Dataset Overview

Introduction

This project aims to analyze the thermal efficiency of a slurry cooler in an HDPE plant. The dataset contains various operational parameters that are believed to influence the thermal efficiency of the slurry cooler. By understanding these relationships, we hope to provide actionable insights for optimizing the performance of the slurry cooler.

Dataset Description

The dataset includes the following columns:

1. **Inlet_Temp_C** : The temperature of the slurry entering the cooler.
2. **Outlet_Temp_C** : The temperature of the slurry exiting the cooler.
3. **Thermal Efficiency**: A measure of the cooler's efficiency in transferring heat from the slurry.**This is the target variable we aim to optimize.**
4. **Flow_Rate(L/min)** : The rate at which the slurry flows through the cooler, typically measured in liters per second or cubic meters per hour.
5. **Concentration** : The concentration of the slurry.
6. **Pressure_Drop_kPa** : The difference in pressure between the inlet and outlet of the cooler.
7. **Energy_Consumption_kWh** : The amount of energy consumed by the cooler.

Objective

The primary goal is to identify key factors that influence the thermal efficiency of the slurry cooler. By analyzing the dataset, we aim to:

- **Understand the relationship between primary operational parameters (input temperature, output temperature, flow rate, concentration, and pressure drop) and thermal efficiency**.
- **Investigate the role of energy consumption in thermal efficiency**.
- **Provide actionable insights for optimizing the performance of the slurry cooler, leading to better energy consumption and operational cost management**.

Data Source

The data was collected from GAIL,HDPE plant during our summer internship phase(16 may to 16 june),data was collected from an HDPE plant during regular operations. Data was recorded each day at 3-hour intervals ,providing a comprehensive view of the cooler's performance under various conditions.

Data Preprocessing

Before analysis, the dataset will undergo preprocessing steps to handle missing values, outliers. This ensures the accuracy and reliability of the analysis.

Exploratory Data Analysis (EDA)

Initial exploratory data analysis will be conducted to visualize the data distribution and understand the relationships between different parameters. This includes descriptive statistics, correlation analysis, and scatter plots.

Statistical Analysis

Hypothesis testing was conducted to assess specific relationships and differences within the dataset.In particular, we used the t-test to evaluate whether there were significant differences between groups.

Insights and Recommendations

Optimize Energy Use: Balance increased energy consumption with cost-effectiveness to enhance efficiency while managing costs.

Consider Cost vs. Benefit: Weigh the benefits of improved efficiency against the higher costs and potential plant impact of increased energy consumption.

Conclusion

This project will provide a comprehensive analysis of the factors influencing the thermal efficiency of a slurry cooler in an HDPE plant. The insights gained will help in making informed decisions to enhance the cooler's performance and operational efficiency.

DATA PREPROCESSING

```
#perform linear operation
import numpy as np
#Data manipulation
import pandas as pd
#Data visualization
import matplotlib.pyplot as plt
import seaborn as sns
from scipy import stats
from scipy.stats import ttest_ind

#Load the data
df = pd.read_csv(r"K:\THERMAL_EFFICIENCY.csv") # importing csv file

df.head()
```

```
         Date      Time  Inlet_Temp_C  Outlet_Temp_C
Specific_heat_capacity  \
0  20-05-2024  00:00:00         77.48          50.13
4.18
1  20-05-2024  15:00:00         84.15          52.48
4.18
2  20-05-2024  18:00:00         79.41          35.29
4.18
3  20-05-2024  21:00:00         96.73          54.68
4.18
4  21-05-2024  00:00:00         87.92          59.22
4.18

   Flow_Rate(L/min)  Thermal_Efficiency  Pressure_Drop_kPa
Concentration_PPM  \
0            251.29               85.43              23.65
450.13
1            385.24               82.17              38.74
982.36
2            437.98               71.58              19.85
201.78
3            278.49               74.28              48.23
635.47
4            456.32               93.24              12.41
46.89

   Energy_Consumption_kWh
0                   29.89
1                   18.98
2                   19.73
3                   21.34
4                   22.19
```

```
df.shape
```

```
(68, 10)
```

