene data (Farias, 2009) with a mathematical formulated viscoelastic fractional model, the Maxwell fractional model(Jaishankar & McKinley, 2012).

Seeing the complexity level of Maxwell fractional model, is known that models on the literature can be more or less complex and divided in Newtonian (as Newton model)(Pinho, 2003), non-Newtonian inelastic (they are models that consider the variation of shear viscosity with shear rate) (Pinho, 2003)and viscoelastic (Viscoelastic models combine viscous component and elastic component and they can have differential or integral mathematical formulations)(Pinho, 2003).

First viscoelastic linear models date from XIX century and are the linear viscoelastic model of Maxwell (Maxwell, 1867) and the linear viscoelastic model of Kelvin-Voight (Bird, Armstrong, & Hassanger, 1987). A possible representation of this genre of models is given by the combination of discrete elements as springs (Hooke Law), where tension (τ) is directly proportional to deformation (γ)) to represent the elastic model, and dashpots (Newton law) (Bird et al., 1987).

With Fractional Viscoelastic models, an analogy with discrete elements can be done. On Figure 1 is presented this new element, the "springpot", that allows the interpolation of the behaviour of traditional elements spring and dashpot through the order considered for the derivative. In this way is obtained a continuous variation between the behaviour of solids and liquids. Hooke law (spring – derivative of order 0 (D^0)) and Newton law (dashpot – derivative of order 1 (D^1)) becomes a particular case of springpot (Friedrich, Schiessel, & Blumen, 1999).

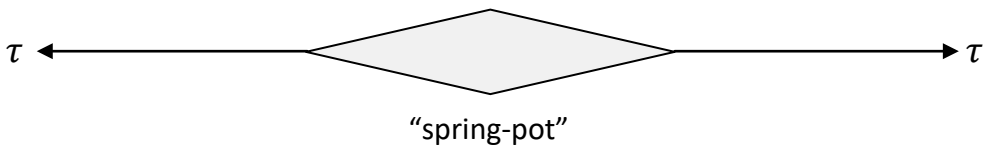

Figure 1: "Spring-pot" as generalization of the concept Spring-dashpot.

Below are presented the Equation 1, G'(ω), and the Equation 2, G''(ω),, equations of storage modulus, and Loss modulus of Maxwell fractional model (a model constituted by two springpot in series). These equations are used to fit the data of Farias.

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$$G'(\omega)=\frac{(\Phi_2\omega^{\beta})^2\Phi_1\omega^{\alpha}Cos\left(\frac{\pi}{2}\alpha\right)+(\Phi_1\omega^{\alpha})^2\Phi_2\omega^{\beta}Cos\left(\frac{\pi}{2}\beta\right)}{(\Phi_1\omega^{\alpha})^2+(\Phi_2\omega^{\beta})^2+2\Phi_1\omega^{\alpha}\Phi_2\omega^{\beta}Cos\left(\frac{\pi}{2}(\alpha-\beta)\right)} \quad \text{(Equation 1)}$$

$$G''(\omega)=\frac{(\Phi_2\omega^{\beta})^2\Phi_1\omega^{\alpha}Sin\left(\frac{\pi}{2}\alpha\right)+(\Phi_1\omega^{\alpha})^2\Phi_2\omega^{\beta}Sin\left(\frac{\pi}{2}\beta\right)}{(\Phi_1\omega^{\alpha})^2+(\Phi_2\omega^{\beta})^2+2\Phi_1\omega^{\alpha}\Phi_2\omega^{\beta}Cos\left(\frac{\pi}{2}(\alpha-\beta)\right)} \quad \text{(Equation 2)}$$

The Maxwell Fractional model to be valid must be > 0 for Φ_2 and Φ_1, and for α and β the observation of the final result is 0 < α and β <1 (Jaishankar & McKinley, 2012).

Fractional theory is not applied only in viscoelasticity.

This theory is applied on migration of biological cells in complex spatial domains (Cusimano, Burrage, & Burrage, 2013), on lithium-ion batteries involving fractional differentiation (Sabatier, Merveillaut, Francisco, Guillemard, & Porcelatto, 2014), on spiny neuronal dendrites (Henry, Langlands, & Wearne, 2008), on human motion tracking (Michailas, Martin, Lasse, & Manoli Yiannos, 2014) and also on fractional order cancer (Ahmed, Hashis, & Rihan, 2012).

On an engineering level these models can be applied on continuum mechanics (Drapaca & Sivaloganathan, 2012), on the optimization of fractional order dynamic chemical processing systems (Flores-Tlacuahuac & Biegler, 2014), on supercapacitors, batteries and fuel cells (Freeborn, Maundy, & Elwakil, 2015).

II. Resources and Techniques

On this work itis used data that Farias presented on her work (Farias, 2009), gently given by a group of eminent researchers and presented in work as "Evaluation of Reptation Model for predicting the linear viscoelastic properties of entangled linear polymers" (Ruymbeke, Keunings, Hagenaars, & Bailly, 2002) and also "Determination of the molecular weight distribution of the entangled linear polymers from linear viscoelasticity data" (Ruymbeke et al., 2002). As seen on table 1, there are 2 different polystyrene synthesized by anionic polymerisation and free radical polymerisation tested at 170 °C (Farias, 2009) with different polydispersity index.

Their characteristics are presented on Table 1.

Table 1: Characteristics of the Polystyrenes used on this work

	Mw (g/mol)	Mw/Mn	Test temperature °C
Anionic Polymerisation PS (PS_a)	355500	1.03	170
Free-radical Polymerisation PS (PS_f)	361100	1.44	170

These two Polystyrenes were analysed according to Farias on a rotational rheometer ARES (Advanced Rheometric Expansion System) of controlled deformation throughout dynamic experiments with parallel plate geometry(Farias, 2009). The GPC (Gel Permeation Chromatography) gives the medium molar mass and the Polydispersity index with the help of a liquid chromatographer Waters Alliance model GPC 1 V2000 equipped with refraction index(Farias, 2009).

For more information it is necessary to consult two works, the "Evaluation of Reptation Model for predicting the linear viscoelastic properties of entangled linear polymers" (Ruymbeke et al., 2002) and also the "Determination of the molecular weight distribution of the entangled linear polymers from linear viscoelasticity data" (Ruymbeke et al., 2002).

This data of G'(ω) and G''(ω) of SAOS experiments was placed on a computer program previous computed by Alveswhich is possible to be found on the article website (Alves, 2017), using the same principle. Alves modified the file .cdf of Normand et al. (Normand, Eisenberg, & Peleg, 2012)used to evaluate a stochastic model inactivation for heat activation spores of Bacillus spp (Corradini, Normand, Eisenberg, & Peleg, 2010)and converted it into a .cdf file to perform adjustment of fractional viscoelastic data. The file .cdf is easily modified if replaced the equation and the dataset.

III. Results and Discussion of Results

The results of the work are presented on Table 2 for Maxwell fractional model adjustment to the experimental SAOS dynamic experimental data of Farias.

Table 2: Maxwell Fractional Model results of adjustment for the different PS used in this work

	Φ_1	Φ_2	α	β	R^2
Anionic Polymerisation PS (PS_a)	1029000	132900	0.987	0.120	0.9987
Free-radical Polymerisation PS (PS_f)	275800	116400	0.842	0.126	0.990

Accordingly to parameters values is observed that all values are >0 for Φ_2 and Φ_1, which means that in this case it obeys the thermodynamic restrictions. Therefore, for α and β the observation of the final result is 0< α and β<1, which gives valid thermodynamic results.

Below are presented the graphics of the adjustments done with the material functions G'(ω) and G''(ω) of Maxwell Fractional Model with the experimental data of Farias, the anionic polymerisation data of Polystyrene (Figure 2) and free-radical polymerisation data of Polystyrene (Figure 3).

Figure 2 shows an almost perfect adjustment for G'(ω) and G''(ω) in all the domain of ω with exception for ω>200 rad/s. For this value the result is not perfectly coincident, and means that the model is not valid for values of ω>200 rad/s.

On Figure 3 is observed the same thing as Figure 1 but here for values of ω>100 rad/s, which results on a bad coincidence result. Here, also for periods of ω<0.05 rad/s relative to G'(ω) and G''(ω) the fit is not good.

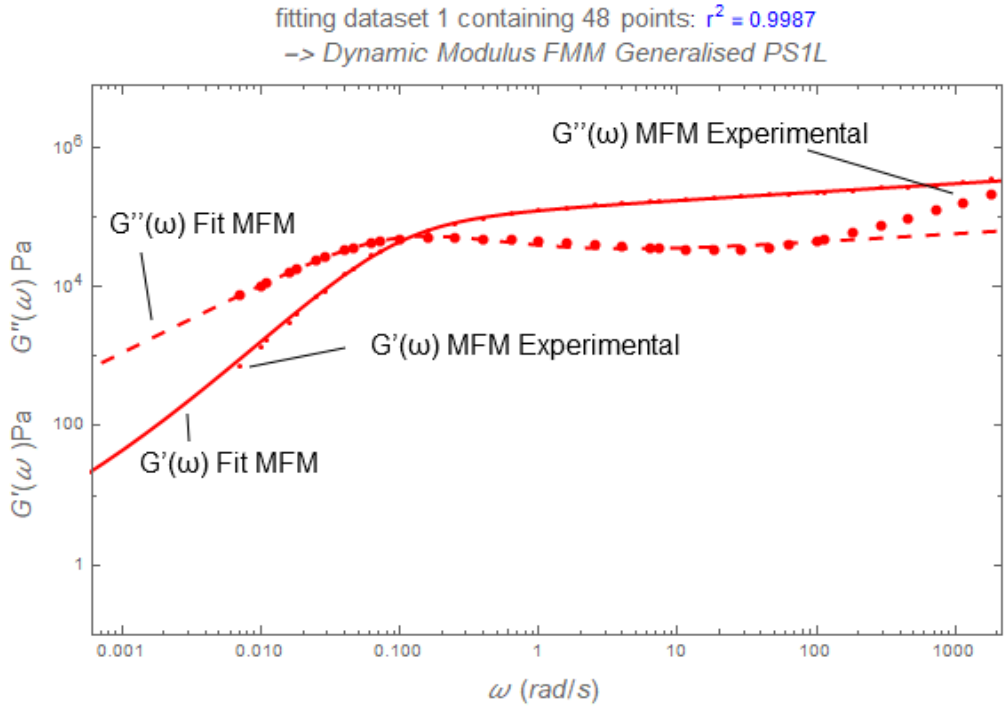

Figure 2: Maxwell Fractional Model adjustment for SAOS experimental data of an anionic Polymerisation PS

