

# Software program for computing coulombic efficiency and power densities generated by microbial fuel cells through treating livestock slurry and wastewater

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**Abstract:** To perform the calculations of the coulombic efficiency, areal and volumetric power densities generated by microbial fuel cells (MFCs), several procedures should be accomplished; this necessitates long period and efforts, beside the probability of committing errors. This article aims at developing a tool to support users, engineers, and specialists in performing these computations by developing a desktop software that can run on laptops and computers. A mathematical model was developed to perform the calculations. Next, a flowchart was generated, and the mathematical model was incorporated in the flowchart. Then, Microsoft Visual FoxPro 9.0 Service Pack 2.0 was implemented to configure the software by combining the flowchart, mathematical model, and interface creation. Data were obtained from government associations, wastewater treatment plants, non-governmental organizations (NGOs), and literature. The data obtained for performing the calculations in the traditional way were utilized to generate output data which were matched with the output data obtained from the software. The results of both the traditional method and the program were congruous. The software is able to calculate the coulombic efficiency, area and volumetric energy density of MFCs by processing various feedstocks such as livestock manure and wastewater.

**Keywords:** microbial fuel cells, software, programming, wastewater treatment, manure management, electricity generation

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## 1 Introduction

The wastewater is classified into the following categories: (1) domestic or municipal wastewater, which is also called sewage or sewer water; (2) agricultural wastewater such as livestock slurry; and (3) agro-industrial wastewater such as whey which is disposed by the dairy industries as by-product, and

several other types of wastes disposed by the different food processing industries such as palm oil mill effluent, etc (Samer, 2015a, 2015b).

Several treatment methods used in conventional wastewater treatment (Turcios and Papenbrock, 2014). Domestic and industrial wastewaters arriving to the wastewater treatment plants were characterized by irregularity in the quantity and kind of the pollutants (Prokopov et al., 2014). Physical, chemical, and biological treatment were used in conventional wastewater plants, physical treatment such as sedimentation to remove large solid particles, biological processes such as oxidation (Doan and

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Lohi, 2009) and biological filtration, (Samdani and Choudhary, 2017). Finally, chemical processes such as precipitation, neutralization, chlorination, and disinfection (Burievich and Tolibovich, 2020).

Microbial fuel cell (MFC) is a novel bioelectrochemical technology which is able of decaying organic matter including an instantaneous electricity production by microorganisms (Slate et al., 2019; Liu et al., 2020). MFC is a distinctive sustainable technology that is able of treating wastewater and produce electricity due to biodegradation of various organic complexes. MFC has been acknowledged as a prospective technology for the combination of electricity production with wastewater treatment. MFC relies on exo-electrogenic microorganisms to catalyze the electrochemical bioreactions taking place on the electrode surfaces (Moustafa et al., 2021). Bacteria are employed in MFCs to generate electricity while performing the biodegradation of organic compounds or biowastes (Oh and Logan, 2005). MFCs contain cathode and anode compartments separated by a proton exchange membrane (PEM) or a salt bridge.

MFCs had different types, though, the plain designs used in the laboratories include double-chamber MFC, single-chamber MFC, up flow MFC and stacked MFC (Kumar et al., 2017). Different types of MFCs were be mentioned in previous studies: flat MFC (Cristiani et al., 2019), single chambered (Washington et al., 2017; Masoom et al., 2021), and double chambered MFCs (Shaheen et al, 2013; Attia et al., 2024a,b).

Microorganisms available in the anode chamber of a MFC oxidize the feedstocks and generate protons and electrons. The electrons are attracted by the anode and are transmitted to the cathode via an electric circuit. The hydrogen protons travel through the cathode compartment and combine with O<sub>2</sub> to form H<sub>2</sub>O after traversing the PEM (Rabaey and Verstraete, 2005; Moustafa et al., 2021). The electric current creation is achieved by separating microorganisms from O<sub>2</sub> and this necessitates an

anaerobic anode compartment (Goswami and Mishra, 2018). MFCs are desirable to generate bioelectricity by exploiting numerous biowastes (Khera and Chandra, 2012). The MFC is an apparatus that implements bioactivities to produce electricity from organic compounds (Logan and Regan, 2006). Within the MFCs, the modification of accumulated energy in biochemical bonds of organic compounds into electricity is achieved by microbial bioreactions. Generally, bioreaction is bioconversion of the substratum into CO<sub>2</sub> and H<sub>2</sub>O with an accompanying generation of electricity. The MFCs are able to generate electrical energy using the electrons current from the anode to the cathode in the electric circuit (Du et al., 2007; Goswami and Mishra, 2018). There are various advantages of MFCs over biogas technology. First, electrical energy is the most appropriate form of power for several industrial and social activities. Second, MFCs are beneficial to certain types of wastewaters which are unsuitable for biogas processes, and wastewater with BODs lower than 500 mg per liter (Rittmann, 2008; Moustafa et al., 2021).

Recent developments in the realm of microbial fuel cells are centered around the incorporation of innovative technologies such as (Moustafa et al., 2021), nanotechnology (Attia et al., 2018, 2021; Abdelsalam and Samer, 2019; Samer et al., 2021), laser radiation (Abdelsalam and Samer et al., 2019; Abdelsalam et al., 2021), and the utilization of life cycle analysis (LCA) and environmental impact assessment (EIA) with specialized software (Abdelsalam and Hijazi et al., 2019; Hijazi, et al., 2020b; Hijazi, et al., 2020a; Samer and Hijazi et al., 2021; Alengebawy et al., 2022). These novel approaches necessitate extensive computations that can be facilitated through a newly designed software application suitable for installation on personal computing devices.

The software applications utilize symbolic representations of scenarios and heuristics to replicate the cognitive processes of professionals. The primary

role of an IT and AI engineer is to capture the heuristics and reasoning methodologies of experts when executing complex problem-solving tasks and represent them through electronic diagrams such as flowcharts, specifically decision trees (Broner et al., 1990; Greer et al., 1994; Samer et al., 2011, 2022, 2023a,b). The diverse range of tasks carried out by software applications encompasses various functions (Giarratano and Riley, 2005; Samer, 2010; Samer et al., 2012). The combination of mathematical models with software programs is referred to as hybrid systems. Hybrid systems offer the advantage of providing quantitative data through simulations for the software, thereby supplying crucial parameters (Greer et al., 1994; Samer et al., 2013). Typical configuration of a software application consists of a computer program containing a set of algorithms that analyze input data by user related to a specific issue (Yoo, 1989; Giarratano and Riley, 2005; Samer et al., 2019).

