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6/04/25

LABORATORY ASSIGNMENT-4

PROBLEM STATEMENT

Simulation of the behaviour of smart sensors and actuators found in modern automotive and environmental monitoring systems. The focus is on two main types of electrochemical sensors.

- Metal Oxide Sensors (MOS):- these sensors operate based on changes in electrical resistance when exposed to various gases. Their behaviour is modelled using an exponential relationship between gas concentration and sensor resistance.
- Potentiometric Sensors:- commonly used for pH measurement these sensors rely on the Nernst equation to convert hydrogen ion activity into a measurable voltage.
- Chemical Sensors:- modeling the airbags inflation using the ideal gas law and determining the deployment force based on pressure and surface area.

SIGNIFICANCE AND REAL WORLD APPLICATIONS

1. Metal Oxide Sensors

Applications :- Environmental monitoring detecting pollutants such as CO, CH_4, NO_2.

Automotive systems - monitoring exhaust emissions to ensure compliance with env regulations.

Industrial Safety:- Early detection of hazardous gases

Significance - Real Time Responce, Cost Effectiveness

2. Potentiometric Sensors

Water Quality Control - pH sensors are used for monitoring acidity & alkalinity in water bodies & treatment plants

Biomedicine:- used in blood gas analyzer.

Significance is accuracy and versatility.

3. Chemical Actuators

Airbag system are critical for moder cars, providing protection during collision.

Significance :- Life Saving, Precision engineering

PROBLEM ANALYSIS

1. Metal Oxide Sensors (MOS)

Key Eqn :- $R_g = R_a \times \exp\left(\frac{E_a}{k \times T}\right)$

Given :- $R_a = 1000$ ohms (resistance in clean air)

$E_a = 0.7eV$ (activation energy)

$T = 300K$ (temperature)

$k = 8.617 \times 10^{-5} eV/K$ (Boltzmann const)

$R_g = 1000 \times e^{\left(\frac{0.7}{8.617 \times 10^{-5} \times 300}\right)} = 1000 \times e^{(27.07)}$

This shows sensors high sensitivity to the presence of reducing or oxidizing gases.

2. Potentiometric Sensor Simulation

Key Eqn :- Nernst Eqn $E = E_0 - (0.0591 \times pH)$

Given :- $E_0 = 0.4V$ (standard electrode potential)

$pH = 7$ (neutral pH)

$E = 0.4 - (0.0591 \times 7) = -0.0137V$

This small negative ph shows shift in neutral pH & serves as baseline for comparing changes at diff pH.

3. Airbag System Simulation

$P = \frac{n \times R \times T}{V}$ Given - $n = 0.5$ mol (no of moles)

$T = 300K$ (temperature)

$V = 0.05 m3$ $R = 8.314 J/(mol \cdot K)$

$P = \frac{0.5 \times 8.314 \times 300}{0.05} \approx 24942 Pa$

$F = P \times A = 24942 \times 0.3 \approx 7482.6N$

This demonstrated how the pressure generated by chemical reaction

PreLab Questions Electrochemical Sensors

Q1 What factors influence resistance change in MOS Sensor?.

Ans Factors influencing are-

(I) temperature

(II) activation energy

(III) gas concentration

(IV) gas type (reducing or oxidizing)

These interactions with oxygen species on the metal oxide surface alters electron flow, leading to change in resistance.

Q2 How does the nernst eqn helps determine pH lev

It is directly link the output voltage with hydrogen ion concentration using formula

$$E = E_0 - (0.0591 \times pH)$$

If pH changes the sensor voltage linearly varies with it, giving pH measurement.

Q3 Why is temperature compensation important in electrochemical sensor readings?

For Metal oxide sensor, resistance is exponetially related to temperature

$$R_g = R_a \times exp\left(\frac{E_a}{R \times T}\right)$$

For Potentiometer sensor, the nernst eqn assumes 25°C, variation can occur is temperature varies.