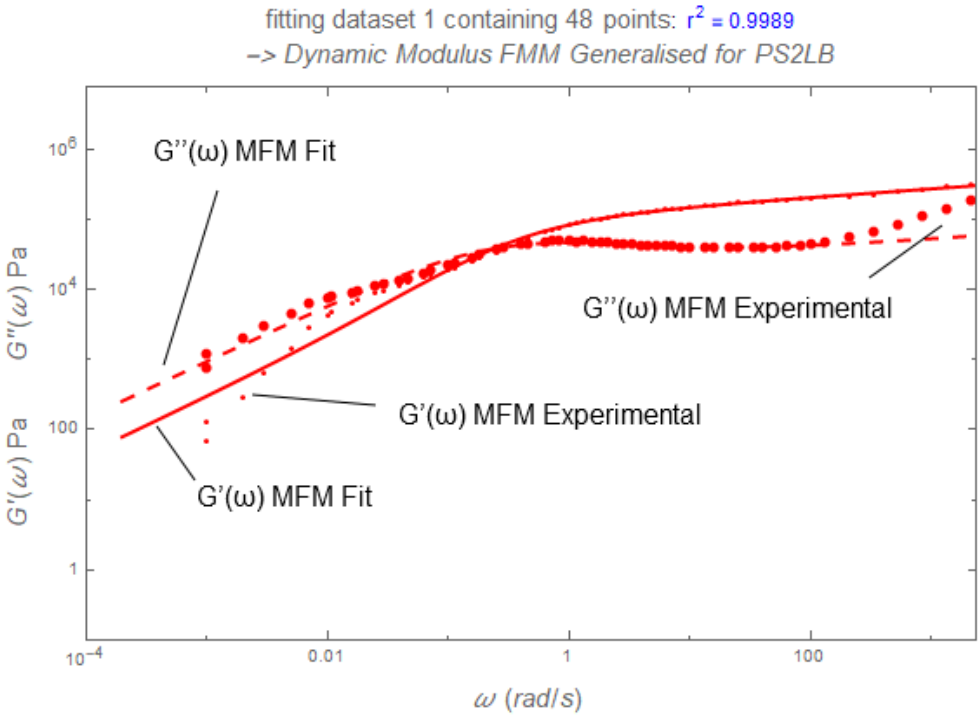

Figure 3: Maxwell Fractional Model adjustment for SAOS experimental data of an free-radical polymerisation PS

Although, the final results in questions of adjusted R squared are very high, and this results in a good model to adjust these experimental data in SAOS experiments.

The anionic polymerized polystyrene as observed on section 5 has polydispersity index correspondent to 1.03 adjusting almost perfectly, which means that exist an high correlation between Maxwell fractional model and the polydispersity index of anionic polymerised polystyrene.

The free radical polymerization Polystyrene has a bigger polydispersity index equal to 1.44 and the quality of adjustment is not comparable to the anionic polymerisation of polystyrene, what means that for Mw = 1.44 Mn the correlation between Maxwell fractional model and polydispersity index of free radical based polymerisation cannot be done.

So, I think that with these proofs that the overall quality of Maxwell fractional model has a correlation with polydispersity index for anionic polymerisation polydispersity index however the same is not completely valid for free-radical based polymerisation of polystyrene.

IV. Conclusion

With this work was possible to perform two fits for two different polystyrenes with an overall good quality obeying the thermodynamic restrictions imposed by Maxwell Fractional Model in SAOS dynamics.

However is possible to find now a correlation with the polydispersity index of the polymer of Polystyrene with the Maxwell fractional model.

It is concluded in this work that Maxwell fractional model is able to describe the behaviour when Mw/Mn is closer to 1 but the same is not completely valid for polydispersity index of 1.44.

V. Acknowledgements

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Experimental Investigation of Dust Effect on PV Module Performance

By Abhishek Kumar Tripathi, Ch.S.N. Murthy & M. Aruna
National Institute of Technology Karnataka

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Keywords: dust, short circuit current, open circuit voltage, maximum power output.

GJRE-J Classification: FOR Code: 091405

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Keywords: dust, short circuit current, open circuit voltage, maximum power output.

I. Introduction

Water, power and health are three most essential things for any country. Apart from water and health, power is utmost important for every person. The production of power depends on fossil fuel, nuclear and renewable energy sources. Due to the fast depletion of fossil fuel and unsafe activity of nuclear energy sources renewable energy sources could be a good choice for power generation in future course of action (Sayigh., 2011). There are various types of renewable energy sources, such as biomass, geothermal, wind, hydro and solar. Among all renewable sources, solar energy experienced a rapid growth and popularity in last one decade (Mekhilef et al., 2011, Bayod-Rújula et al., 2011, Oliver & Jackson., 2001 and Chueco-Fernández & Bayod-Rújula., 2010). In solar energy, solar radiation coming from sun is converted into electrical energy with the help of solar photovoltaic (PV) module. Photovoltaic is an effect in which, whenever sunlight strikes on PV module surface it creates free electron and hole pairs. This creation of free electron hole pairs is the main cause of electric power generation in PV system. The solar energy now a day's getting much more attention because of its availability and easy access in remote areas compared to other means of energy sources. Also the costs of PV panel have dropped substantially over the last few years (Dincer., 2011).

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II. Effect of Dust on pv Module Performance

The performance of PV panel depends on various environmental parameters, like solar radiation, ambient temperature, humidity, wind speed and dust. Among these parameters dust affects the PV panel performance more significantly. Dust is defined as the minute solid particles less than 500 μm in diameter. Dust deposition is a function of various environmental and weather conditions. Dust particles in the atmosphere generates from various sources, like movement of vehicles, drilling operation, working of HEMM, weather, volcanic eruptions, exhaust from industries etc. Such airborne dust particles settle down on PV module surface, which curtains the solar radiation falling on the module surface. (Saidan et al. 2016, Adinoyi & Said., 2013 and Semaoui., 2015). The surface finish of the module, its tilt angle, humidity in the environment and wind speed influence the dust settlement on the module surface. Therefore, the deposition of dust on module surface varies from place to place. (Mani & Pillai., 2010 and Kaldellis & Kapsali., 2011). In a study it was found that due to sand dust deposition on PV panel surface the reduction in short circuit current (I_{SC}) and maximum power output (P_{MAX}) are respectively 40% and 34% (Hasan & Ghoneim., 2005). Similarly, another study shown that the reduction in PV module conversion efficiency were 10%, 16% and 20% respectively for 12.5 g/m^2, 25 g/m^2 and 37.5 g/m^2 dust deposition on its surface (Shobokshy & Hussein., 1993). The study carried out for exposure of PV module for outdoor environment revealed that the reduction in glass transmittance was ranging from 90.7% to 87.6% after 33 days of its exposure into outside environment (Hee et al., 2012). One more study indicated that the dust significantly affects the optical transmittance of PV module, which reduces the electrical parameters like, Isc and Pmax up to 2.23% and 7.98%, respectively (Semaoui et al., 2015). In this paper an attempt has

been made to investigate and analyse the influence of dust deposition on PV module performance.

III. Laboratory Set-up and Methodology

To understand the influence of dust deposition on module surface an indoor laboratory experiment was performed using 20W polycrystalline PV module at 545W/m^2 constant solar radiation. Red soil of size less than 75µ was used in this study, which is prepared using sieve analysis process. The dust was distributed uniformly on module surface with the help of strainer. A set of solar simulators were used to generate an artificial solar radiation. A Digital Multimeter Fluke 178+ and DT830B were used to measure the electrical response of PV panel. The rheostat of rating 320 ohm was acting as an output load for PV module. Initially the electrical responses of PV module, such as current, voltage and power measurements of clean PV module were recorded by varying its load using rheostat.

To study the influence of dust accumulation on module, red soil was spread on the module surface, and its respective electrical responses were measured as discussed above. This procedure was repeated for three different mass deposition of dust, such as 5gm, 7gm and 12gm. Table 1 gives the variation in Isc, Voc and Pmax for four different conditions of module surface. With the help of these experimental results, current-Voltage and Power-Voltage characteristics of PV module are plotted.

Further, to study the influence of type of dust pollutants on PV module performance two different types of dust pollutants, such as red soil dust and lime stone dust of size less than 75µ were used. These dust pollutants were uniformly distributed on the module surface in the mass of 5gm and the electrical responses of PV module, such as current, voltage and power were recorded for both the type of dust.

Table 1: Experimental results

Dust (gm)	Isc (amp)	Voc (volt)	Pmax (watt)
0	0.36	19.70	5.022
5	0.32	18.95	3.726
7	0.30	18.90	3.564
12	0.24	18.30	2.916

IV. Results and Discussion

Figure 1 shows the comparison of I-V characteristics of PV module for different mass of dust deposition on the module surface. The results in Table 1 indicate that the reduction in I_{SC} and V_{OC} are respectively 33.33% and 6.64% for 12gm of dust deposition on module surface. As depicted in Figure 1 the open circuit voltage of PV module is less affected, whereas short circuit current is significantly reduced with increase in dust deposition. Due to this significant reduction in I_{SC} the performance of PV module degrades considerably. Figure 2 depicts P-V characteristic of PV module for different mass of dust deposition. The reduction in P_{MAX} is 42% for dust deposition of 12gm. The results of this study show that the reduction in I_{SC} and P_{MAX} of PV module depends on the mass deposition of dust particle on its surface. Moreover, the reduction in I_{SC} and P_{MAX} of PV module due to dust deposition is more significantly compared to V_{OC}. This is because of the direct relation of solar radiation to the I_{SC}, whereas the V_{OC} of PV modules is proportion to the logarithm of solar radiation. The reduction shows a negative linear trend as shown in Figure 3 and Figure 4.