The objective is to develop desktop software to perform computations on laptops and personal computers. To be precise, the software computes the coulombic efficiency, areal and volumetric power densities generated by the MFCs.

Programming concepts are manifested in software that has been customized by utilizing two programming paradigms. The initial paradigm involves the application of structured system analysis and design techniques, which focus on the technical aspects of software customization. The second paradigm entails the utilization of Microsoft Visual FoxPro 9.0 - Service Pack 2.0 to create a barrier between the program and specific procedures.

## 2 Materials and methods

### 2.1 Knowledge acquisition

The simulation models were created using the variables, factors, parameters, and constants of the MFCs accessible in the literature (Alzate-Gaviria, 2011; Liu et al., 2005; Tao et al., 2015; Moustafa et al., 2021). Additionally, communications were created with experts in the following Egyptian

institutions to mimic their expertise reasoning and employing it in developing the structured induction of the software:

- (1) Ministry of Environment and Egyptian Environmental Affairs Agency
- (2) Ministry of Agriculture and Land Reclamation (livestock manure is one of the MFCs feedstocks)
- (3) National Research Center
- (4) New and Renewable Energy Authority
- (5) Corporation of Bioenergy for Sustainable Rural Development
- (6) Several wastewater treatment units

After amassing a substantial amount of data and information, a software application was created to aid users, engineers, and experts in analyzing the performance metrics, variables, and characteristics of microbial fuel cells. This software can be installed on personal computers and laptops. Its primary function is to calculate the coulombic efficiency, as well as the areal and volumetric power densities produced by microbial fuel cells. As a result, this computational tool serves as an advanced system that utilizes expertise, logic, and cognitive processes to address complex issues that require significant knowledge to resolve. By employing symbolic representations of knowledge and rules of thumb, this software emulates the logical reasoning employed by professionals. The merging of mathematical models with software applications is commonly referred to as hybrid systems. The advantage of utilizing hybrid systems lies in their ability to provide both qualitative and quantitative data to the software, thereby furnishing essential parameters for the simulation models.

### 2.2 Data acquisition

The data utilized in the configuration of the software were obtained from the aforementioned institutions. Displayed in Table 1 are the acquired data utilized in the validation and assessment of the developed software. The shaded columns in gray represent the output data, which are the computed data. Conversely, the unshaded columns denote the input data.

**Table 1 The coulombic efficiency (CE), voltage (V), electric current (I), electric resistance (R), power (P), substrate volume (v), volumetric power (P<sub>D</sub>), surface area of the anode (A), aerial power density (P<sub>AD</sub>) of different lab-scale microbial fuel cells**

Microbial Fuel Cell	CE (%)	V (V)	I (A)	R (kΩ)	P (W)	v (m <sup>3</sup> )	P <sub>D</sub> (mW/m <sup>3</sup> )	A (m <sup>2</sup> )	P <sub>AD</sub> (mW/m <sup>2</sup> )
1	8.54	0.616	0.770E-05		0.47432E-05		3.20		23.60
2	9.33	0.650	0.813E-05		0.52877E-05		3.53		26.31
3	8.12	0.623	0.779E-05		0.48547E-05		3.24		24.15
4	8.78	0.613	0.766E-05	80	0.46941E-05	1.50E-03	3.13	2.01E-04	23.35
5	8.95	0.641	0.801E-05		0.51328E-05		3.42		25.57
6	9.14	0.652	0.815E-05		0.53138E-05		3.54		26.44
7	9.09	0.630	0.788E-05		0.49675E-05		3.31		24.71

**2.3 Programming**

Microsoft Visual FoxPro 9.0 Service Pack 2.0 was employed in the creation of a software application through the amalgamation of the flowchart and the mathematical model alongside the development of the user interface. The developed software consisted of a total of 8 programming nodes (Tables 2 through 9) structured within 7 codes

(Figures 1 through 7). Tables 2 through 9 delineate the programming syntax of key components such as the main form unit, model selection, addition of new elements, data loading, computation, data exportation, return to the main interface, and program termination. Conversely, Table 10 exhibits the instruments utilized during the programming of the said application.

**Table 2 Main form unit**

```
thisform.pageframe1.ActivePage=1
thisform.container1.Visible= .T.
myselection=1
thisform.image2.Picture=(SYS(5)+SYS(2003)+"\images\coulombic efficiency pic.png")
thisform.image2.Visible= .T.
```

**Table 3 Model selection**

```
thisform.pageframe1.ActivePage=1
thisform.container1.Visible= .T.
myselection=1
thisform.image2.Picture=(SYS(5)+SYS(2003)+"\images\coulombic efficiency pic.png")
thisform.image2.Visible= .T.
thisform.pageframe1.ActivePage=1
thisform.container1.Visible= .T.
myselection=1
thisform.image2.Picture=(SYS(5)+SYS(2003)+"\images\coulombic efficiency pic.png")
thisform.image2.Visible= .T.
```

**Table 4 “Add New” as one of the tools for model data control**

```
IF myselection=1
    thisform.pageframe1.page1.h3.Value=0
    thisform.pageframe1.page1.j3.Value=0
    thisform.pageframe1.page1.h5.Value=0
    thisform.pageframe1.page1.h7.Value=0
    thisform.pageframe1.page1.j7.Value=0
    thisform.pageframe1.page1.f12.Value=0
    thisform.pageframe1.page1.i12.Value=0
    thisform.pageframe1.page1.g20.Value=0
    thisform.pageframe1.page1.h3.Enabled= .T.
    thisform.pageframe1.page1.j3.Enabled= .T.
    thisform.pageframe1.page1.h5.Enabled= .T.
    thisform.pageframe1.page1.h7.Enabled= .T.
```

```

thisform.pageframe1.page1.j7.Enabled= .T.
thisform.pageframe1.page1.f12.Enabled= .T.
thisform.pageframe1.page1.h3.SetFocus
thisform.pageframe1.page1.ref.Caption="-----"
ENDIF

IF myselection=2
    thisform.pageframe1.page2.h2.Value=0
    thisform.pageframe1.page2.q2.Value=0
    thisform.pageframe1.page2.h10.Value=0
    thisform.pageframe1.page2.b20.Value=0
    thisform.pageframe1.page2.k17.Value=0
    thisform.pageframe1.page2.q17.Value=0
    thisform.pageframe1.page2.g28.Value=0
    thisform.pageframe1.page2.p28.Value=0
    thisform.pageframe1.page2.h2.Enabled= .T.
    thisform.pageframe1.page2.q2.Enabled= .T.
    thisform.pageframe1.page2.k17.Enabled= .T.
    thisform.pageframe1.page2.q17.Enabled= .T.
    thisform.pageframe1.page2.h2.SetFocus
    thisform.pageframe1.page2.ref.Caption="-----"
ENDIF