Analysis Questions

Q1 How does gas concentration impact the resistance of the MOS sensor in simulation?
Higher is the gas concentration enhances interaction on sensor surface, activation energy would be less causes an exponential decrease in resistance due to enhanced flow.

Q2 Modify the program to include temperature dependency to more realistic model.
It already uses $R_0 = R_a \times exp\left(\frac{E_a}{k \times T}\right)$

we can add realism but adding dynamic model for gas specific properties, humidity & time-based response curve.

Pre-Lab Questions (Chemical Actuators)

Q1 How does an airbag system utilize chemical actuators for deployment?
collision detection triggers pyrotechnic reaction, generating gas rapidly. This inflate airbag within milliseconds the protect passengers.

Q2 How does force exerted by airbag relate to pressure & A?
$F = P \times A$
greater the pressure or airbag surface area increases proportionally the force exerted.

Q3 Explain how ideal gas law governs the expansion of airbag.
$PV = nRT$ as gas production $n\uparrow$ & temp $T\uparrow$, pressure increases in a fixed volume & hence inflating airbag.

Pseudocode

① Metal Oxide Sensor

```
Begin
    //define Ra, Ea, T, k
    define function to calc resistance in presence of
            return Ra * EXP(Ea/(k*T))
    define simulate sensor response for diff gas
            Rg = calculate_resis(Ra, Ea, T, k)
    ENDFOR
END
```

② Potentiometric Sensor

```
Begin
    //define sensor params E0

    calculate_potential(E0, pH):
        return E0-(0.0591*pH)
    //simulate sensor response for various pH values
END
```

③ Airbag Simulation

```
Begin
    Define sensor params n, T, V, A, R
    pressure = (n*R*T)/V
    force = pressure*A

END
```

TestCase-1

Sensor 1 MOS

```
f:\sensorsLabLA1\LA4-22BCT0046>cd "f:\sensorsLabLA1\LA4-22BCT0046\" && gcc LA4-22BCT0046.c -o LA4-22BCT0046 && "f:\sensorsLabLA1\LA4-22BCT0046\"LA4-22BCT0046
Enter sensor type (mos/ph/airbag): mos
Data saved to LA4-22BCT0046.csv

f:\sensorsLabLA1\LA4-22BCT0046>
```

CSV

```
LA4-22BCT0046 > LA4-22BCT0046.csv
Temperature,Resistance
300,1.9922e-006
320,6.6727e-006
340,1.9387e-005
360,5.0034e-005
380,1.1686e-004
400,2.5075e-004
420,5.0029e-004
440,9.3743e-004
460,1.6632e-003
480,2.8131e-003
500,4.5623e-003
```

Sensor 2 pH

```
f:\sensorsLabLA1\LA4-22BCT0046>cd "f:\sensorsLabLA1\LA4-22BCT0046\" && gcc LA4-22BCT0046.c -o LA4-22BCT0046 && "f:\sensorsLabLA1\LA4-22BCT0046\"LA4-22BCT0046
Enter sensor type (mos/ph/airbag): ph
Data saved to LA4-22BCT0046.csv

f:\sensorsLabLA1\LA4-22BCT0046>
```

CSV

```
LA4-22BCT0046 > LA4-22BCT0046.csv
pH,Potential
4.0,0.4636
5.0,0.4045
6.0,0.3454
7.0,0.2863
8.0,0.2272
9.0,0.1681
10.0,0.1090
```