The electrical responses of the module were also recorded for two type of above said dust pollutants and its current-voltage and power-voltage characteristic were plotted, which are shown in Figure 5 and Figure 6. The reading of I_{SC}, V_{OC} and P_{MAX} for all three defined condition (i.e., clean, covered by red soil dust and covered by lime stone dust) of PV module is given in Table 2. As given in Table 2 the influence of red soil dust on PV module performance is more severe than the lime stone dust. This indicates that the performance degradation of PV module is not only depends on mass of dust deposition but also on the type of dust.

Table 2: Electrical responses for the three different conditions

Module Surface Condition	I_{SC} (amp)	V_{OC} (volt)	P_{MAX} (watt)
Clean condition	0.36	19.7	5.022
Dusty Condition (with 5gm of lime stone dust)	0.31	19.25	4.05
Dusty Condition (with 5gm of red soil dust)	0.28	18.95	3.726

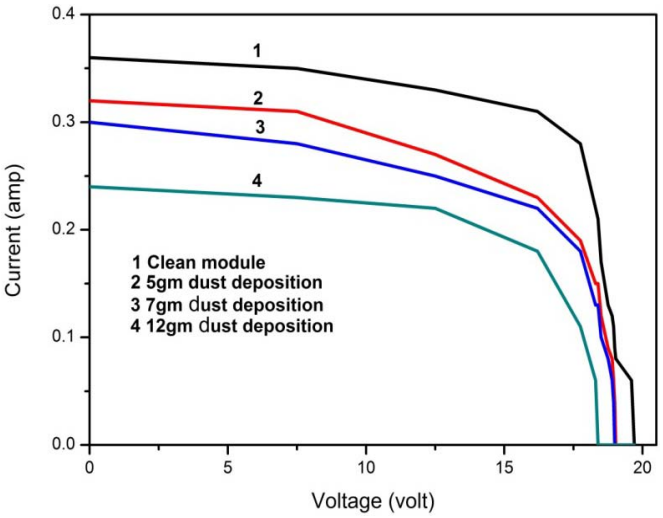

Fig. 1: Current-Voltage characteristics of the PV module

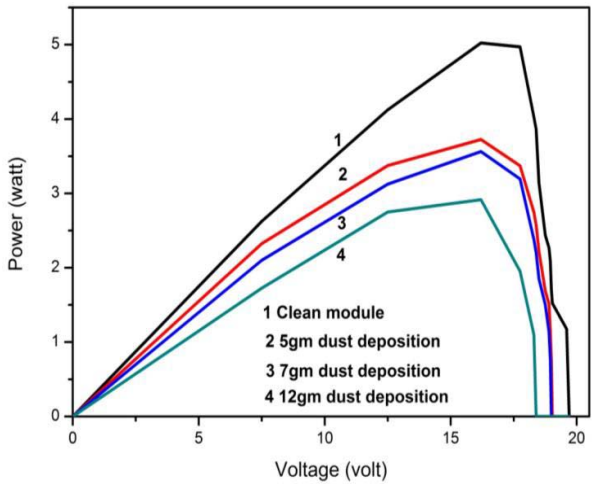

Fig. 2: Power–Voltage characteristics of the PV module

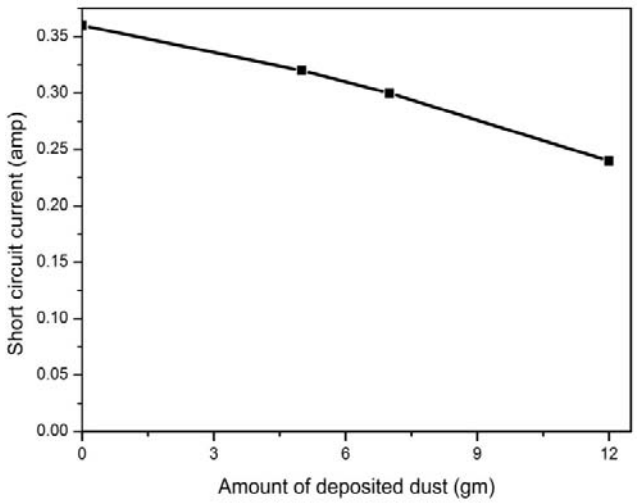

Fig. 3: Reduction in short circuit current w.r.t. mass of dust deposition

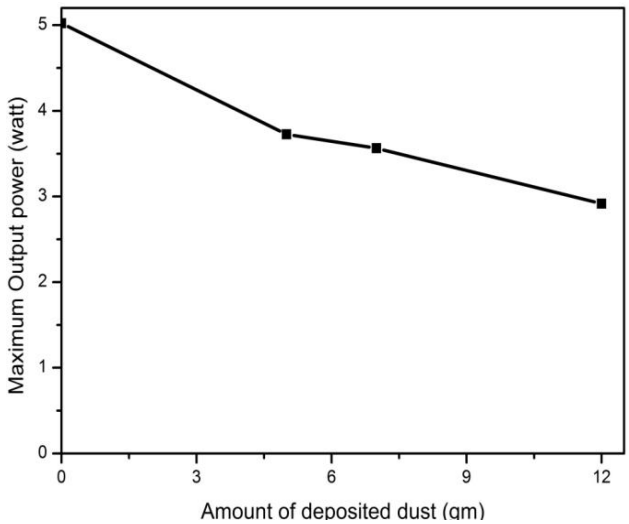

Fig. 4: Reduction in maximum power output w.r.t. mass of dust deposition

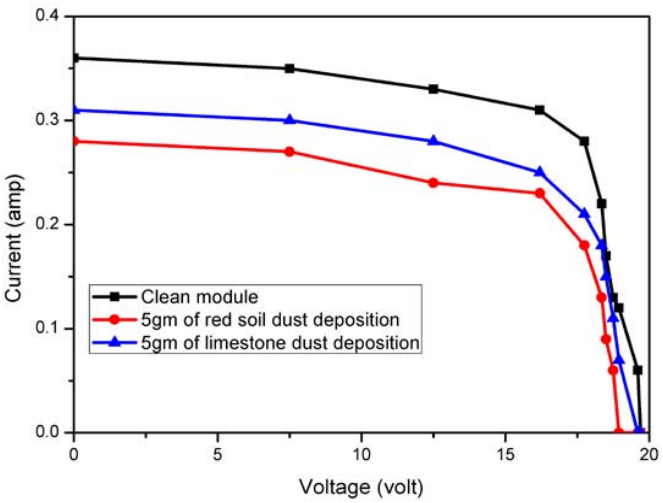

Fig. 5: Current-voltage characteristic of PV module w.r.t. dust deposition

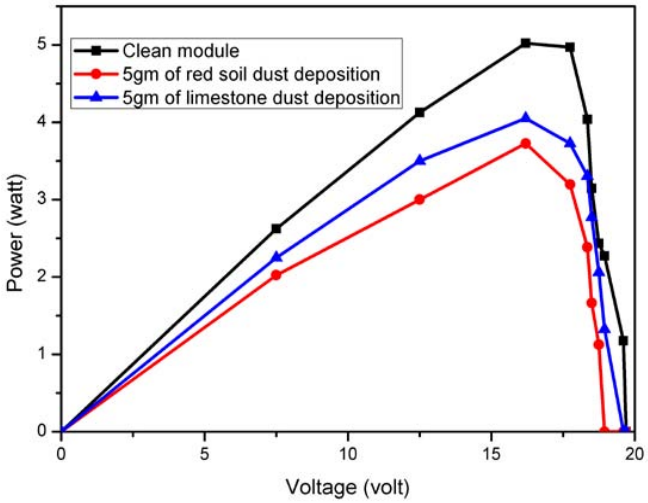

Fig. 6: Power-voltage characteristic of PV module w.r.t. dust deposition

The performance of PV panel in a dusty environment can be decided by the term normalised power output. The normalised power output (P_N) of PV module due to dust deposition is defined as the ratio of power output of dusty module (P_d) to the power output of clean panel (Pc), as given in Equation 1. Therefore, the reduction in normalised power output (P_{RN}) of PV module can be defined by Equation 2. The normalised power of PV panel in the dusty environment indicates the performance of a dust panel w.r.t a clean panel. The higher value of normalised power output represents the better operation of the module in dusty environment. The reduction in normalised power output measures the degradation level of module performance. The higher value of the reduction in normalised power output of PV module represents the higher level of the degradation in module performance. Therefore, it is very vital to know about the normalised power output due to dust accumulation on module surface. The relation of

normalized power output and reduction in normalized power output of PV module with reference to the mass of deposited dust on its surface is shown in Figure 7 and Figure 8.

$$P_N = \frac{P_d}{P_c} \quad (1)$$

where,

P_d= Power output of dusty module (in watt)
P_c= Power output of clean module (in watt)
P_N= Normalised power output of PV module

$$P_{RN} = 1 - \frac{P_d}{P_c} \quad (2)$$

where,

P_d= Power output of dusty module (in watt)
P_c= Power output of clean module (in watt)
P_{RN}= Reduction in normalized power output of PV module

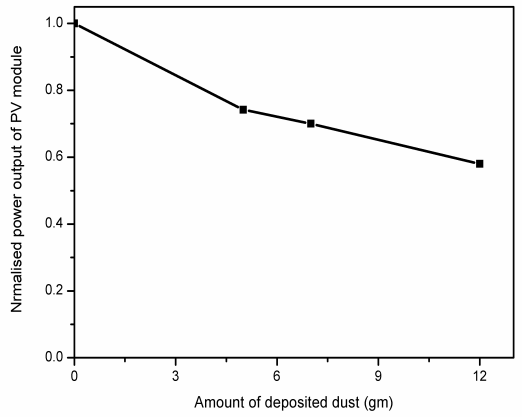

Fig. 7: Normalised power output of PV module w.r.t. amount of dust deposition

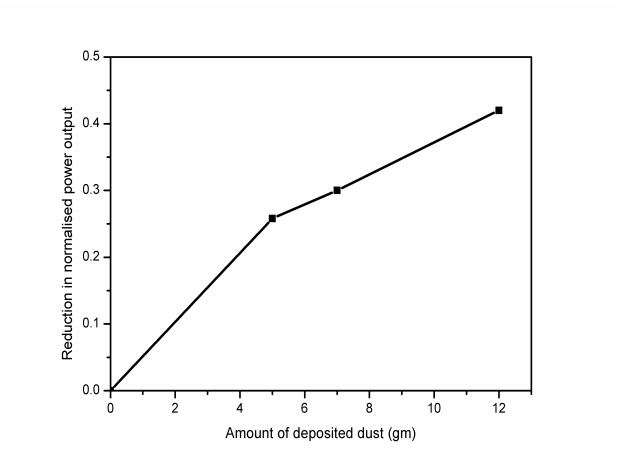

Fig. 8: Reduction in normalised power output of PV module w.r.t. mass of dust deposition

V. Conclusions

Solar energy could be a good choice of electrical power generation in remote areas, particularly in locations where access of power is difficult, like in mining areas, deserts, hill tops, forest etc. The aim of this paper is to study and analyse the influence of dust deposition on PV module performance. The results of the study shows that the reduction in short circuit current and open circuit voltage is respectively 33.33% and 6.64% for 12gm of dust deposition on module surface. The reduction in PV module performance due to dust accumulation is also depends on the type of dust pollutants. It was found that the accumulation of red soil on the module surface affects the module performance more severely than the lime stone dust.