```

---

**Table 5 “Load Data” as one of the tools for model data control**

---

```

lcOldDefault = (SYS(5)+SYS(2003))

IF myselection=1
SET DEFAULT TO (SYS(5) + SYS(2003)+"\outputs\MFCs\')
ofile=GETFILE('xlsx,xls,XLSX,XLS', 'Browse Excel Files:')
SET DEFAULT TO (lcOldDefault)
IF EMPTY(ofile)
    MessageBox("You didn't select any file !", "", 0)
ELSE
    lo_Workbook = lo_Excel.Application.Workbooks.Open(ofile)
    WITH lo_excel
        thisform.pageframe1.page1.H3.Value=.Range("C2").Value
        thisform.pageframe1.page1.j3.Value=.Range("G2").Value
        thisform.pageframe1.page1.h5.Value=.Range("C4").Value
        thisform.pageframe1.page1.h7.Value=.Range("C6").Value
        thisform.pageframe1.page1.j7.Value=.Range("G6").Value
        thisform.pageframe1.page1.f12.Value=.Range("C9").Value
        thisform.pageframe1.page1.i12.Value=.Range("E10").Value
        thisform.pageframe1.page1.g20.Value=.Range("E18").Value
    ENDWITH
    thisform.pageframe1.page1.h3.Enabled= .T.
    thisform.pageframe1.page1.j3.Enabled= .T.
    thisform.pageframe1.page1.h5.Enabled= .T.
    thisform.pageframe1.page1.h7.Enabled= .T.
    thisform.pageframe1.page1.j7.Enabled= .T.
    thisform.pageframe1.page1.f12.Enabled= .T.
    thisform.pageframe1.page1.h3.SetFocus
    thisform.pageframe1.page1.ref.Caption=justFName(ofile)
    lo_Workbook.Close()
ENDIF

ENDIF

IF myselection=2
SET DEFAULT TO (SYS(5) + SYS(2003)+"\outputs\Electric Circuit\')
ofile=GETFILE('xlsx,xls,XLSX,XLS', 'Browse Excel Files:')
SET DEFAULT TO (lcOldDefault)
IF EMPTY(ofile)
    MessageBox("You didn't select any file !", "", 0)

```

---

```

ELSE
lo_Workbook = lo_Excel.Application.Workbooks.Open(ofile)
WITH lo_excel
thisform.pageframe1.page2.h2.Value=.Range("h2").Value
thisform.pageframe1.page2.q2.Value=.Range("q2").Value
thisform.pageframe1.page2.h10.Value=.Range("h10").Value
thisform.pageframe1.page2.b20.Value=.Range("b20").Value
thisform.pageframe1.page2.k17.Value=.Range("k17").Value
thisform.pageframe1.page2.q17.Value=.Range("q17").Value
thisform.pageframe1.page2.g28.Value=.Range("g28").Value
thisform.pageframe1.page2.p28.Value=.Range("p28").Value
ENDWITH
thisform.pageframe1.page2.h2.Enabled= .T.
thisform.pageframe1.page2.q2.Enabled= .T.
thisform.pageframe1.page2.k17.Enabled= .T.
thisform.pageframe1.page2.q17.Enabled= .T.
thisform.pageframe1.page2.h2.SetFocus
thisform.pageframe1.page2.ref.Caption=justFName(ofile)
lo_Workbook.Close()
ENDIF

ENDIF

```

---

**Table 6 “Calculate” as one of the tools for model data control**

---

```

IF myselection=1
IF thisform.pageframe1.page1.h3.Value=0 or;
thisform.pageframe1.page1.j3.Value=0 or;
thisform.pageframe1.page1.h5.Value=0 or;
thisform.pageframe1.page1.h7.Value=0 or;
thisform.pageframe1.page1.j7.Value=0 or;
thisform.pageframe1.page1.f12.Value=0
MessageBox("Please Add Missing Values", "Missing Values", 0)
thisform.pageframe1.page1.h3.SetFocus
else
thisform.pageframe1.page1.i12.Value=((thisform.pageframe1.page1.h3.Value*thisform.pageframe1.page1.h5.Value*thisform.pageframe1.page1.j3.Value*thisform.pageframe1.page1.j7.Value)/(thisform.pageframe1.page1.h7.Value))
thisform.pageframe1.page1.g20.Value=((thisform.pageframe1.page1.f12.Value/thisform.pageframe1.page1.i12.Value)*100)
endif

ENDIF

IF myselection=2
IF thisform.pageframe1.page2.h2.Value=0 or;
thisform.pageframe1.page2.q2.Value=0 or;
thisform.pageframe1.page2.k17.Value=0 or;
thisform.pageframe1.page2.q17.Value=0
MessageBox("Please Add Missing Values", "Missing Values", 0)
thisform.pageframe1.page2.h2.SetFocus
else
thisform.pageframe1.page2.h10.Value=(thisform.pageframe1.page2.h2.Value*thisform.pageframe1.page2.q2.Value)
thisform.pageframe1.page2.b20.Value=(thisform.pageframe1.page2.h2.Value*thisform.pageframe1.page2.h10.Value)
thisform.pageframe1.page2.g28.Value=(thisform.pageframe1.page2.b20.Value/thisform.pageframe1.page2.k17.Value)
thisform.pageframe1.page2.p28.Value=(thisform.pageframe1.page2.b20.Value/thisform.pageframe1.page2.q17.Value)
endif

ENDIF

```

---

**Table 7 “Export Data” as one of the tools for model data control**

---

```

IF myselection=1
lo_Workbook = lo_Excel.Application.Workbooks.Open(sys(5)+sys(2003)+"\temp\"+"MCFsTemplate")
WITH lo_excel
.Range("C2").Value=thisform.pageframe1.page1.h3.Value
.Range("G2").Value=thisform.pageframe1.page1.j3.value
.Range("C4").Value=thisform.pageframe1.page1.h5.value

```

---

```
.Range("C6").Value=thisform.pageframe1.page1.h7.value
.Range("G6").Value=thisform.pageframe1.page1.j7.value
.Range("C9").Value=thisform.pageframe1.page1.f12.value
.Range("E10").Value=thisform.pageframe1.page1.i12.value
.Range("E18").Value=thisform.pageframe1.page1.g20.value
```