"In above dataset there are 68 rows and 10 columns"

```
df.info()
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 68 entries, 0 to 67
Data columns (total 10 columns):
 #   Column                  Non-Null Count  Dtype
---  ------                  --------------  -----
 0   Date                    68 non-null     object
 1   Time                    68 non-null     object
 2   Inlet_Temp_C            68 non-null     float64
 3   Outlet_Temp_C           68 non-null     float64
 4   Specific_heat_capacity  68 non-null     float64
```

```
 5   Flow_Rate(L/min)        66 non-null     float64
 6   Thermal_Efficiency      67 non-null     float64
 7   Pressure_Drop_kPa       67 non-null     float64
 8   Concentration_PPM       67 non-null     float64
 9   Energy_Consumption_kWh  67 non-null     float64
dtypes: float64(8), object(2)
memory usage: 5.4+ KB
```

```
#check the null values
df.isnull().sum()
```

```
Date                        0
Time                        0
Inlet_Temp_C                0
Outlet_Temp_C               0
Specific_heat_capacity      0
Flow_Rate(L/min)            2
Thermal_Efficiency          1
Pressure_Drop_kPa           1
Concentration_PPM           1
Energy_Consumption_kWh      1
dtype: int64
```

```
df.dtypes
```

```
Date                         object
Time                         object
Inlet_Temp_C                float64
Outlet_Temp_C               float64
Specific_heat_capacity      float64
Flow_Rate(L/min)            float64
Thermal_Efficiency          float64
Pressure_Drop_kPa           float64
Concentration_PPM           float64
Energy_Consumption_kWh      float64
dtype: object
```

```
#Handle missing values
df["Flow_Rate(L/min)"]=df["Flow_Rate(L/min)"].fillna(df["Flow_Rate(L/
min)"].mean())
df["Thermal_Efficiency"]=df["Thermal_Efficiency"].fillna(df["Thermal_E
fficiency"].mean())
df["Pressure_Drop_kPa"]=
df["Pressure_Drop_kPa"].fillna(df["Pressure_Drop_kPa"].mean())
df["Energy_Consumption_kWh"]=df["Energy_Consumption_kWh"].fillna(df["E
nergy_Consumption_kWh"].mean())
df["Concentration_PPM"]=df["Concentration_PPM"].fillna(df["Concentrati
on_PPM"].median())
df
```

```
          Date      Time  Inlet_Temp_C  Outlet_Temp_C
Specific_heat_capacity  \
0   20-05-2024  00:00:00         77.48          50.13
4.18
1   20-05-2024  15:00:00         84.15          52.48
4.18
2   20-05-2024  18:00:00         79.41          35.29
4.18
3   20-05-2024  21:00:00         96.73          54.68
4.18
4   21-05-2024  00:00:00         87.92          59.22
4.18
..         ...       ...           ...            ...
...
63  08-06-2024  21:00:00         83.34          53.78
4.18
64  09-06-2024  00:00:00         70.12          39.56
4.18
65  09-06-2024  15:00:00         76.45          43.12
4.18
66  09-06-2024  18:00:00         92.34          56.23
4.18
67  09-06-2024  21:00:00         88.56          53.67
4.18

    Flow_Rate(L/min)  Thermal_Efficiency  Pressure_Drop_kPa  \
0             251.29               85.43              23.65
1             385.24               82.17              38.74
2             437.98               71.58              19.85
3             278.49               74.28              48.23
4             456.32               93.24              12.41
..               ...                 ...                ...
63            465.67               81.12              27.89
64            230.12               81.67              33.45
65            290.34               79.89              29.56
66            213.45               77.12              30.78
67            391.78               80.45              34.23

    Concentration_PPM  Energy_Consumption_kWh
0              450.13                   29.89
1              982.36                   18.98
2              201.78                   19.73
3              635.47                   21.34
4               46.89                   22.19
..                ...                     ...
63             680.56                   30.56
64             529.78                   22.78
65             618.34                   27.34
66             595.67                   29.12
67             690.12                   31.78
```

```
[68 rows x 10 columns]
```

```
df.isnull().sum()
```

```
Date                        0
Time                        0
Inlet_Temp_C                0
Outlet_Temp_C               0
Specific_heat_capacity      0
Flow_Rate(L/min)            0
Thermal_Efficiency          0
Pressure_Drop_kPa           0
Concentration_PPM           0
Energy_Consumption_kWh      0
dtype: int64
```

Exploratory Data Analysis (EDA)