The reduction in maximum power output is up to 42%, which is significant when compared to power output of a clean PV module. This study demonstrated that the performance of PV module reduces with the increment in the dust deposition on its surface. Hence, this study demonstrates that a complete cleaning action of dust from PV module surface at regular interval must be ensured to improve the efficiency of PV module.

Abbreviations

I_{SC}	Short circuit current
P_{MAX}	Maximum power output
V_{OC}	Open circuit voltage
w.r.t	With respect to
PV	Photovoltaic
P_c	Power output of clean module
P_d	Power output of dusty module
P_N	Normalised power output
P_{RN}	Reduction in Normalised power output

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Performance Simulation of Two-Bed Silica Gel-Water Adsorption Chillers

By Najeh Ghilen, Souad Messai, Slimane Gabsi, Mohammed El Ganaoui & Riad Benelmir

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Abstract- This paper presents a transient model of a two bed silica gel - water solar adsorption cooling system. This program is then utilized to simulate the performance of a sample solar adsorption cooling system used for cooling a room that comprises an area of 9 m2 located in Nancy city in France. The system has been simulated with typical weather data of solar radiation and ambient temperatures of France. The results include effects of the hot water temperature, cooling water temperature and chiller water temperature and cycle time on COP, refrigeration capacity and cycled mass are studied in order to determine their optimum values able to maximize the overall performance of the system under analysis for its adaptation to the Tunisian climate.

Keywords: *solar adsorption chiller, silica gel-water, simulation, performance.*

GJRE-J Classification: *FOR Code: 091599*

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Performance Simulation of Two-Bed Silica Gel-Water Adsorption Chillers

Najeh Ghilen [α], Souad Messai [σ], Slimane Gabsi [ρ], Mohammed El Ganaoui [ω] & Riad Benelmir [¥]

Abstract- This paper presents a transient model of a two bed silica gel - water solar adsorption cooling system. This program is then utilized to simulate the performance of a sample solar adsorption cooling system used for cooling a room that comprises an area of 9 m2 located in Nancy city in France. The system has been simulated with typical weather data of solar radiation and ambient temperatures of France. The results include effects of the hot water temperature, cooling water temperature and chiller water temperature and cycle time on COP, refrigeration capacity and cycled mass are studied in order to determine their optimum values able to maximize the overall performance of the system under analysis for its adaptation to the Tunisian climate.

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I. Introduction

With the increasing economic development and environment protection, adsorption refrigeration technology as the green refrigeration method has received more and more attention in recent years because it can save energy and is environmentally friendly. Adsorption refrigeration can be driven by low-grade heat source, such as waste heat from the process industry and solar energy.

The adsorption cooling and heat pump systems could utilize low temperature waste heat or renewable energy sources. The working pairs of adsorption cooling and heat pump are mainly dominated by activated carbon/ammonia, activated carbon/methanol and activated carbon fiber (ACF)/ammonia, silica gel/water and zeolite/water pairs.

In this context, silica gel-water was selected as the adsorbent – adsorbate pair. Compared with other adsorbents, silica gel can be regenerated at a relatively low temperature (below 100°C, and typically about 85°C). It also has a large uptake capacity for water which has a high latent heat of evaporation; up to 40% of its dry mass. A silica gel-water adsorption chiller is able to make use of industrial waste heat to effect useful cooling.

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Many researchers evaluated the performance of adsorption cooling and heat pump systems based on working pairs, system design and methodology. A transient simulation model for adsorption cooling system using silica gel/water pair powered by renewable energy was investigated by a number of researchers [1-7]. Restuccia et al. [8] reported an experimental and numerical study of a lab-scale adsorption chiller using the macroporous silica gel impregnated with $CaCl_2$ as the adsorbent. At a 90-95°C heat source, the authors showed that the measured COP values were up to 0.6. With the aim of improving silica gel-water adsorption chillers design with two adsorption/desorption chambers, Liu et al. [9] demonstrated that with the new chiller, a COP of about 0.5 is reached. In the same way, Nùñez et al. [10] presented the development of a prototype of a small adsorption heat pump using silica gel-water pair. The purpose of minimizing primer energy consumption is achieved. In fact, for air-conditioning of 12-15°C, a cooling COP of 0.5 is found. Wang et al. [11] built and tested a novel silica gel-water adsorption chiller. For a hot water temperature of 84.8°C, a cooling water temperature of 30.6°C and a chilled water outlet temperature of 11.7°C, the measured COP is about 0.38. The authors proved that the application of this adsorption chiller is successful especially for low grade heat source. Xia et al. [12] presented an improved two bed silica gel-water adsorption chiller. The improved chiller is composed of three vacuum chambers: two adsorption/desorption vacuum chambers and one heat pipe working vacuum chamber. A heat pipe is used to combine the evaporators of the two adsorption/desorption units. An improvement of at least 12% for the COP was reached compared to the formers chillers. Hen et al. [13] investigated an improved compact silica gel-water adsorption chiller without vacuum valves. To improve the performance of the chiller, a heat and mass recovery process is carried out. The COP is measured about 0.49. Liu et al. [14] developed a new adsorption water chiller without refrigerant valves. The working pair is silica gel-water with mass recovery process. The COP range was 0.2-0.42 depending on the operating conditions.

Saha et al. [15} proposed a new two-stage non-regenerative adsorption chiller design and experimental prototype silica gel–water adsorption chiller. To exploit solar/waste heat of temperatures below 70°C, staged regeneration is necessary. The two-stage cycle can be

operated effectively with 55°C solar/waste heat in combination with a 30°C coolant temperature. He et al. [16] carried out a novel two stages adsorption chiller with different adsorbents such as Zeolite and activated carbon. The two-stage cycle can be operated effectively with a generator temperature of 45-50°C.

A two stage activated carbon cycle using R134a and R507A refrigerants in the two stages was investigated by Habib et al. [17]. The evaporator of the R134a cycle was connected to the condenser of the R507a system. The performance in this cycle was comparatively low, achieving COPs of only 0.04-0.1.

A novel three-bed, two-evaporator system was proposed and modeled by Miyazaki et al. [18]. The dual evaporator allows two beds to be adsorbing simultaneously, while a third is desorbing. A bed is connected to a low pressure evaporator and then when reaching near saturation conditions for that bed, it is connected to a high pressure evaporator and adsorption continues. COP for this system design increased by 70%, while SCP increased by 50% for this system design compared to a standard adsorption chiller working at the same conditions.

Several configurations were investigated by Li et al. [19], including a bed-to-bed re-adsorption process. It was found that using a bed-to-bed system improved the cooling capacity of the system by delivering cooling at both the evaporator and first adsorbent bed, although at different cooling output temperatures. The bed-to-bed design was also made adaptable so that the process could incorporate internal heat recovery, depending on the desired output, or operate as a conventional system. The COP doubled when operating in bed-to-bed mode compared to conventional operation.

K. Habib et al. [20] presents the theoretical analysis of the performance of solar powered combined adsorption refrigeration cycles that has been designed for Singapore and Malaysia and similar tropical regions using evacuated tube solar collectors. This novel cycle amalgamates the activated carbon (AC)-R507A as the bottoming cycle and activated carbon-R134a cycle as the topping cycle and deliver refrigeration load as low as -10 °C at the bottoming cycle. A simulation program has been developed for modeling and performance evaluation for the solar driven combined adsorption refrigeration cycle using the meteorological data of Singapore and Malaysia. The results show that the combined cycle is in phase with the weather. The optimum cooling capacity, coefficient of performance (COP) and chiller efficiency are calculated in terms of cycle time, switching time, regeneration and brine inlet temperatures.

A. Sadeghlu et al. [21], divided combined ADRS into four types based on different arrangements of two working pairs, Zeolite 13x/$CaCl_2$-water and Silica gel (RD type)–water, to analyze the performance of combined ADRS. After validating mathematical models with available experimental data, ADRS is simulated by using Simulink–Matlab software to achieve optimum times for various processes. The results of simulation show that the cooling capacity of the system with Zeolite 13x/$CaCl_2$-water is more than the other types. The results have shown that the arrangement of adsorbents affects cooling capacity of combined ADRS significantly. In Type A, Zeolite 13x/$CaCl_2$-water has been used as an adsorbent for both top and bottom cycles. This type not only has more cooling capacity than the other types, but also the effect of hot water temperature on cooling capacity of this type is less than the others. Furthermore, a sensitivity analysis has been done to determine the importance of each parameter on ADRS system because the cooling capacity and the COP are influenced by many constant parameters.

The objective of this paper is the development of a global simulation model flexible in changing operating conditions using Simulink. The optimization tools are used to enable selecting the optimum operating conditions corresponding to the best performance in order to adapt this machine in to Tunisian climate that having a cooling temperature up to 40°C and heating temperature up to 85°C.