ENDWITH

```
nfile=INPUTBOX("Enter File Name","Excel file name ",thisform.pageframe1.page1.ref.Caption)
IF EMPTY(nfile)
  MessageBox("Please enter file name !", "", 0)
ELSE
  lo_Workbook.SaveAs(sys(5)+sys(2003)+"\outputs\MFCs\"+nfile+".xlsx")
  lo_Workbook = lo_Excel.Application.Workbooks.Open(sys(5)+sys(2003)+"\outputs\MFCs\"+nfile+".xlsx")
  thisform.pageframe1.page1.ref.Caption=nfile
  lo_Excel.windowstate=1
  lo_Excel.Visible = .T.
  lo_Workbook.SAVE()
ENDIF
ENDIF
```

IF myselection=2

```
lo_Workbook = lo_Excel.Application.Workbooks.Open(sys(5)+sys(2003)+"\temp\"+"Electric Circuit Template")
WITH lo_excel
.Range("h2").Value=thisform.pageframe1.page2.h2.Value
.Range("q2").Value=thisform.pageframe1.page2.q2.value
.Range("h10").Value=thisform.pageframe1.page2.h10.value
.Range("B20").Value=thisform.pageframe1.page2.b20.value
.Range("k17").Value=thisform.pageframe1.page2.k17.value
.Range("q17").Value=thisform.pageframe1.page2.q17.value
.Range("g28").Value=thisform.pageframe1.page2.g28.value
.Range("p28").Value=thisform.pageframe1.page2.p28.value
```

ENDWITH

```
nfile=INPUTBOX("Enter File Name","Excel file name ",thisform.pageframe1.page2.ref.Caption)
IF EMPTY(nfile)
  MessageBox("Please enter file name !", "", 0)
ELSE
  lo_Workbook.SaveAs(sys(5)+sys(2003)+"\outputs\Electric Circuit\"+nfile+".xlsx")
  lo_Workbook = lo_Excel.Application.Workbooks.Open(sys(5)+sys(2003)+"\outputs\Electric Circuit\"+nfile+".xlsx")
  thisform.pageframe1.page2.ref.Caption=nfile
  lo_Excel.windowstate=1
  lo_Excel.Visible = .T.
  lo_Workbook.SAVE()
ENDIF
ENDIF
```

---

**Table 8 “Main Screen (Return to main screen)” as one of the tools for model data control**

---

```
thisform.container1.Visible= .F.
thisform.pageframe1.ActivePage=3
thisform.image2.Visible= .F.
```

---

**Table 9 “Exit” as one of the tools for model data control**

---

```
quit
lo_Excel=.NULL. && free memory
RELEASE lo_Excel && remove variable from memory
```

---

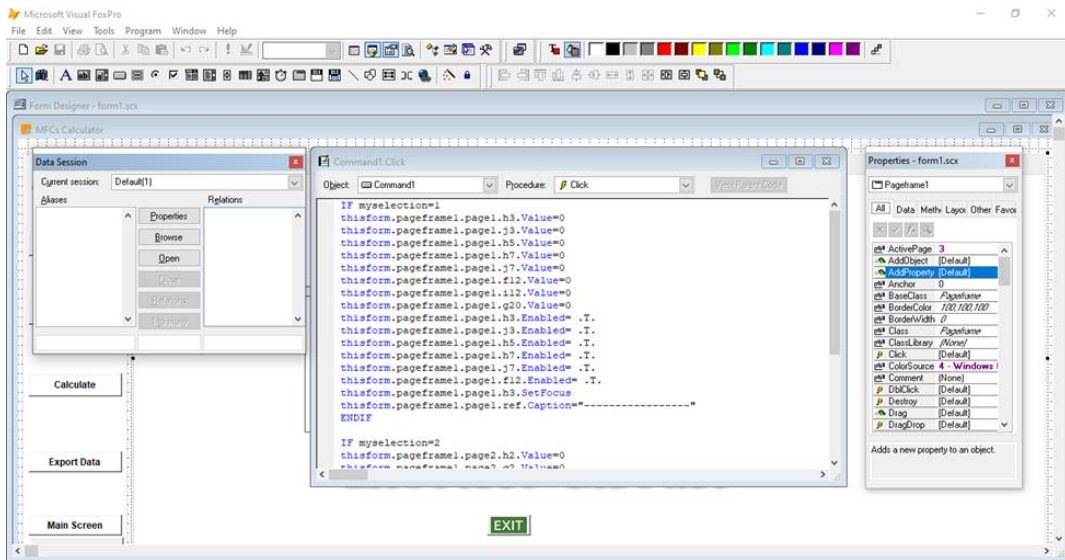


Figure 1 The developed codes (Part 1)

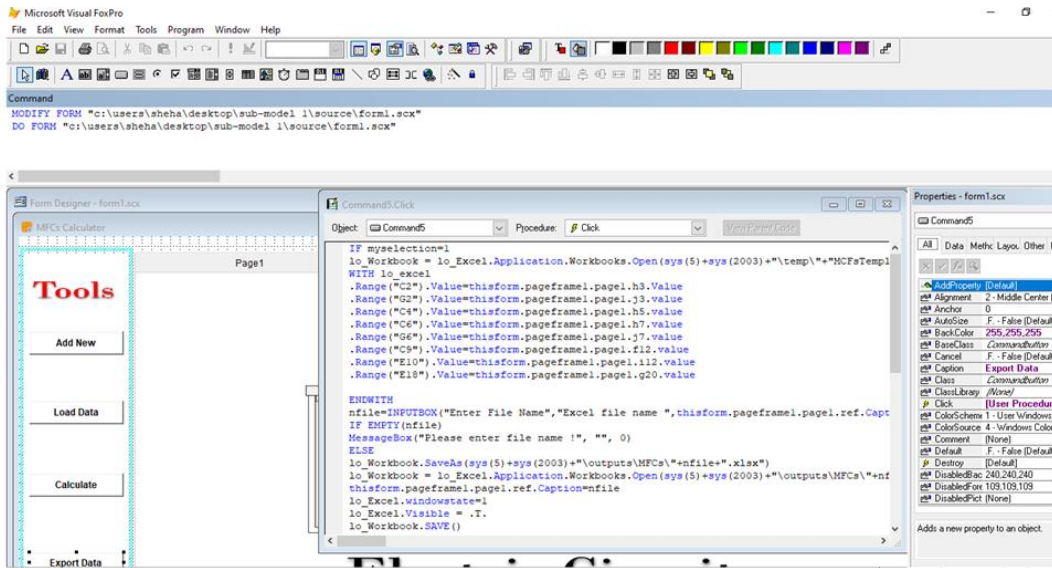


Figure 2 The developed codes (Part 2)