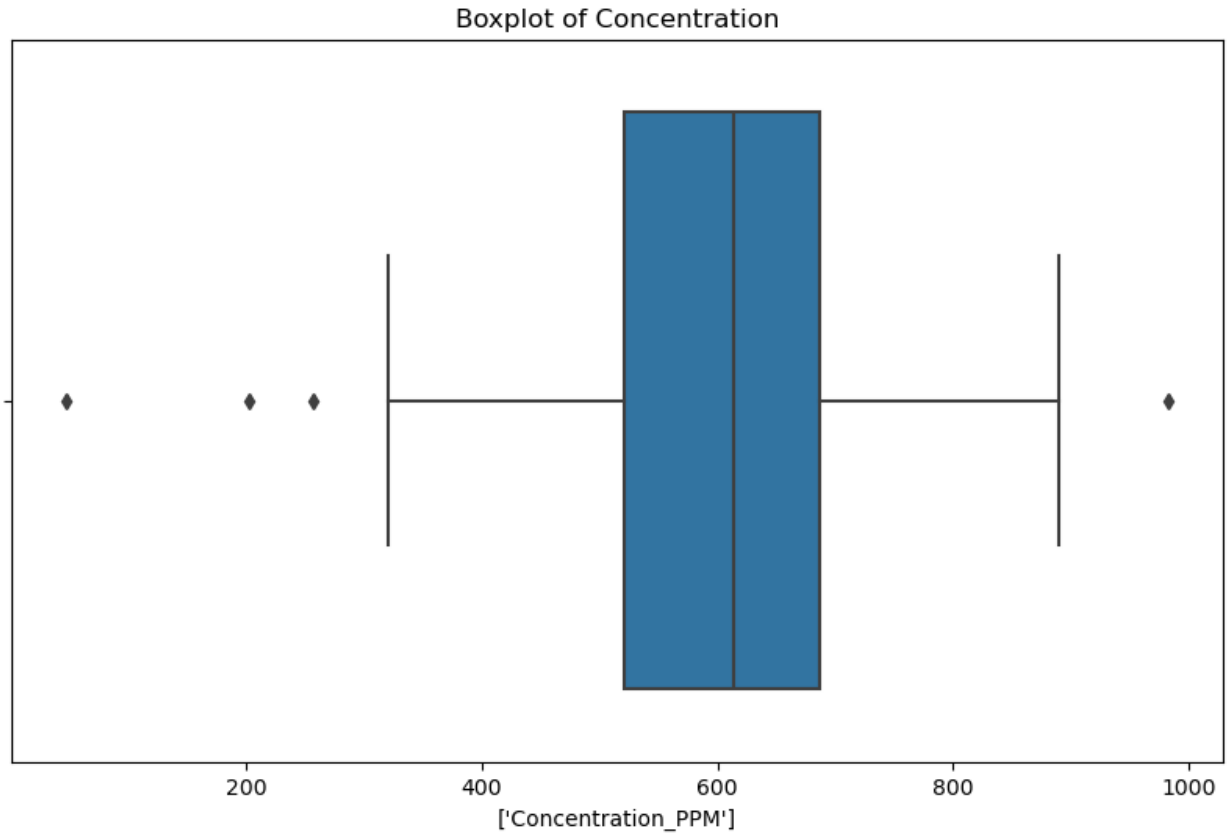
```
df.describe()
```

```
       Inlet_Temp_C  Outlet_Temp_C  Specific_heat_capacity
Flow_Rate(L/min)  \
count     68.000000      68.000000            6.800000e+01
68.000000
mean      83.131765      48.369118            4.180000e+00
320.349848
std        9.284582       7.505023            5.368692e-15
93.094412
min       61.540000      31.560000            4.180000e+00
145.320000
25%       77.412500      42.467500            4.180000e+00
248.685000
50%       83.965000      49.985000            4.180000e+00
313.685000
75%       89.850000      54.260000            4.180000e+00
399.167500
max       97.670000      60.120000            4.180000e+00
489.670000

       Thermal_Efficiency  Pressure_Drop_kPa  Concentration_PPM  \
count           68.000000          68.000000          68.000000
mean            80.854030          29.541642         585.116618
std              4.666116           7.137653         157.610533
min             70.320000          12.410000          46.890000
25%             77.887500          25.297500         520.765000
50%             80.762015          29.230000         613.670000
75%             82.842500          33.330000         686.200000
```

```
max                93.240000           48.230000          982.360000
```

```
       Energy_Consumption_kWh
count               68.000000
mean                27.029552
std                  4.284280
min                 12.450000
25%                 23.752500
50%                 27.715000
75%                 29.807500
max                 36.780000
```

```
#identification of outliers
plt.figure(figsize=(10, 6))
sns.boxplot(x=df['Concentration_PPM'])
plt.title('Boxplot of Concentration')
plt.xlabel(['Concentration_PPM'])
plt.show()
```




```
#removing outliers
Q1 = df['Concentration_PPM'].quantile(0.25)
Q3 = df['Concentration_PPM'].quantile(0.75)
```

```
# Calculate the IQR
IQR = Q3 - Q1

# Define the lower and upper bounds for detecting outliers
lower_bound = Q1 - 1.5 * IQR
upper_bound = Q3 + 1.5 * IQR

# Filter out the outliers
df_no_outliers = df[(df['Concentration_PPM'] >= lower_bound) &
(df['Concentration_PPM'] <= upper_bound)]

print("Original DataFrame:")
print(df)
print("\nDataFrame without outliers:")
print(df_no_outliers)
```

```
Original DataFrame:
          Date      Time  Inlet_Temp_C  Outlet_Temp_C
Specific_heat_capacity  \
0   20-05-2024  00:00:00         77.48          50.13
4.18
1   20-05-2024  15:00:00         84.15          52.48
4.18
2   20-05-2024  18:00:00         79.41          35.29
4.18
3   20-05-2024  21:00:00         96.73          54.68
4.18
4   21-05-2024  00:00:00         87.92          59.22
4.18
..         ...       ...           ...            ...
...
63  08-06-2024  21:00:00         83.34          53.78
4.18
64  09-06-2024  00:00:00         70.12          39.56
4.18
65  09-06-2024  15:00:00         76.45          43.12
4.18
66  09-06-2024  18:00:00         92.34          56.23
4.18
67  09-06-2024  21:00:00         88.56          53.67
4.18

    Flow_Rate(L/min)  Thermal_Efficiency  Pressure_Drop_kPa  \
0             251.29               85.43              23.65
1             385.24               82.17              38.74
2             437.98               71.58              19.85
3             278.49               74.28              48.23
4             456.32               93.24              12.41
..               ...                 ...                ...
63            465.67               81.12              27.89
```

```
64             230.12                81.67               33.45
65             290.34                79.89               29.56
66             213.45                77.12               30.78
67             391.78                80.45               34.23

    Concentration_PPM  Energy_Consumption_kWh
0              450.13                   29.89
1              982.36                   18.98
2              201.78                   19.73
3              635.47                   21.34
4               46.89                   22.19
..                ...                     ...
63             680.56                   30.56
64             529.78                   22.78
65             618.34                   27.34
66             595.67                   29.12
67             690.12                   31.78

[68 rows x 10 columns]

DataFrame without outliers:
          Date      Time  Inlet_Temp_C  Outlet_Temp_C
Specific_heat_capacity  \
0   20-05-2024  00:00:00         77.48          50.13
4.18
3   20-05-2024  21:00:00         96.73          54.68
4.18
5   21-05-2024  15:00:00         61.54          31.56
4.18
6   21-05-2024  18:00:00         74.21          33.57
4.18
8   22-05-2024  00:00:00         94.45          59.22
4.18
..         ...       ...           ...            ...
...
63  08-06-2024  21:00:00         83.34          53.78
4.18
64  09-06-2024  00:00:00         70.12          39.56
4.18
65  09-06-2024  15:00:00         76.45          43.12
4.18
66  09-06-2024  18:00:00         92.34          56.23
4.18
67  09-06-2024  21:00:00         88.56          53.67
4.18

    Flow_Rate(L/min)  Thermal_Efficiency  Pressure_Drop_kPa  \
0             251.29               85.43              23.65
3             278.49               74.28              48.23
5             385.24               85.65              23.47
```

```
6              302.78                72.18                17.56
8              321.47                89.78                45.67
..                ...                  ...                  ...
63             465.67                81.12                27.89
64             230.12                81.67                33.45
65             290.34                79.89                29.56
66             213.45                77.12                30.78
67             391.78                80.45                34.23

    Concentration_PPM  Energy_Consumption_kWh
0              450.13                   29.89
3              635.47                   21.34
5              710.21                   31.76
6              458.65                   12.45
8              645.23                   34.12
..                ...                     ...
63             680.56                   30.56
64             529.78                   22.78
65             618.34                   27.34
66             595.67                   29.12
67             690.12                   31.78

[64 rows x 10 columns]
```