II. Experimental Device

Figure 1 illustrates the experimental unit, driven by solar energy, provided from solar collectors, and the fuel source such as the natural gas. This platform combine cogeneration (by the production of electricity and heating), solar cooling, and sustainable construction (wood structure). Two similar adjacent chambers, with opposite comfort demand, are the users of heating and refrigeration.

The major components contained in the platform and ENERBAT which are included in the experiments carried out are:

Solar panel: On the roof, a solar field with 16 solar collectors, 2.4 m^2 each is installed. The collector characteristics are given in the following:

Hot water tank thermal stratification: The heat provided by the solar panel or by the co-generator is stored in the hot water cylinder, to thermal lamination, with a capacity of 1500 liters. The hot water fed from the tank to the adsorption refrigerating machine.

Dry cooler: The dry cooler constitutes the cooling circuit of the machine adsorption

Two-room climate: it consists of two rooms a warm room and a hot room represents the test cell.

Adsorption refrigerating machine: The adsorption machine, SorTech brand, the product chilled water circulating through the cooling ceiling of the cold room. Hot water supplied from the refrigerating machine of the balloon.

Co-generator: The used co-generator is an internal combustion engine coupled with electric generator which recovers more than 90 % of heat from coolant, lubricant, and exhaust gas. Thus, it is used as mean of producing electricity (220 V, 50 Hz) and heat (hot water at 85°C). Its electrical and thermal efficiencies are approximately 25 % and 65 %, respectively.

Data acquisition: The data are acquired and manipulated as two dimensional graphs and tabulated. Instrumentation also allows regulation of the tri-generation unit.

In this paper we focus only on the refrigeration machine for which we developed a simulation model that is confronted to experimental measurements.

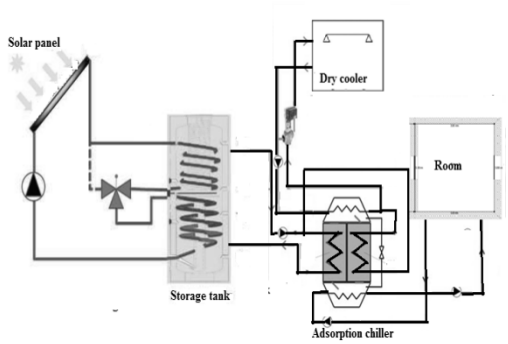


Fig. 1: Experimental device (Enerbat plateform)

III. Mathematical Model

a) Assumptions

In order to develop a mathematical model, a number of assumptions are required.

- ✓ The temperature, pressure and the amount of water vapor adsorbed are uniform throughout the adsorber beds.
- ✓ There is no external heat loss to the environment as all the beds are well-insulated.
- ✓ The condensate can flow into the evaporator easily.
- ✓ All desorbed water vapor from the desorber will flow into the condenser immediately and the condensate will flow into the evaporator directly.
- ✓ The condensate will evaporate instantaneously in the evaporator and will be adsorbed in the adsorber immediately.
- ✓ The adsorbed phase is considered as a liquid and the adsorbate gas is assumed to be an ideal gas.
- ✓ The thermal resistance between the metal tube and the adsorbent bed is neglected.
- ✓ Flow resistance arising from the water flowing in the pipeline is neglected.
- ✓ The properties of the fluid, the metal tube and adsorbate vapor are constant.

According to these assumptions, the dynamic behavior of heat and mass transfer inside different components of the adsorption chiller can be written as shown below.

b) Rate of Adsorption/desorption

The rate of adsorption or desorption is calculated by the linear driving force kinetic equation, The coefficients of LDF equation for silica gel/water are determined by Chihara and Suzuki [22] and are given in the below.:

$$\frac{\partial w}{\partial t} = K_s(w^* - w) \quad (kg/kg.s) \tag{1}$$

The effective mass transfer coefficient inside the pores k_s is given by:

$$K_s = F_0 \frac{D_s}{R_p^2} \quad (s^{-1}) \tag{2}$$

The effective diffusivity is defined as follows:

$$D_s = D_{s0} e^{-E_a/RT} \quad (m^2/s) \tag{3}$$

Where:

D_{so}= 2.54 10-4m^2/s, R_P = 1.7 10^{-4} m, E_a = 4.2 104 J/mol, F_0 = 15

R = 8,314 J/mol K

The equilibrium uptake of silica gel- water pair is estimated using the equation developed by Boelman [23].

$$w^* = 0.346\left(\frac{P_s(T_r)}{P_s(T_a)}\right)^{1/1.6} (kg_{water}/kg_{silica\ el}) \tag{4}$$

Where $P_s(T_w)$ and $P_s(T_s)$ are respectively the corresponding saturated vapor pressures of the refrigerant at temperatures T_r (water vapor) and T_a (adsorbent). P_s for water vapor is estimated using the following equation:

$$P_{sat}(T) = 133{,}32\exp\left(18{,}3 - \frac{3820}{T-46{,}1}\right) \tag{5}$$

c) Energy balance of adsorber

The adsorption energy balance is described by:

$$(m_{ad}c_{ad} + m_a c_a + m_a w c p_r)\frac{dT_{ad}}{dt} = m_a \Delta H_{ads}\frac{dw}{dt} + m_a cp_{r,v}\frac{dw}{dt}(T_{ev} - T_{ad}) + \dot{m}_{f,ad}\, cp_f (T_{f,in} - T_{f,out}) \ (kW) \tag{6}$$

The outlet temperature of cooling water can be expressed as

$$T_{ad,out} = T_{ad} + (T_{ad,in} - T_{ad})\exp\left(-\frac{U_{ad}A_{ad}}{\dot{m}_{f,ad}\, cp_{f,ad}}\right) \tag{7}$$

d) Energy balance of desorber

The desorption energy balance is described by:

$$(m_{de}\,c_{de} + m_a\,c_a + m_a\,w c p_r)\frac{dT_{de}}{dt} = m_a \Delta H_{ads}\frac{dw}{dt} + \dot{m}_{f,de}\,cp_f(T_{f,in} - T_{f,out})\ (kW) \quad (8)$$

The outlet temperature of hot water can be expressed as

$$T_{de,out} = T_{de} + (T_{de,in} - T_{de})\exp\left(-\frac{U_{de}\,A_{de}}{\dot{m}_{f\,de}\,cp_f}\right) \quad (9)$$

e) Energy balance of condenser

The condenser energy balance equation can be written as

$$(m_{r,cd}\,cp_r + m_{cd}\,c_{cd})\frac{dT_{cd}}{dt} = -m_a\frac{dw_{des}}{dt}L_v - m_a\,cp_{r,v}\frac{dw_{des}}{dt}(T_{de} - T_{cd}) + \dot{m}_{f,cd}\,cp_f(T_{f,in} - T_{f,out})(kW) \quad (10)$$

The outlet temperature of cooling water can be expressed as

$$T_{cd,out} = T_{cd} + (T_{cd,in} - T_{cd})\exp\left(-\frac{U_{cd}\,A_{cd}}{\dot{m}_{f\,cd}\,cp_{f\,cd}}\right) \quad (11)$$

f) Energy balance of evaporator

The energy balance in the evaporator is expressed as

$$(m_{ev}\,c_{ev} + m_{r,ev}\,c_{p,r})\frac{dT_{ev}}{dt} = -m_a\frac{dw_{ads}}{dt}L_v - m_a\frac{dw_{des}}{dt}c_{p,r}(T_{cd} - T_{ev}) + \dot{m}_{f,ev}\,c_{p,f}(T_{f,in} - T_{f,out})(kW) \quad (12)$$

The outlet temperature of chilled water can be written as

$$T_{ev,out} = T_{ev} + (T_{ev,in} - T_{ev})\exp\left(-\frac{U_{ev}\,A_{ev}}{\dot{m}_{f,ev}\,cp_{f,ev}}\right) \quad (13)$$

g) Mass balance in the evaporator

The mass balance for the refrigerant can be expressed by neglecting the gas phase as:

$$\frac{dm_{r,ev}}{dt} = -m_a\left(\frac{dw_{ads}}{dt} + \frac{dw_{des}}{dt}\right) \quad (14)$$

Where, m_a is the adsorbent mass.

h) System performance equations

The COP value is defined by the following equation:

$$COP = \frac{Q_{ev}}{Q_{de}} \quad (15)$$

The cooling capacity of the system is expressed by:

$$Q_{ev} = \frac{\int_0^{t_{cycle}} \dot{m}_{f,ev}\,cp_f(T_{ev,in} - T_{ev,out})dt}{t_{cycle}} \quad (16)$$

Where:

$$Q_{de} = \frac{\int_0^{t_{cyc\,le}} \dot{m}_{f,de}\,cp_f(T_{de,in} - T_{de,out})dt}{t_{cycle}} \quad (17)$$

Specific Cooling Power

$$SCP = \frac{Q_{ev}}{m_a} \quad (18)$$

Where:

m_a = 50 Kg, ΔH_{ads} = 2800 kJ/kg, L_v = 2500 kJ/kg, $C_{cd}, C_{ev} C_{ad}$ = 0.386 kJ/kg. K, $Cp_{r,v}$ = 1.85 kJ/kg. K, C_a = 0.924 kJ/kg.K , C_{pr} = 4.18 kJ/kg.k, $\dot{m}_{f,ad}$ = 1.6 m³/h, $\dot{m}_{f,cd}$ = 3.7 m³/h, $\dot{m}_{f,ev}$ = 2 m³/h, $T_{ev,in}$ = 15°C, $T_{cd,in}$ =22 °C, $T_{gn,in}$ =62 °C t_{cycle} = 840 s,

IV. Results and Discussion

a) Model validation

Figure 2 shows the experimental and numerical temperature profiles of the hot, cooling and chilled water. After about 7mn, the hot water outlet temperature approaches to the inlet temperature, thus the heat consumed by the desorber after this point, will be quite small. But the difference between outlet and inlet temperature for the cooling water 1.8°C after cooling the adsorber for 7mn which shows that adsorber is sufficiently cooled down and the adsorption ability remains strong until the end of adsorption phase. Therefore the cycle time is taken as 14mn. It is worthy of note that the difference between outlet and inlet temperature of hot water after heating the desorber for 7mn is 3°C. It is also observed that the outlet temperature of chilled water reaches its minimum after each bed is heated/cooled for 50s. At this point the cooling power is at its maximum and the outlet temperature of chilled water is 11.8°C. The switching time is taken as 40s.