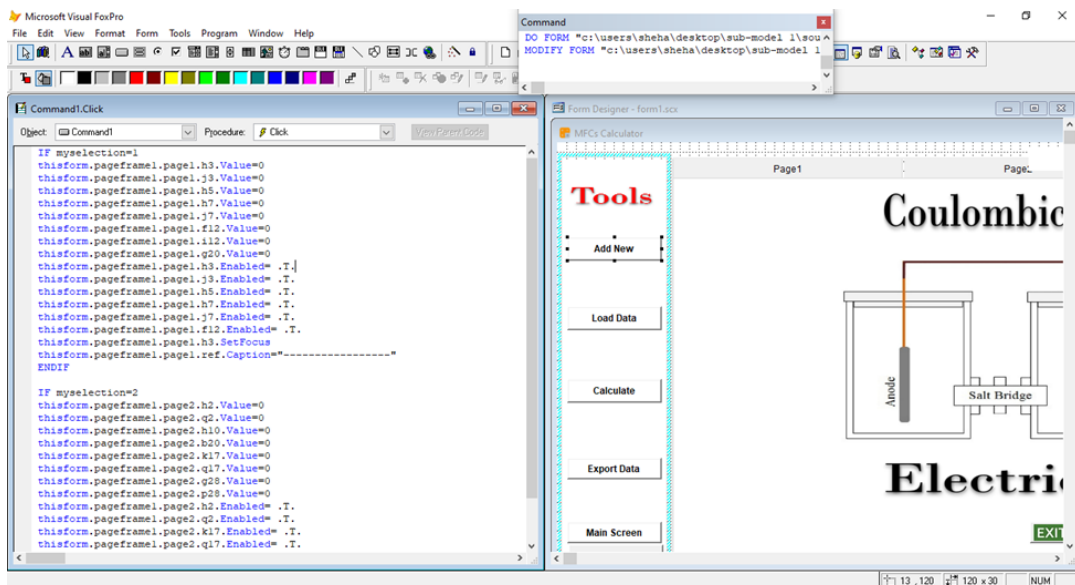


Figure 3 The developed codes (Part 3)



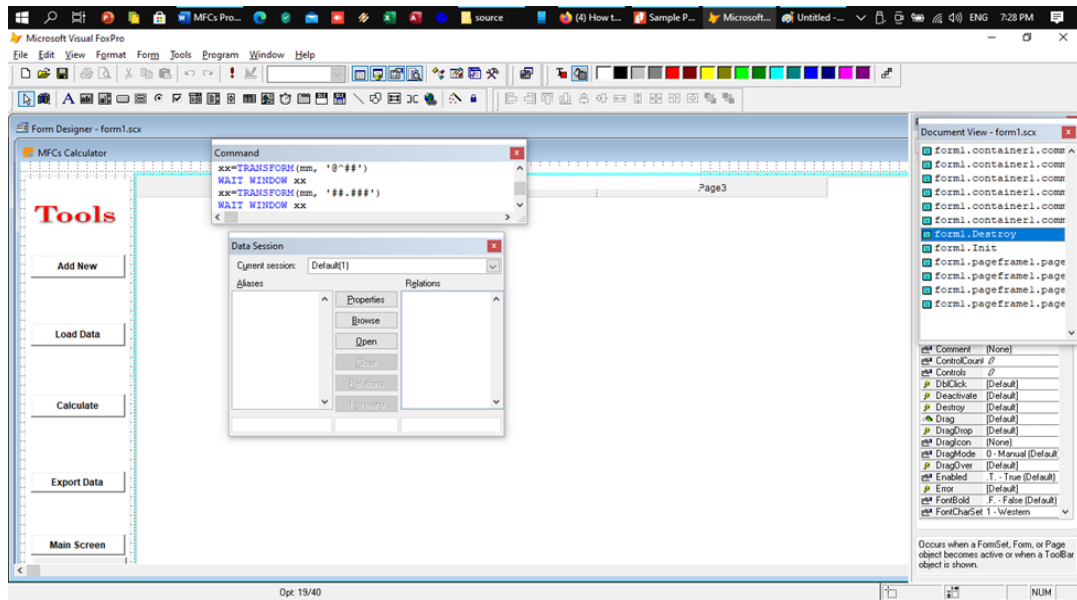


Figure 4 The developed codes (Part 4)

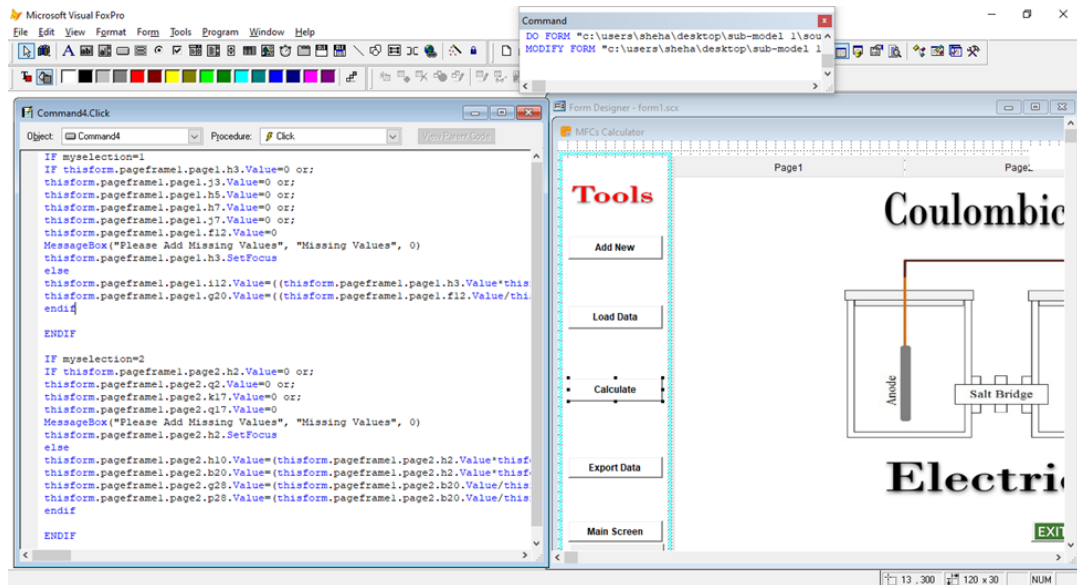


Figure 5 The developed codes (Part 5)