Sensor 3 Airbag

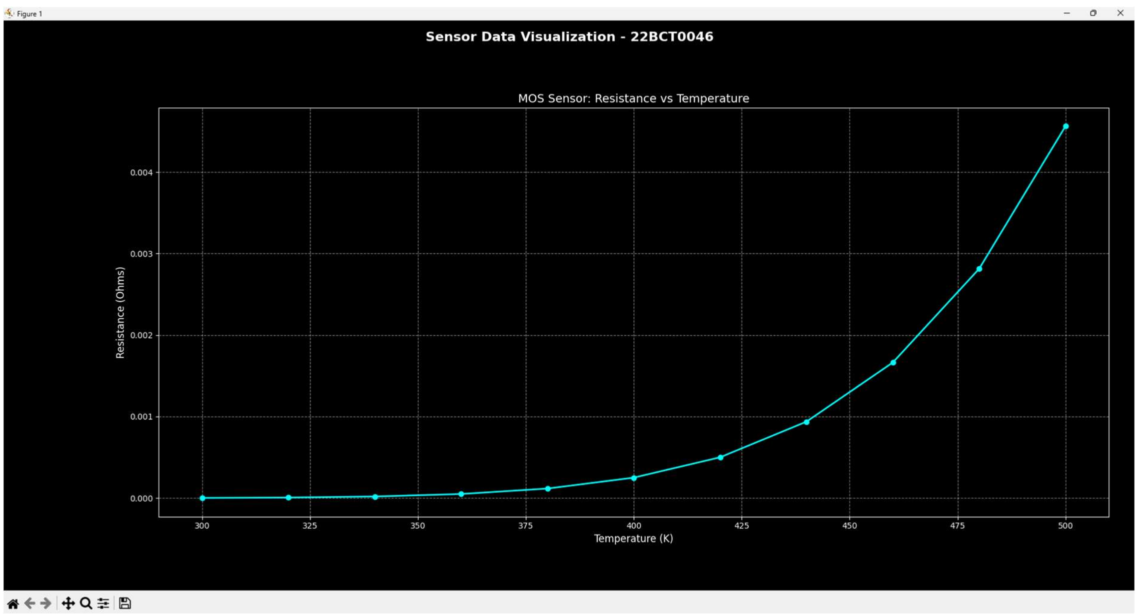
```
f:\sensorsLabLA1\LA4-22BCT0046>cd "f:\sensorsLabLA1\LA4-22BCT0046\" && gcc LA4-22BCT0046.c -o LA4-22BCT0046 && "f:\sensorsLabLA1\LA4-22BCT0046\"LA4-22BCT0046
Enter sensor type (mos/ph/airbag): airbag
Data saved to LA4-22BCT0046.csv

f:\sensorsLabLA1\LA4-22BCT0046>
```

CSV

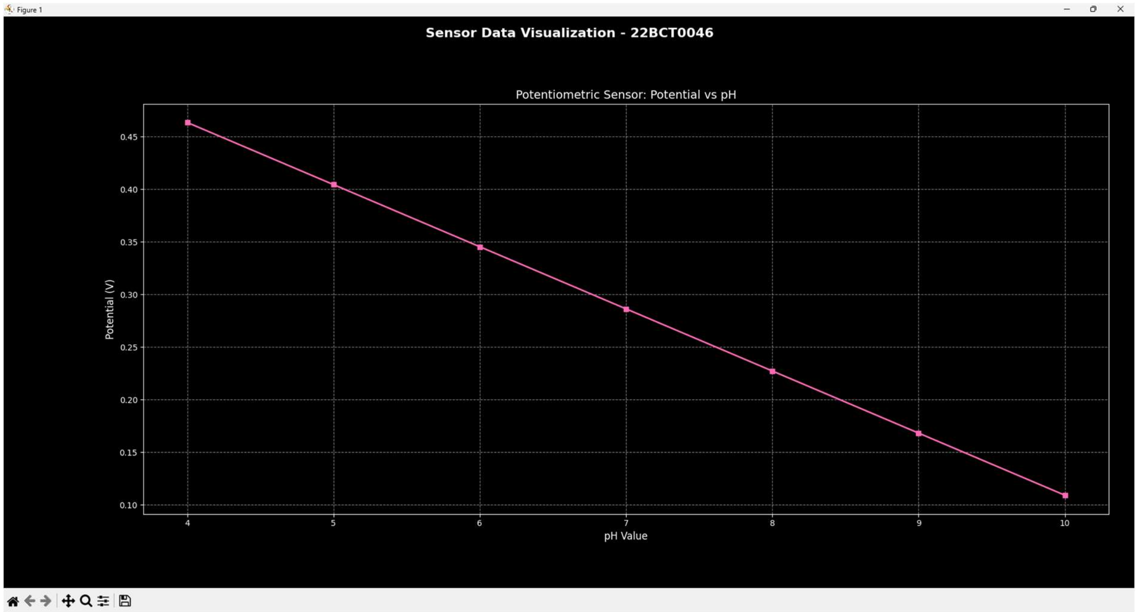
LA4-22BCT0046 > LA4-22BCT0046.csv

```
Temperature,Pressure,Force
300,2078.50,1039.25
330,2286.35,1143.18
360,2494.20,1247.10
390,2702.05,1351.03
420,2909.90,1454.95
450,3117.75,1558.88
480,3325.60,1662.80
510,3533.45,1766.73
540,3741.30,1870.65
570,3949.15,1974.58
600,4157.00,2078.50
```