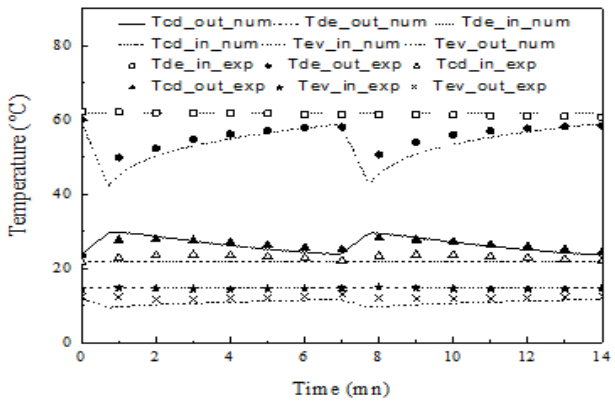


Fig. 2: Overall outlet temperature profile of heat transfer fluid for two beds adsorption chiller.

b) Parametric Study of the adsorption machine

Cooling / Heating/chilled water inlet temperature influences adsorption chiller performance. Lowering cooling water inlet temperature not only increases cooling capacity, but also enhances adsorption chiller COP, due to the significant increase in adsorption rate. Increasing heating water temperature also enhances chiller cooling capacity due to enhancing desorption rate that generate the adsorbed refrigerant prior to the evaporation/adsorption mode. However, it negatively influences the chiller COP depending on the cooling water inlet temperature.

- *Effect of hot water inlet temperature*

Figure 3 presents the change in chiller cooling capacity (SCP) and COP versus hot water inlet temperature at various cooling water inlet temperatures. Other operating conditions (cycle time, chilled water inlet temperature and secondary fluid flow rate) remain constant at their design values. As the hot water inlet temperature increases the chiller cooling capacity increases for all cooling water inlet temperatures. As for COP, with hot water temperature variation from 55 to 95 °C, COP increases. Because a higher hot water temperature causes a higher heating power as well as a higher refrigerating capacity. For temperatures below 85°C, remained relatively constant with the increase in the generation temperature, this is due to the insufficient refrigerant circulation required to generate the cooling power.

It is clear that the sorption process is much faster for the highest temperatures. This means that the increase of hot water inlet temperature allows an increase in the rate of desorption and thereafter a faster heat transfer that generates the refrigerant adsorbed before the evaporation / adsorption phase.

Lowering the cooling water temperature increases the specific cooling capacity and coefficient of performance, because the condensation is faster for lower condenser cooling water temperatures, also because of the increase in adsorption rate.

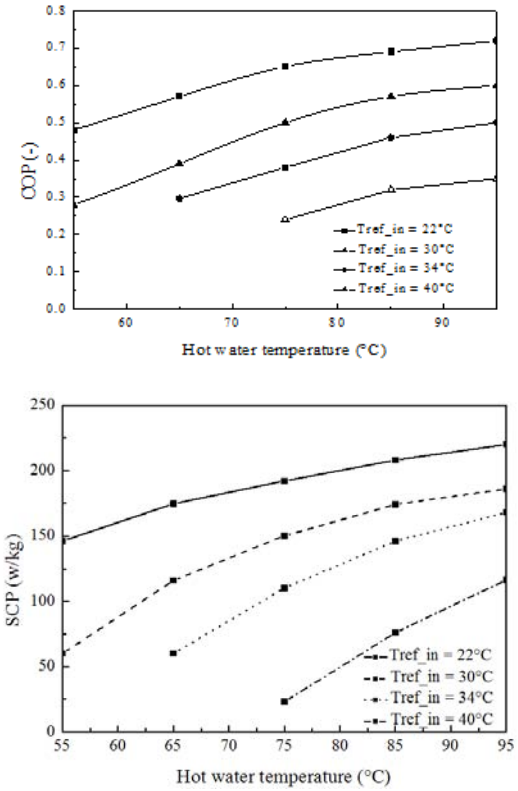


Fig. 3: Hot water inlet temperature influence on chiller COP and SCP (Tev_in=15°C, tcycle=840s).

Figure 4 shows the change in the outlet chilled temperature versus hot water inlet temperature for variable cooling water inlet temperature, there is a slight variation of the evaporator outlet temperature that decreases with an increasing the heating water temperature.

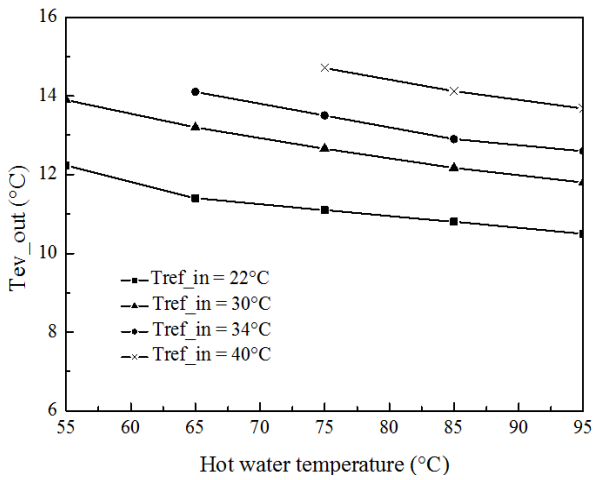


Fig. 4: Hot water inlet temperature influence on Tev_out (Tev_in=15°C, tcycle=840s).

The efficiency shows the ratio between the actual coefficient of performance and the Carnot cycle coefficient of performance ideal inverse (Figure 5).

The Carnot coefficient of performance is calculated by the following relation:

$$COP_{carnot} = \left[\frac{\overline{T_{ad}} - \overline{T_{de}}}{\overline{T_{de}}}\right] * \left[\frac{\overline{T_{ev}}}{\overline{T_{ad}} - \overline{T_{ev}}}\right] \quad (19)$$

The adsorption efficiency of the machine is determined by:

$$\eta = \frac{COP}{COP_{carnot}} \quad (20)$$

Efficiency increases with increasing hot water inlet temperature and lowering the cooling water inlet temperature.

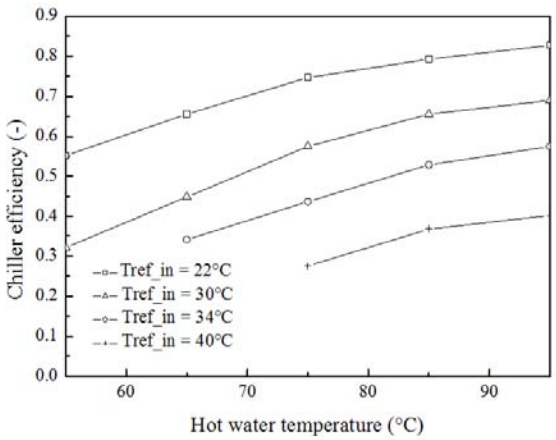


Fig. 5: Hot water inlet temperature influence on chiller efficiency (Tev_in=15°C, tcycle=840s).

- *Effect of chilled water inlet temperature*

In this part, the hot water inlet temperature is set at 85 ° C and the cooling water inlet temperature is 40 ° C (as Tunisian conditions), we will vary the chilled water inlet temperature and see the effect on the performance of the adsorption chiller.

Figure 6 shows the change in COP and SCP versus the inlet evaporator temperature, it is noted that for a variation of the latter to 20 ° C a variation of COP and SCP respectively 0.2 and 0.481 kW / kg; thus increasing the evaporator inlet temperature increases evaporation rates and then increase the cold production thus increasing system performance.

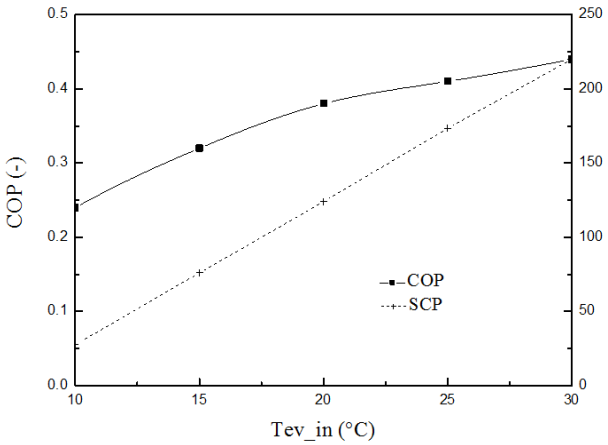


Fig. 6: Effect of chilled water inlet temperature on COP and SCP (Tref_in=40°C, Tde_in=85°C, tcycle=840s).

Figure 7 shows the chilled water outlet temperature against its inlet temperature. It is found that the temperature difference between inlet and outlet are kept in constant, which means they are in linear relationship, for an inlet chilled water temperature of 30 ° C we can have a chilled outlet temperature of 27 ° C.

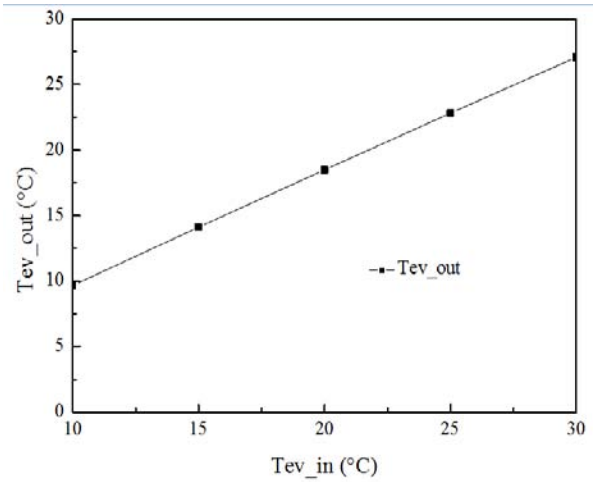


Fig. 7: The relationship between chilled water outlet temperature and inlet temperature. (Tref_in=40°C, Tde_in=85°C, tcycle=840s).