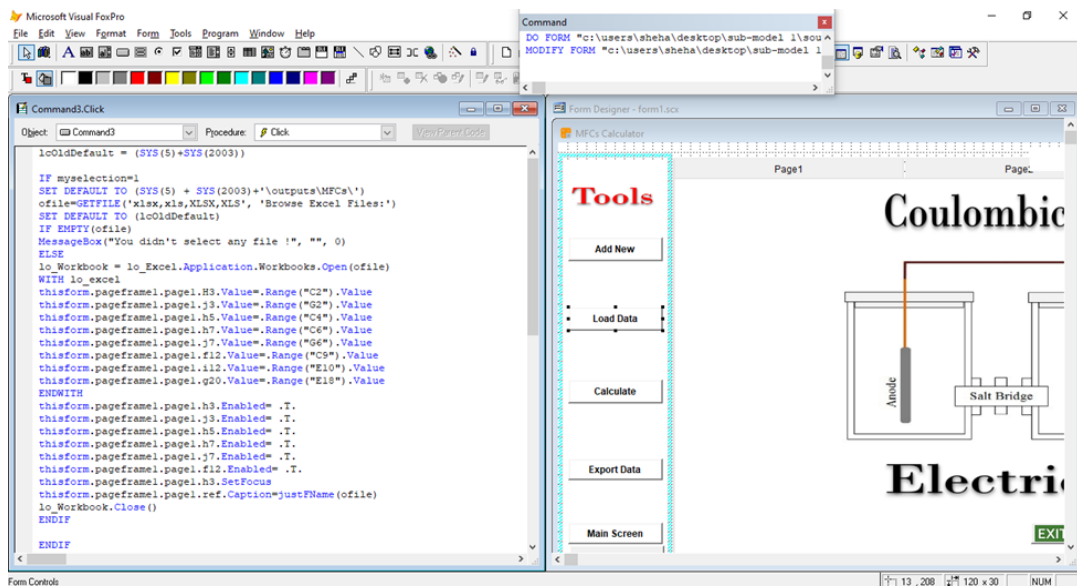


Figure 6 The developed codes (Part 6)

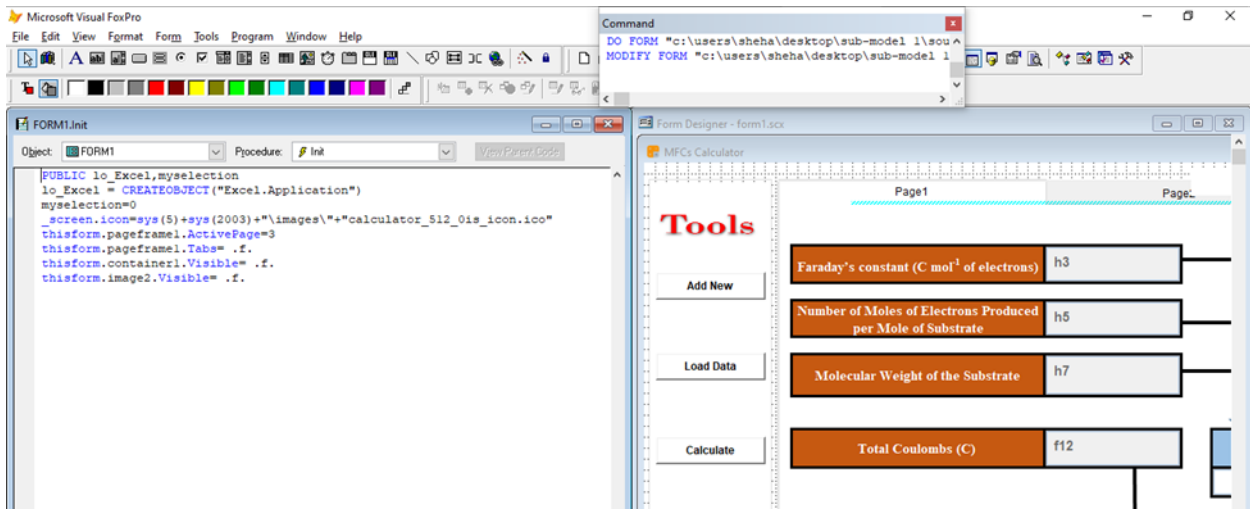


Figure 7 The developed codes (Part 7)

Table 10 Application programming used tools

Tools	Styles and Significance
Add New	Adding new set of data
Load data	Load Data from Excel file
Calculate	Calculate MFCs parameters and get results as output
Export Data	Export data and save in Excel file for later use
MMain Screen	Return to program main screen to select another model

2.4 Mathematical modeling

2.4.1 Coulombic efficiency

The coulombic efficiency (*CE*, %) of the MFCs is known as the amount of organic matter compounds recovered as electrical energy, and is calculated using to the following mathematical equations (Alzate-Gaviria, 2011; Liu et al., 2005):

$$CE = \frac{C_p}{C_{ti}} \times 100\% \quad (1)$$

Where,

*C<sub>p</sub>* = total coulombs (C) is computed as current integral (A) to time (day);

*C<sub>ti</sub>* = coulombs theoretical amount (C).

The diagram of current (Y-axis) versus MFC operational time (X-axis) is implemented to find out *C<sub>p</sub>*. The entire charge (*q*) in coulombs is determined by integrating the zone underneath the curve. Besides, the coulombs theoretical amount (*C<sub>ti</sub>*) is calculated using the following mathematical equation:

$$C_{ti} = \left[ \frac{F \times b \times S \times v}{M} \right] \quad (2)$$

Where,

*F* = Faraday’s constant (96,485.33 C mol<sup>-1</sup> of electrons);

*b* = number of electrons moles per substrate mole;

*S* = substrate concentration (g L<sup>-1</sup>);

*v* = liquid volume (L);

*M* = substrate molecular weight.

2.4.2 Resistance

Based on Ohm’s Law, the resistance is computed by the mathematical equation:

$$V = I \times R \quad (3)$$

Where,

*V* = Voltage, V

*I* = Current, A

*R* = External Resistance, Ω

The polarization curve can be plotted by corroborating outer resistances through the interval of each min to achieve steady voltages. The inner resistance and the maximum power density are determined by investigating the polarization curve (Tao et al., 2015).

2.4.3 Power and power density

Based on the Power Law, the power is calculated using the following mathematical equation:

$$P = I \times V \quad (4)$$

Where,

*P*: Power, W

The power density ( $P_D$ ) produced by MFCs is calculated in  $W\ m^{-3}$  using the substrate volume ( $v$ ) and the power calculated using Equation 4, as follows:

$$P_D = \frac{I \times V}{v} \quad (5)$$

The areal power density is calculated as follows (Tao et al., 2015):

$$P_D = \frac{I \times V}{A} \quad (6)$$

Where,

A: projection surface area of the anode,  $m^2$

$P_{AD}$ : Areal power density,  $W\ m^{-2}$

## 2.5 Authentication and valuation

The verification of a software is focused on ascertaining the proper functionality of the software. Additionally, the validation of a software is aimed at determining the precision of the program. The provided data was utilized for executing computations through the traditional method to ascertain the resulting data which was subsequently compared with the data generated by the program. The outputs from both the traditional method and the program are expected to be similar.