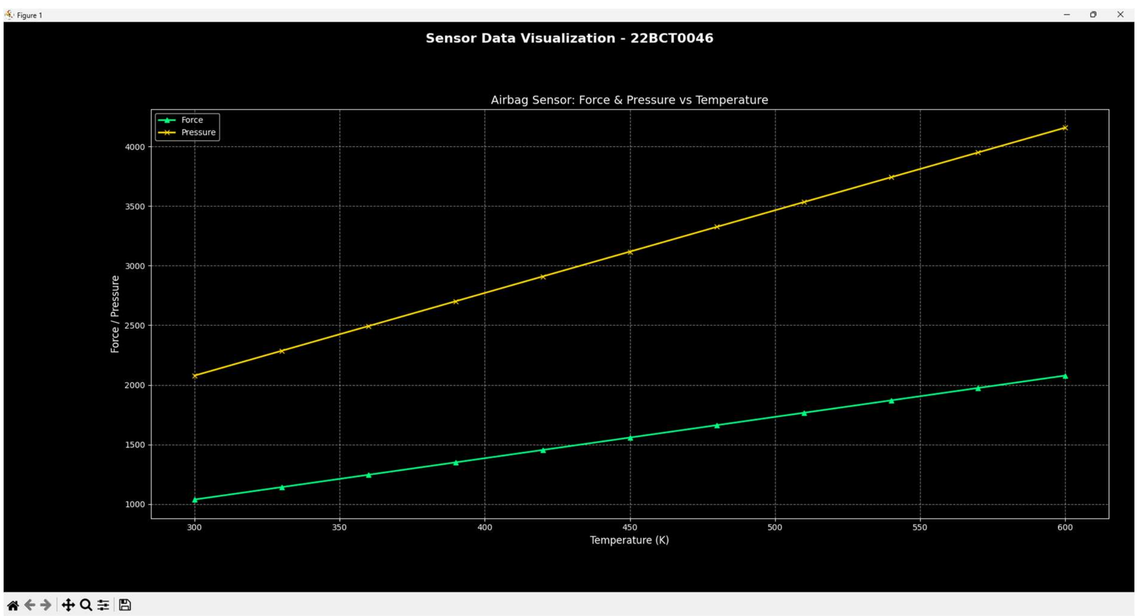
OUTPUT GRAPH 1 MOS



OUTPUT GRAPH 2 pH



OUTPUT GRAPH 3 airbag



Result and Analysis

Metal Oxide Sensor (MOS)-

results- Resistance increases significantly exponentially with gas concentration.
Highlights sensors high sensitivity & importance of temperature activation energy calibration

Potentiometric Sensor

Output voltage decreases linearly with increasing pH, closely matches theoretical

Airbag System

Pressure and force vary significantly with temperature and gas quantity.
Helps determine safe deployment thresholds