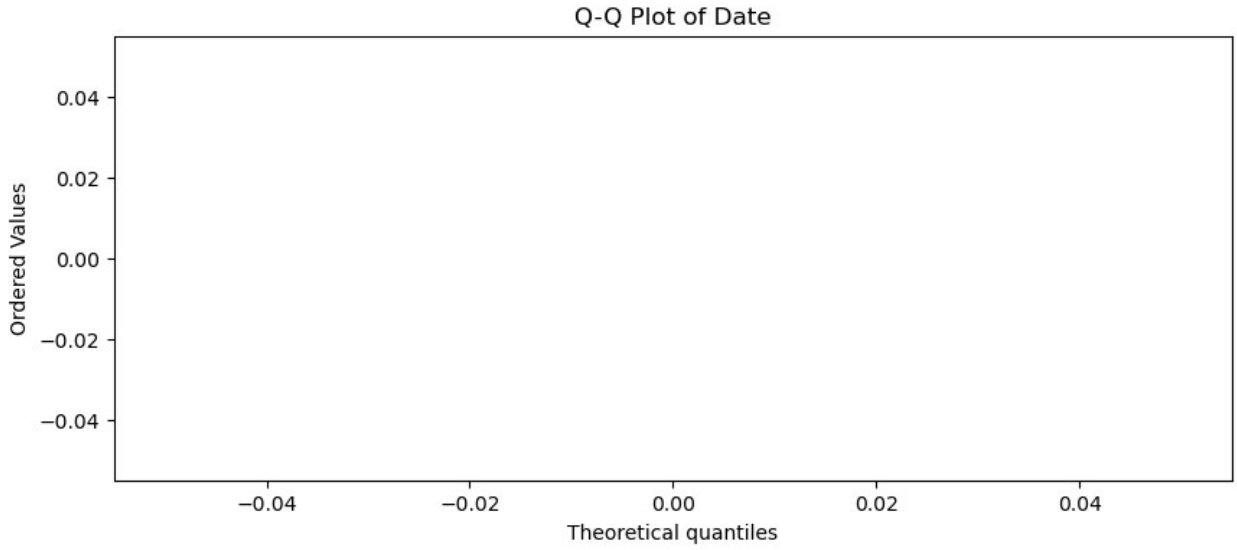
```
df['Date'] = pd.to_numeric(df['Date'], errors='coerce')
df['Time'] = pd.to_numeric(df['Time'], errors='coerce')

df.head()
```

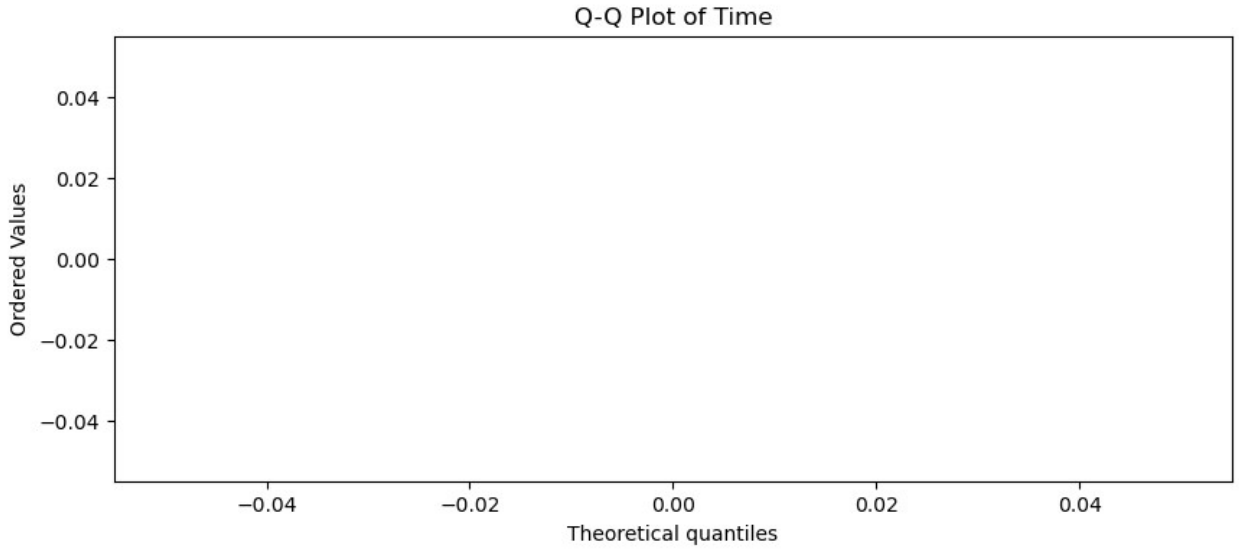
```
   Date  Time  Inlet_Temp_C  Outlet_Temp_C  Specific_heat_capacity  \
0   NaN   NaN         77.48          50.13                    4.18
1   NaN   NaN         84.15          52.48                    4.18
2   NaN   NaN         79.41          35.29                    4.18
3   NaN   NaN         96.73          54.68                    4.18
4   NaN   NaN         87.92          59.22                    4.18

   Flow_Rate(L/min)  Thermal_Efficiency  Pressure_Drop_kPa
Concentration_PPM  \
0            251.29               85.43              23.65
450.13
1            385.24               82.17              38.74
982.36
2            437.98               71.58              19.85
201.78
3            278.49               74.28              48.23
635.47
4            456.32               93.24              12.41
46.89

   Energy_Consumption_kWh
```