- *Effect of cycle time*

The refrigeration capacity and COP variations with the cycle time are shown in Figure 8, the Operating conditions are setting en table 1. The COP increases uniformly with extension of the cycle time under a driving heat source of 85°C. This is because a longer cycle time causes much lower consumption of driving heat, the

maximum COP can be obtained at maximum adsorption / desorption time, which correspond to the minimum heating capacity and maximum adsorbed refrigerant amount. Based on the aforementioned results, the aim is to have a short cycle time with a reasonable performance, so the optimal time 1240s cycle can be a tool to optimize adsorption system.

Table 1: Operating conditions

Tde_in	Tref_in	Tev_in	Total cycle time
85 °C	40 °C	15 °C	640-1400 s
Pre-heating/cooling time	Hot water flow rate	Cooling water flow rate	Chilled water flow rate
40 s	1.6 m3/h	3.7 m3/h	2 m3/h

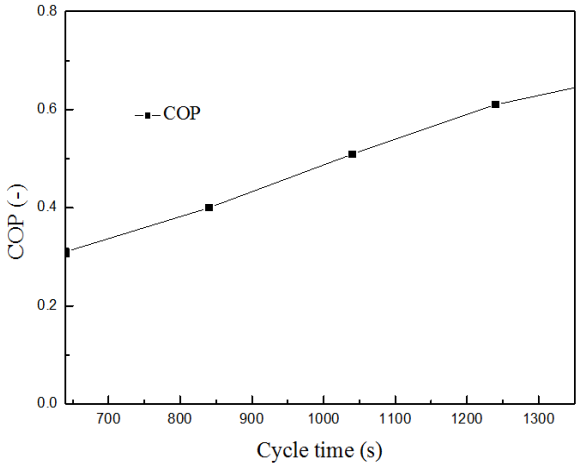
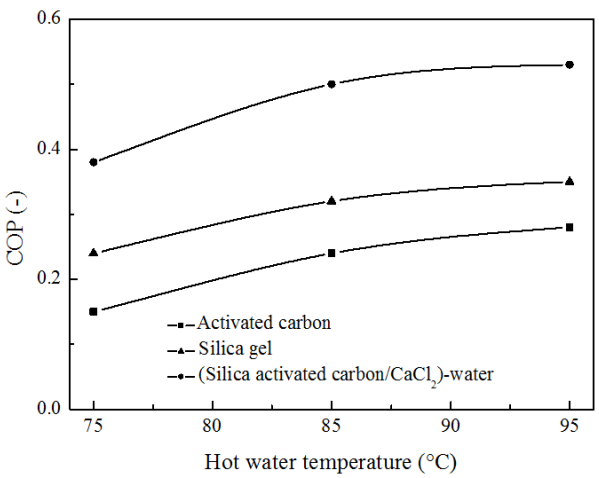


Fig. 8: Effect of cycle time on the COP (Tde_in=85°C, Tref_in=40°C, Tev_in=15°C).

Figures 9 present the variation of COP and SCP according to the hot water inlet temperature. Indeed, water vapor is desorbed rapidly to a higher regeneration temperature to desorb most of the water vapor to be adsorbed in the next adsorption process.

Curves COP and the SCP for different adsorbents; silica gel, activated carbon and adsorbent composite (silica activated carbon/$CaCl_2$)/eau, shows that for adsorbent composite, the COP and SCP is greater.



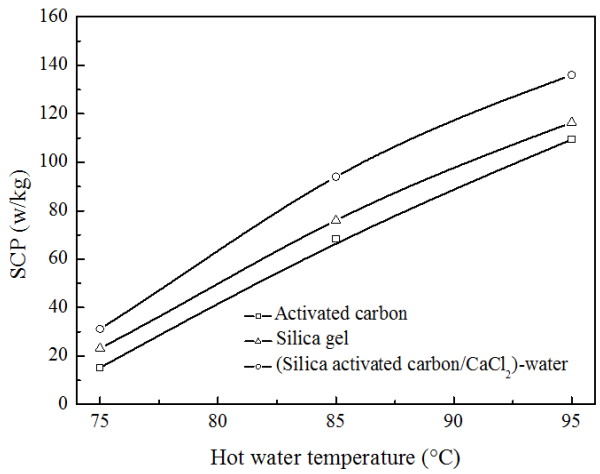


Fig. 9: Hot water inlet temperature influence on chiller COP and SCP (Tcycle=840s, Tref_in=40°C, Tev_in=15°C).

V. Conclusion

This work presents a solar adsorption refrigeration system using silica gel / water pairs. We have developed a numerical model for simulating the heat and mass transfer of the adsorption and regeneration processes in the two beds. This allowed us to study the influence of the regeneration, cooling and evaporator inlet temperature on the performance of the machine. The results show that the study parameters have a great impact on system performance for its adaptation to the Tunisian climate. It is preferable to work with a high regeneration and evaporation temperature where the coefficient of performance reaches its maximum value and a lower temperature at the cooling water of condenser and adsorber. The adaptation of chiller to the Tunisian climate was made. for a hot water inlet temperature of 85°C and a cooling water inlet temperature of 40°C we had a COP=0,3 and an SCP= 57 W/kg.

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Nomenclature

A	Heat transfer area, m^2
Cp	Specific heat, kJ/kg.K
DS0	Coefficient, (m^2/s)
E	Heat exchanger efficiency:
L	Latent heat of vaporization, kJ/kg
m	Masse, kg
$\acute{m}_f$	Mass flow rate, kg/s
ΔH	Isosteric heat of adsorption, kJ/kg
P	Pressure, Pa
Q	heat, kJ
SCP	Specific cooling power, kW/kg
t	Time, s

T Temperatures, °C
U Overall conductance, $W/m^2.K$
$w, w*$ Instantaneous Uptake, Equilibrium uptake, kg de réfrigérant/kg d'adsorbant
COP Coefficient of performance of the machine

Subscripts

a Adsorbent (silica gel)
ad Adsorber
ads Adsorption
cd Condenser
cycle Cycle
ev Evaporator
de Desorber
f Coolant
in Inlet
j Coolant indice
max Maximum
min Minimum
num Numerical
out Outlet
r Refrigerant
r,v Refrigerant vapor
v Vapor

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The IBOARS can initially review research papers of their institute and recommend them to publish with respective journal of Global Journals. It can also review the papers of other institutions after obtaining our consent. The second review will be done by peer reviewer of Global Journals Incorporation (USA) The Board is at liberty to appoint a peer reviewer with the approval of chairperson after consulting us.

The author fees of such paper may be waived off up to 40%.

The Global Journals Incorporation (USA) at its discretion can also refer double blind peer reviewed paper at their end to the board for the verification and to get recommendation for final stage of acceptance of publication.

The IBOARS can organize symposium/seminar/conference in their country on behalf of Global Journals Incorporation (USA)-OARS (USA). The terms and conditions can be discussed separately.

The Board can also play vital role by exploring and giving valuable suggestions regarding the Standards of "Open Association of Research Society, U.S.A (OARS)" so that proper amendment can take place for the benefit of entire research community. We shall provide details of particular standard only on receipt of request from the Board.

The board members can also join us as Individual Fellow with 40% discount on total fees applicable to Individual Fellow. They will be entitled to avail all the benefits as declared. Please visit Individual Fellow-sub menu of GlobalJournals.org to have more relevant details.

We shall provide you intimation regarding launching of e-version of journal of your stream time to time. This may be utilized in your library for the enrichment of knowledge of your students as well as it can also be helpful for the concerned faculty members.

After nomination of your institution as "Institutional Fellow" and constantly functioning successfully for one year, we can consider giving recognition to your institute to function as Regional/Zonal office on our behalf.
The board can also take up the additional allied activities for betterment after our consultation.

The following entitlements are applicable to individual Fellows:

Open Association of Research Society, U.S.A (OARS) By-laws states that an individual Fellow may use the designations as applicable, or the corresponding initials. The Credentials of individual Fellow and Associate designations signify that the individual has gained knowledge of the fundamental concepts. One is magnanimous and proficient in an expertise course covering the professional code of conduct, and follows recognized standards of practice.

Open Association of Research Society (US)/ Global Journals Incorporation (USA), as described in Corporate Statements, are educational, research publishing and professional membership organizations. Achieving our individual Fellow or Associate status is based mainly on meeting stated educational research requirements.

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We shall provide print version of 12 issues of any three journals [as per your requirement] out of our 38 journals worth $ 2376 USD.

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- The professional accredited with Fellow honor, is entitled to various benefits viz. name, fame, honor, regular flow of income, secured bright future, social status etc.

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- The Fellow can organize symposium/seminar/conference on behalf of Global Journals Incorporation (USA) and he/she can also attend the same organized by other institutes on behalf of Global Journals.
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- • This individual has learned the basic methods of applying those concepts and techniques to common challenging situations. This individual has further demonstrated an in–depth understanding of the application of suitable techniques to a particular area of research practice.

Note :

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- In future, if the board feels the necessity to change any board member, the same can be done with the consent of the chairperson along with anyone board member without our approval.
- In case, the chairperson needs to be replaced then consent of 2/3rd board members are required and they are also required to jointly pass the resolution copy of which should be sent to us. In such case, it will be compulsory to obtain our approval before replacement.
- In case of "Difference of Opinion [if any]" among the Board members, our decision will be final and binding to everyone.

"

Process of submission of Research Paper

The Area or field of specialization may or may not be of any category as mentioned in 'Scope of Journal' menu of the GlobalJournals.org website. There are 37 Research Journal categorized with Six parental Journals GJCST, GJMR, GJRE, GJMBR, GJSFR, GJHSS. For Authors should prefer the mentioned categories. There are three widely used systems UDC, DDC and LCC. The details are available as 'Knowledge Abstract' at Home page. The major advantage of this coding is that, the research work will be exposed to and shared with all over the world as we are being abstracted and indexed worldwide.