## 2.6 Software

Utilizing Microsoft Visual FoxPro 9.0 - Service Pack 2.0, the program was developed by integrating the flowchart and algorithm while establishing the interface. Visual FoxPro emerged within the classification of programming languages commonly known as "xBase" languages, which are characterized by syntax rooted in the dBase programming language.

Visual FoxPro (VFP) is securely combined with its own interactive database mechanism, that expands FoxPro's xBase abilities to maintain SQL query and data management. Different from the majority of database running systems, Visual FoxPro is an ideal, full-configurations, active programming language which is not demanding the implementation of extra common rationale for programming environment. It is employed to create not only "fat client" applications, but then again web applications.

## 3 Results

The developed software can compute the coulombic efficiency, the areal and volumetric power densities generated by MFCs. The simulation results are presented in Figures 8-10, where the figures show the input and output data. The software was developed in a way that if the input data are added, then the coulombic efficiency, the areal and volumetric power densities generated by the MFCs are displayed. The figures are styled as following:

Figure 8 shows the main window of the software where the user can select either to compute the coulombic efficiency or the electric circuit to compute the volumetric and aerial power densities as well as further parameters.

Figure 9 shows the input and output data of the calculations related to the coulombic efficiency, where the user should input the number of moles of electrons per mole of substrate, substrate concentration ( $g\ L^{-1}$ ), liquid volume (L), and substrate molecular weight. Then, the software automatically computes the coulombic efficiency (%).

Figure 10 shows the input and output data of the calculations related to the electric circuit, where the user should input the values of the electric current (A), the external resistance ( $\Omega$ ), the substrate volume ( $v$ ), and the projected surface area of the anode ( $m^2$ ). Then the software automatically computes the voltage (V), the power (W), the power density ( $W\ m^{-3}$ ), and the areal power density ( $W\ m^{-2}$ ).

Furthermore, the software allows the user to save input and output (computed) data as well as to retrieve these data and re-process them.

## 4 Discussion

The acquired data were utilized for conducting computations using the traditional method to produce results that were compared to the output data calculated by the developed program. Both the output data from the traditional method and the program were found to be in agreement. Consequently, the program can be effectively utilized for the estimation of coulombic efficiency, as well as areal and volumetric power densities produced by microbial

fuel cells (MFCs) during the treatment of livestock manure and wastewater. The advantages of the newly created software can be summarized as follows: (1) the software is user-friendly for individuals without professional expertise, such as students and professionals, (2) the software has a compact size, (3) the software allows for regular updates, (4) the software is simple to download and operate, and (5) the software can be easily used by students during the educational process.

#### 4.1 Structured induction

The acquisition of knowledge has been acknowledged as the cornerstone within the realm of software configuration. The methodical utilization of induction implies a proficiency in acquiring and implementing knowledge. Induction, characterized by its contrast to deduction, involves the application of comprehensive knowledge to a situation in order to predict an outcome. This process examines specific instances to generate knowledge that aligns with established patterns. Through a series of examples, essential knowledge is extracted and organized into a decision tree, referred to as a spark map. The digital spark map is then refined into a functional knowledge base for a software system. Structured induction analyzes situations and applies an algorithm to them, resulting in an optimized spark map that adheres to predetermined criteria, featuring informative

attributes at branch nodes and decisions at end nodes. An electronic spark map conveys the structured knowledge derived from specific scenarios and an efficient framework. The development of various electronic spark maps from a given dataset requires optimization to produce the most effective spark map, a process facilitated by the utilization of authentic data from diverse institutions and wastewater treatment facilities for comparison with the software-generated data. The process of acquiring and formalizing knowledge through structured induction involves the implementation of algorithms to derive rules. The adjustable parameters, variables, constants, and criteria of an algorithm are configured to serve as input-output data for the relevant electronic spark map to establish the interface.

Induction serves to organize the descriptive data in order to minimize uncertainty or, in other words, the level of ambiguity in the structure of the spark map. Induction proves to be a valuable tool in software configuration. Nonetheless, it should be viewed as one of several strategies for acquiring knowledge. Meaningful dialogue between experts and artificial intelligence (AI) specialists is a crucial aspect of the process, particularly in the context of employing induction. When used judiciously by the AI specialist, induction has the capability to furnish structured knowledge that reflects precise expertise.