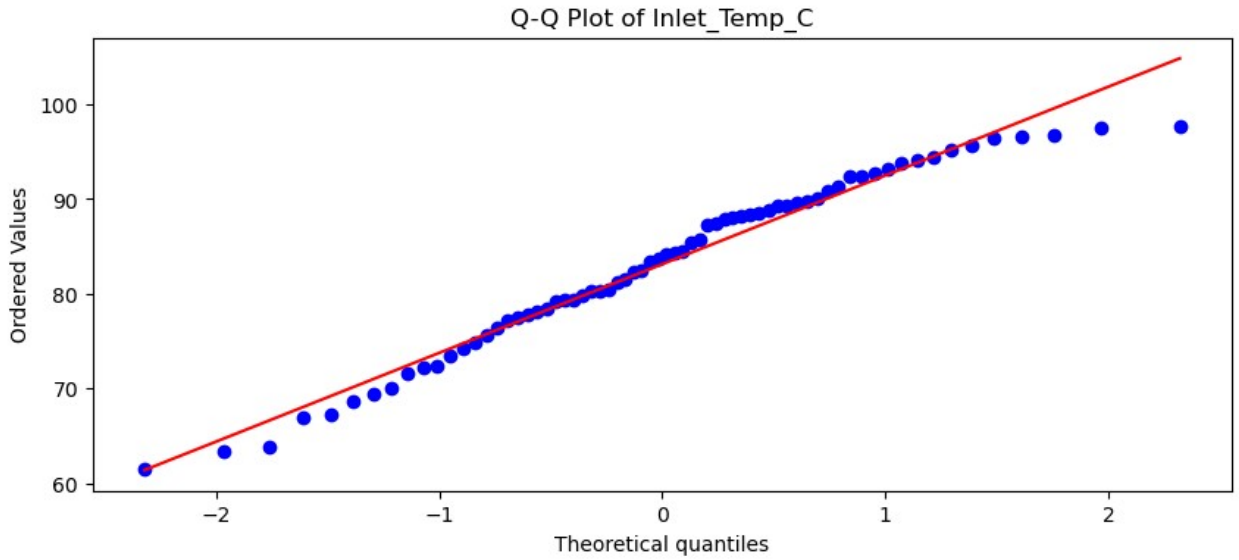
```
0                   29.89
1                   18.98
2                   19.73
3                   21.34
4                   22.19

df_no_outliers

          Date      Time  Inlet_Temp_C  Outlet_Temp_C
Specific_heat_capacity  \
0   20-05-2024  00:00:00         77.48          50.13
4.18
3   20-05-2024  21:00:00         96.73          54.68
4.18
5   21-05-2024  15:00:00         61.54          31.56
4.18
6   21-05-2024  18:00:00         74.21          33.57
4.18
8   22-05-2024  00:00:00         94.45          59.22
4.18
..         ...       ...           ...            ...
...
63  08-06-2024  21:00:00         83.34          53.78
4.18
64  09-06-2024  00:00:00         70.12          39.56
4.18
65  09-06-2024  15:00:00         76.45          43.12
4.18
66  09-06-2024  18:00:00         92.34          56.23
4.18
67  09-06-2024  21:00:00         88.56          53.67
4.18

    Flow_Rate(L/min)  Thermal_Efficiency  Pressure_Drop_kPa  \
0             251.29               85.43              23.65
3             278.49               74.28              48.23
5             385.24               85.65              23.47
6             302.78               72.18              17.56
8             321.47               89.78              45.67
..               ...                 ...                ...
63            465.67               81.12              27.89
64            230.12               81.67              33.45
65            290.34               79.89              29.56
66            213.45               77.12              30.78
67            391.78               80.45              34.23

    Concentration_PPM  Energy_Consumption_kWh
0              450.13                   29.89
3              635.47                   21.34
5              710.21                   31.76
```