The paper should be in proper format. The format can be downloaded from first page of 'Author Guideline' Menu. The Author is expected to follow the general rules as mentioned in this menu. The paper should be written in MS-Word Format (*.DOC,*.DOCX).

The Author can submit the paper either online or offline. The authors should prefer online submission.Online Submission: There are three ways to submit your paper:

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You can use your own standard format also.
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1. General,

2. Ethical Guidelines,

3. Submission of Manuscripts,

4. Manuscript's Category,

5. Structure and Format of Manuscript,

6. After Acceptance.

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Research letters: The letters are small and concise comments on previously published matters.

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The recommended size of original research paper is less than seven thousand words, review papers fewer than seven thousands words also.Preparation of research paper or how to write research paper, are major hurdle, while writing manuscript. The research articles and research letters should be fewer than three thousand words, the structure original research paper; sometime review paper should be as follows:

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(g) Discussion should cover the implications and consequences, not just recapitulating the results; conclusions should be summarizing.

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It is vital, that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

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A major linchpin in research work for the writing research paper is the keyword search, which one will employ to find both library and Internet resources.

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- One should avoid outdated words.

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Numerical Methods: Numerical methods used should be clear and, where appropriate, supported by references.

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References

References follow the Harvard scheme of referencing. References in the text should cite the authors' names followed by the time of their publication, unless there are three or more authors when simply the first author's name is quoted followed by et al. unpublished work has to only be cited where necessary, and only in the text. Copies of references in press in other journals have to be supplied with submitted typescripts. It is necessary that all citations and references be carefully checked before submission, as mistakes or omissions will cause delays.

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24. Never copy others' work: Never copy others' work and give it your name because if evaluator has seen it anywhere you will be in trouble.

25. Take proper rest and food: No matter how many hours you spend for your research activity, if you are not taking care of your health then all your efforts will be in vain. For a quality research, study is must, and this can be done by taking proper rest and food.

26. Go for seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

27. Refresh your mind after intervals: Try to give rest to your mind by listening to soft music or by sleeping in intervals. This will also improve your memory.

28. Make colleagues: Always try to make colleagues. No matter how sharper or intelligent you are, if you make colleagues you can have several ideas, which will be helpful for your research.

29. Think technically: Always think technically. If anything happens, then search its reasons, its benefits, and demerits.

30. Think and then print: When you will go to print your paper, notice that tables are not be split, headings are not detached from their descriptions, and page sequence is maintained.

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33. Report concluded results: Use concluded results. From raw data, filter the results and then conclude your studies based on measurements and observations taken. Significant figures and appropriate number of decimal places should be used. Parenthetical remarks are prohibitive. Proofread carefully at final stage. In the end give outline to your arguments. Spot out perspectives of further study of this subject. Justify your conclusion by at the bottom of them with sufficient justifications and examples.

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Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form, which is presented in the guidelines using the template.
- Please note the criterion for grading the final paper by peer-reviewers.

Final Points:

A purpose of organizing a research paper is to let people to interpret your effort selectively. The journal requires the following sections, submitted in the order listed, each section to start on a new page.

The introduction will be compiled from reference matter and will reflect the design processes or outline of basis that direct you to make study. As you will carry out the process of study, the method and process section will be constructed as like that. The result segment will show related statistics in nearly sequential order and will direct the reviewers next to the similar intellectual paths throughout the data that you took to carry out your study. The discussion section will provide understanding of the data and projections as to the implication of the results. The use of good quality references all through the paper will give the effort trustworthiness by representing an alertness of prior workings.

Writing a research paper is not an easy job no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record keeping are the only means to make straightforward the progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear

· Adhere to recommended page limits

Mistakes to evade

- Insertion a title at the foot of a page with the subsequent text on the next page
- Separating a table/chart or figure - impound each figure/table to a single page
- Submitting a manuscript with pages out of sequence

In every sections of your document

· Use standard writing style including articles ("a", "the," etc.)

· Keep on paying attention on the research topic of the paper

· Use paragraphs to split each significant point (excluding for the abstract)

· Align the primary line of each section

· Present your points in sound order

· Use present tense to report well accepted

· Use past tense to describe specific results

· Shun familiar wording, don't address the reviewer directly, and don't use slang, slang language, or superlatives

· Shun use of extra pictures - include only those figures essential to presenting results

Title Page:

Choose a revealing title. It should be short. It should not have non-standard acronyms or abbreviations. It should not exceed two printed lines. It should include the name(s) and address (es) of all authors.

Abstract:

The summary should be two hundred words or less. It should briefly and clearly explain the key findings reported in the manuscript--must have precise statistics. It should not have abnormal acronyms or abbreviations. It should be logical in itself. Shun citing references at this point.

An abstract is a brief distinct paragraph summary of finished work or work in development. In a minute or less a reviewer can be taught the foundation behind the study, common approach to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Yet, use comprehensive sentences and do not let go readability for briefness. You can maintain it succinct by phrasing sentences so that they provide more than lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study, with the subsequent elements in any summary. Try to maintain the initial two items to no more than one ruling each.

- Reason of the study - theory, overall issue, purpose
- Fundamental goal
- To the point depiction of the research
- Consequences, including definite statistics - if the consequences are quantitative in nature, account quantitative data; results of any numerical analysis should be reported
- Significant conclusions or questions that track from the research(es)

Approach:

- Single section, and succinct
- As a outline of job done, it is always written in past tense
- A conceptual should situate on its own, and not submit to any other part of the paper such as a form or table
- Center on shortening results - bound background information to a verdict or two, if completely necessary
- What you account in an conceptual must be regular with what you reported in the manuscript
- Exact spelling, clearness of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else

Introduction:

The **Introduction** should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable to comprehend and calculate the purpose of your study without having to submit to other works. The basis for the study should be offered. Give most important references but shun difficult to make a comprehensive appraisal of the topic. In the introduction, describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will have no attention in your result. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here. Following approach can create a valuable beginning:

- Explain the value (significance) of the study
- Shield the model - why did you employ this particular system or method? What is its compensation? You strength remark on its appropriateness from a abstract point of vision as well as point out sensible reasons for using it.
- Present a justification. Status your particular theory (es) or aim(s), and describe the logic that led you to choose them.
- Very for a short time explain the tentative propose and how it skilled the declared objectives.

Approach:

- Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done.
- Sort out your thoughts; manufacture one key point with every section. If you make the four points listed above, you will need a least of four paragraphs.

- Present surroundings information only as desirable in order hold up a situation. The reviewer does not desire to read the whole thing you know about a topic.
- Shape the theory/purpose specifically - do not take a broad view.
- As always, give awareness to spelling, simplicity and correctness of sentences and phrases.

Procedures (Methods and Materials):

This part is supposed to be the easiest to carve if you have good skills. A sound written Procedures segment allows a capable scientist to replacement your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt for the least amount of information that would permit another capable scientist to spare your outcome but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section. When a technique is used that has been well described in another object, mention the specific item describing a way but draw the basic principle while stating the situation. The purpose is to text all particular resources and broad procedures, so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step by step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

- Explain materials individually only if the study is so complex that it saves liberty this way.
- Embrace particular materials, and any tools or provisions that are not frequently found in laboratories.
- Do not take in frequently found.
- If use of a definite type of tools.
- Materials may be reported in a part section or else they may be recognized along with your measures.

Methods:

- Report the method (not particulars of each process that engaged the same methodology)
- Describe the method entirely
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures
- Simplify - details how procedures were completed not how they were exclusively performed on a particular day.
- If well known procedures were used, account the procedure by name, possibly with reference, and that's all.

Approach:

- It is embarrassed or not possible to use vigorous voice when documenting methods with no using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result when script up the methods most authors use third person passive voice.
- Use standard style in this and in every other part of the paper - avoid familiar lists, and use full sentences.

What to keep away from

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings - save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part a entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Carry on to be to the point, by means of statistics and tables, if suitable, to present consequences most efficiently.You must obviously differentiate material that would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matter should not be submitted at all except requested by the instructor.

Content

- Sum up your conclusion in text and demonstrate them, if suitable, with figures and tables.
- In manuscript, explain each of your consequences, point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation an exacting study.
- Explain results of control experiments and comprise remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or in manuscript form.

What to stay away from

- Do not discuss or infer your outcome, report surroundings information, or try to explain anything.
- Not at all, take in raw data or intermediate calculations in a research manuscript.
- Do not present the similar data more than once.
- Manuscript should complement any figures or tables, not duplicate the identical information.
- Never confuse figures with tables - there is a difference.

Approach

- As forever, use past tense when you submit to your results, and put the whole thing in a reasonable order.
- Put figures and tables, appropriately numbered, in order at the end of the report
- If you desire, you may place your figures and tables properly within the text of your results part.

Figures and tables

- If you put figures and tables at the end of the details, make certain that they are visibly distinguished from any attach appendix materials, such as raw facts
- Despite of position, each figure must be numbered one after the other and complete with subtitle
- In spite of position, each table must be titled, numbered one after the other and complete with heading
- All figure and table must be adequately complete that it could situate on its own, divide from text

Discussion:

The Discussion is expected the trickiest segment to write and describe. A lot of papers submitted for journal are discarded based on problems with the Discussion. There is no head of state for how long a argument should be. Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implication of the study. The purpose here is to offer an understanding of your results and hold up for all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of result should be visibly described. Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved with prospect, and let it drop at that.

- Make a decision if each premise is supported, discarded, or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."
- Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work
- You may propose future guidelines, such as how the experiment might be personalized to accomplish a new idea.
- Give details all of your remarks as much as possible, focus on mechanisms.
- Make a decision if the tentative design sufficiently addressed the theory, and whether or not it was correctly restricted.
- Try to present substitute explanations if sensible alternatives be present.
- One research will not counter an overall question, so maintain the large picture in mind, where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

- When you refer to information, differentiate data generated by your own studies from available information
- Submit to work done by specific persons (including you) in past tense.
- Submit to generally acknowledged facts and main beliefs in present tense.

Please carefully note down following rules and regulation before submitting your Research Paper to Global Journals Inc. (US):

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Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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