MFCs Calculator

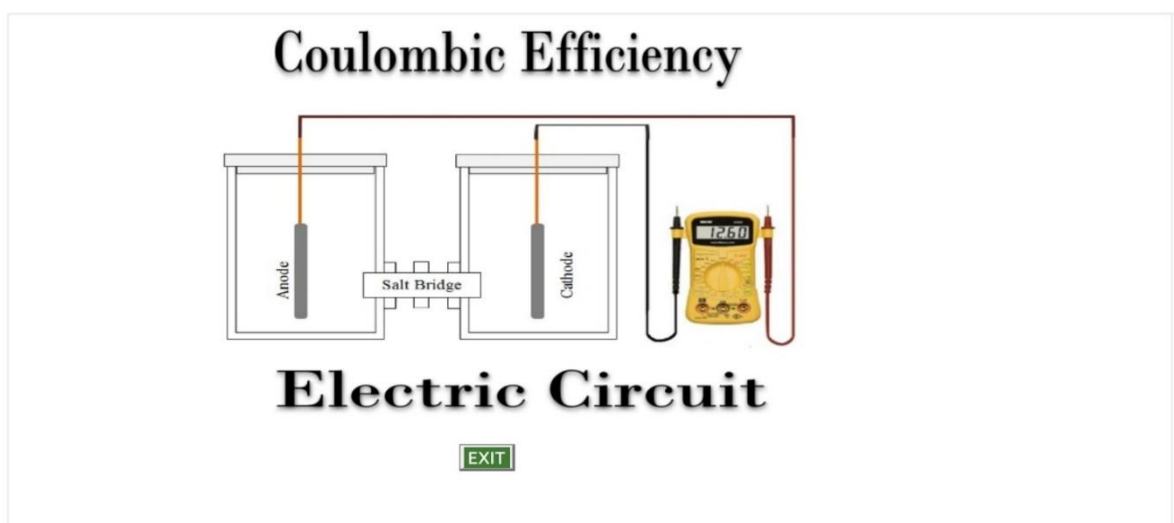


Figure 8 Main window of the software

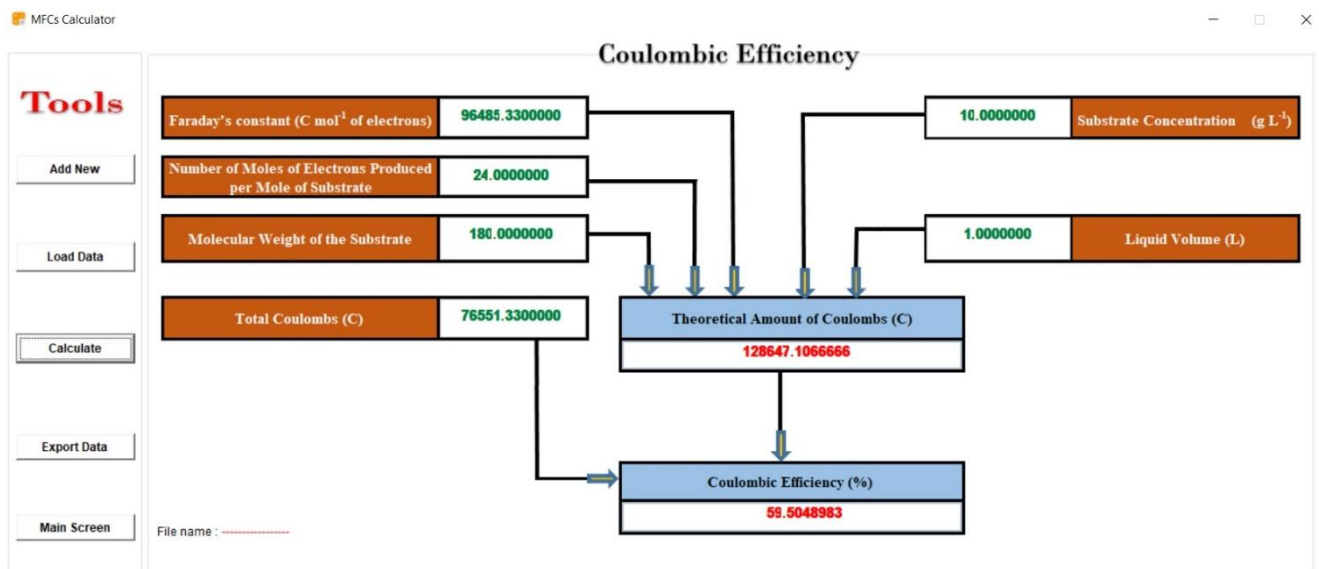


Figure 9 The input and output data window of the calculations related to the coulombic efficiency

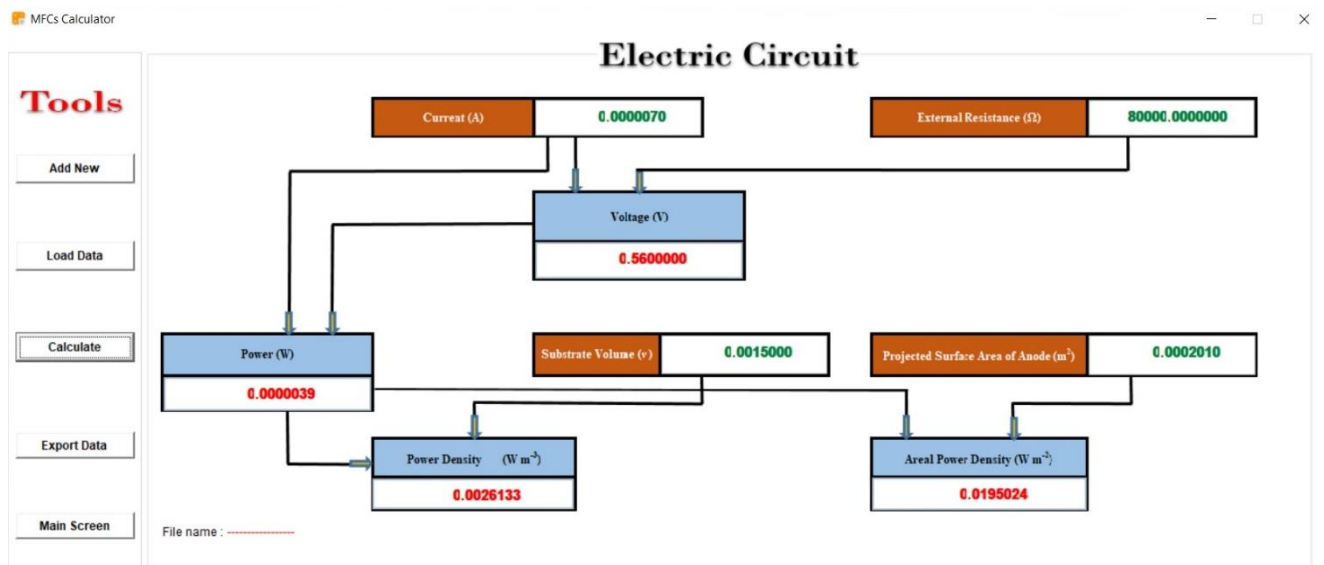


Figure 10 The input and output data window of the calculations related to the electric circuit

**4.2 Educational effect**

The configured program exhibits versatility for applications such as computer-based training (CBT), a learning model where students engage in specific training activities on a computer. Consequently, the configured program can be integrated into the exercises related to microbial fuel cells (MFCs), enabling students to practice utilizing the software during the learning process. Enhancing users' decision-making capabilities beyond their prior educational background yields beneficial outcomes. Particularly, when software aligns with current research publications, it typically facilitates knowledge transfer. This impact is observable in the

configured software.

**4.3 End users**

The program is addressed to practitioners, engineers, specialists, non-specialists in MFCs (MFCs), students, and researchers as well as for teaching professors.

**5 Summary and conclusion**

A computational model was established for the calculation of coulombic efficiency, as well as the areal and volumetric power densities produced by microbial fuel cells. Subsequently, a flowchart was developed, and the algorithm was integrated with the

flowchart. Following this, Microsoft Visual FoxPro 9.0 - Service Pack 2.0 was utilized to enhance the software through the integration of the flowchart and algorithm, and the development of the interface. Data were sourced from governmental bodies, wastewater treatment facilities, non-governmental organizations (NGOs), and relevant literature. These collected data were utilized in conventional computations to generate output data, which were then compared with the output data produced by the software. The results from both the conventional method and the software were found to be consistent. Therefore, it was deduced that the refined software can be effectively utilized for the computation of coulombic efficiency, as well as the areal and volumetric power densities generated by microbial fuel cells (MFCs).

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