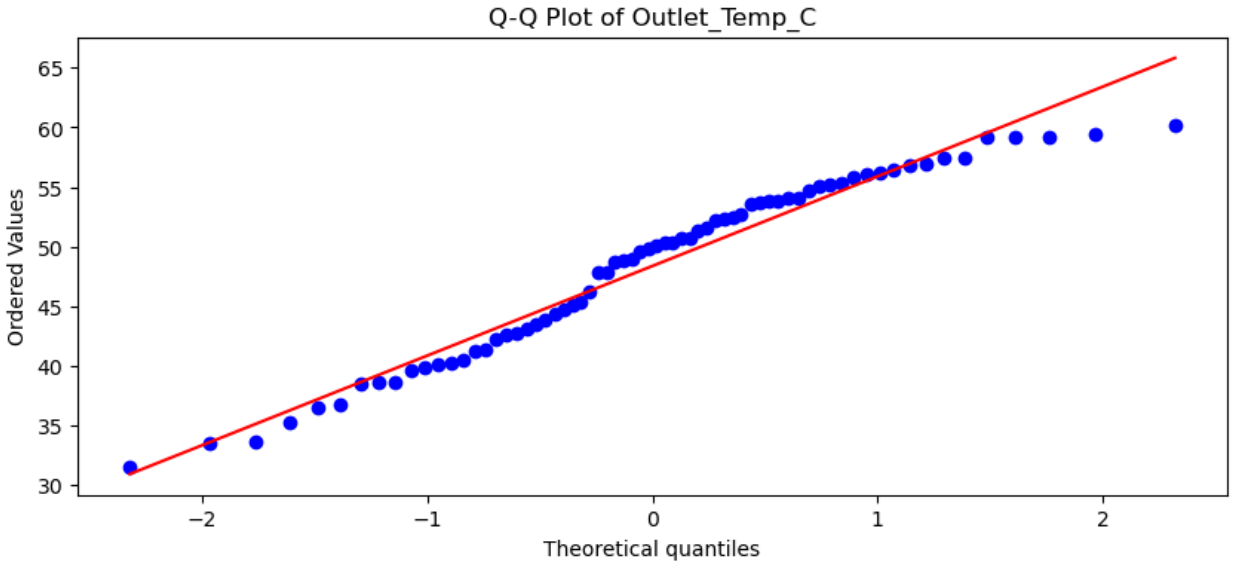
```
6               458.65                  12.45
8               645.23                  34.12
..                 ...                    ...
63              680.56                  30.56
64              529.78                  22.78
65              618.34                  27.34
66              595.67                  29.12
67              690.12                  31.78

[64 rows x 10 columns]
```

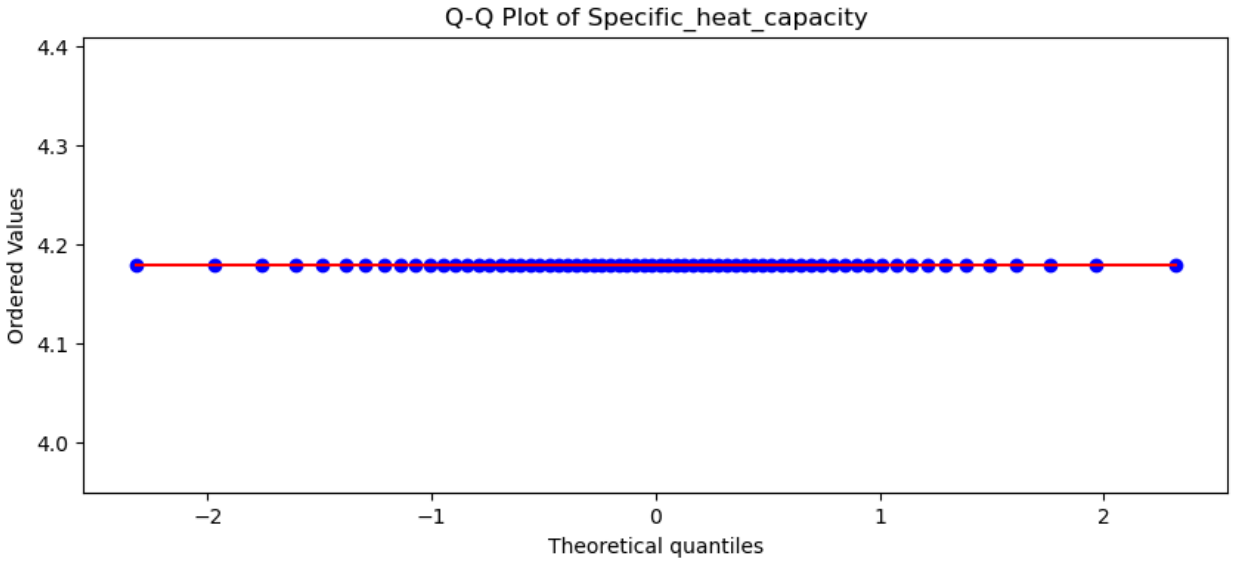
```python
# Q-Q plot(to determine whether the parameters is normally distributed or not)
for column in df_no_outliers:
    plt.figure(figsize=(10, 4))
    stats.probplot(df[column], dist="norm", plot=plt)
    plt.title(f'Q-Q Plot of {column}')
    plt.show()
```

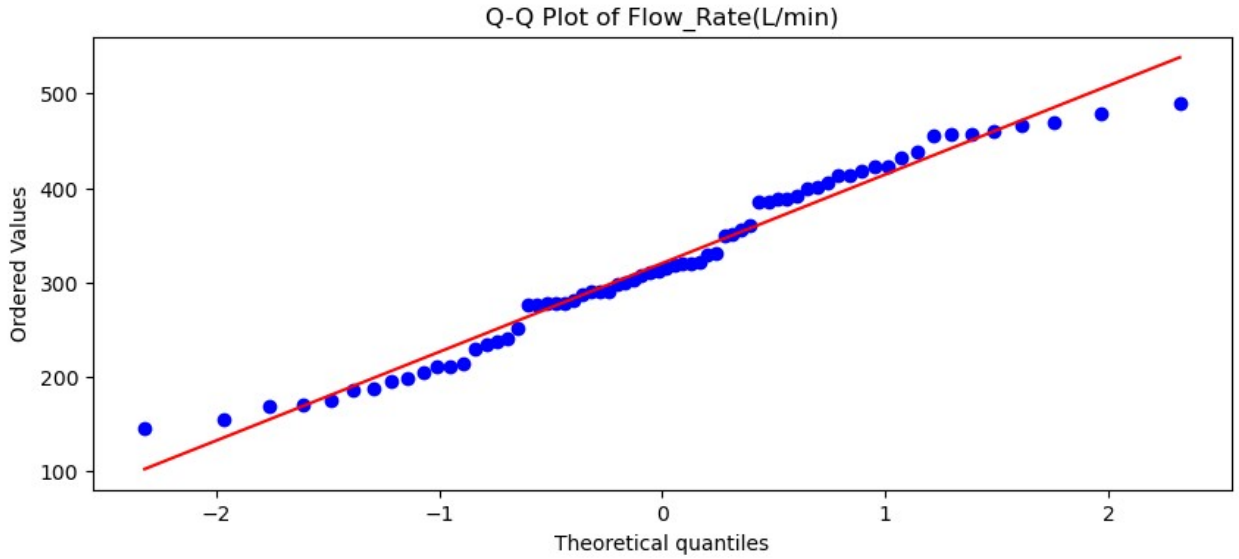


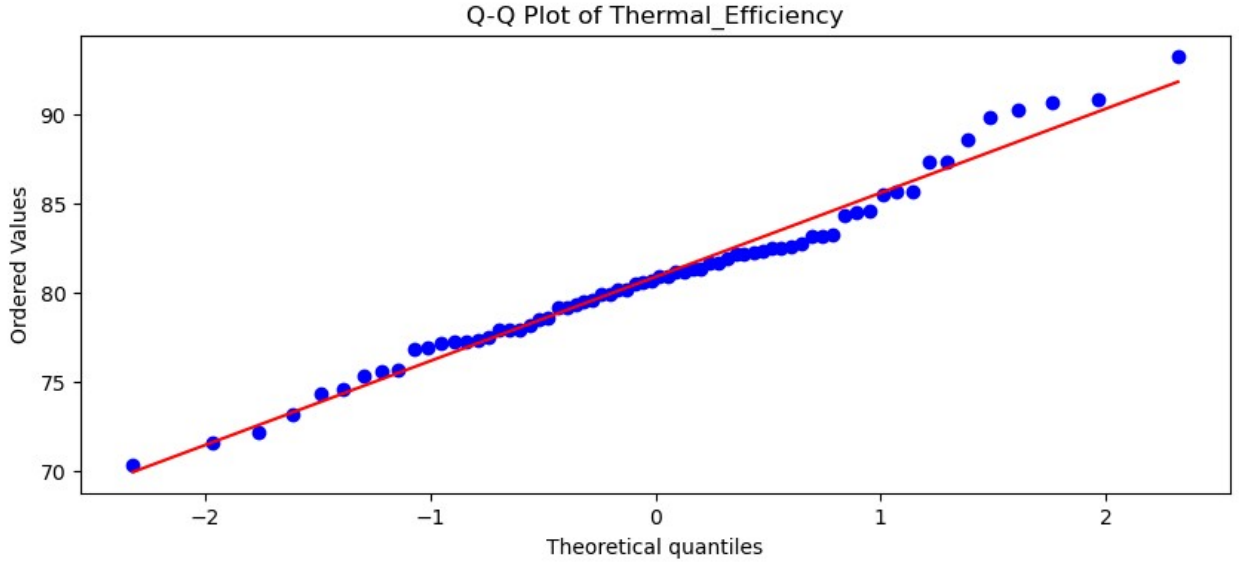

Q-Q Plot of Time
Ordered Values
0.04
0.02
0.00
−0.02
−0.04
−0.04
−0.02
0.00
0.02
0.04
Theoretical quantiles

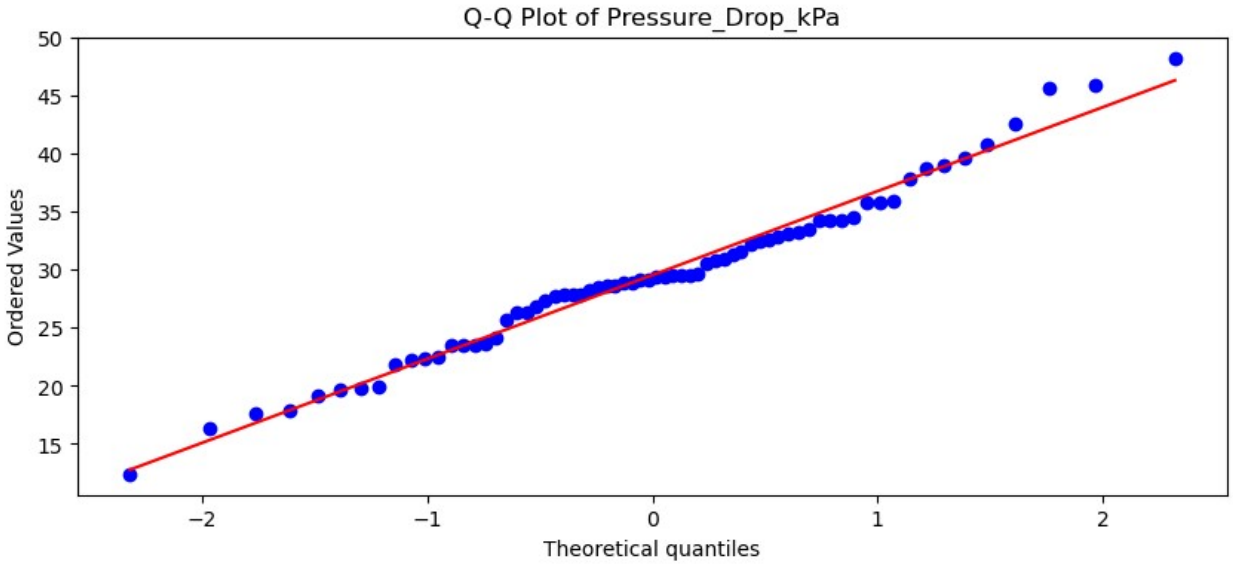

Q-Q Plot of Inlet_Temp_C
Ordered Values
100
90
80
70
60
−2
−1
0
1
2
Theoretical quantiles

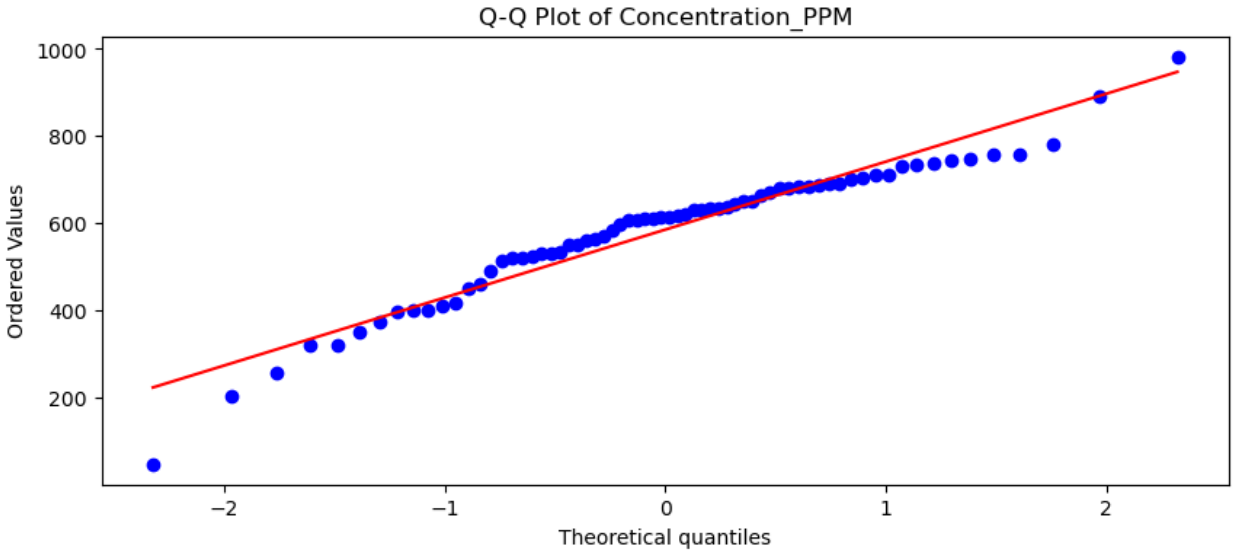

Q-Q Plot of Outlet_Temp_C
Ordered Values
Theoretical quantiles
65
60
55
50
45
40
35
30
−2
−1
0
1
2

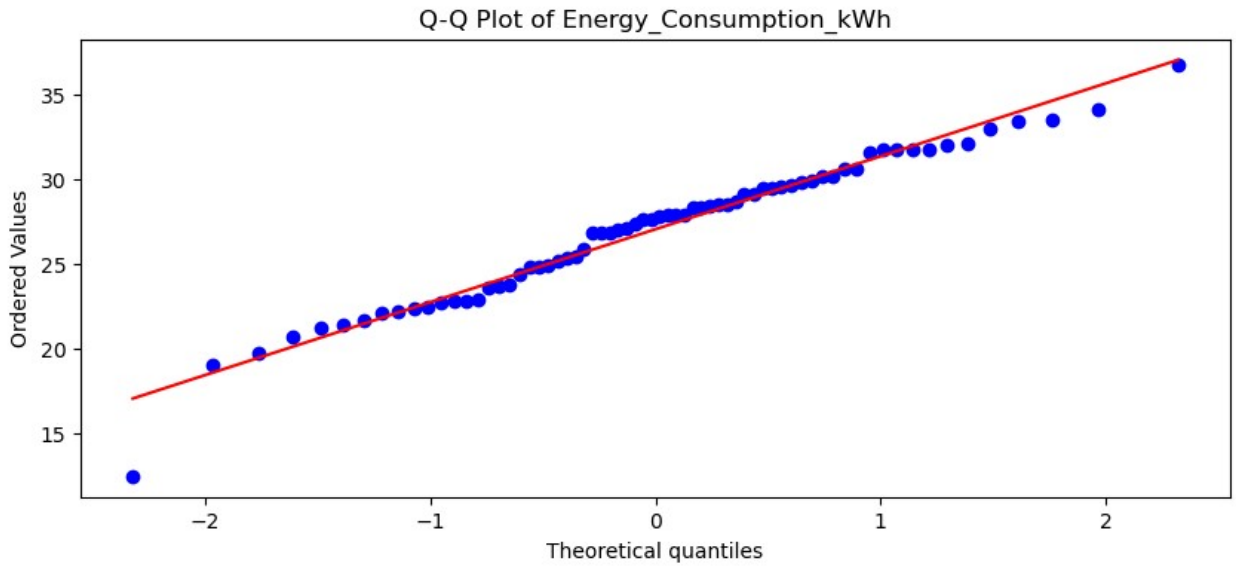

Q-Q Plot of Specific_heat_capacity
Ordered Values
Theoretical quantiles
4.4
4.3
4.2
4.1
4.0
−2
−1
0
1
2


Q-Q Plot of Flow_Rate(L/min)
Ordered Values
Theoretical quantiles
500
400
300
200
100
−2
−1
0
1
2

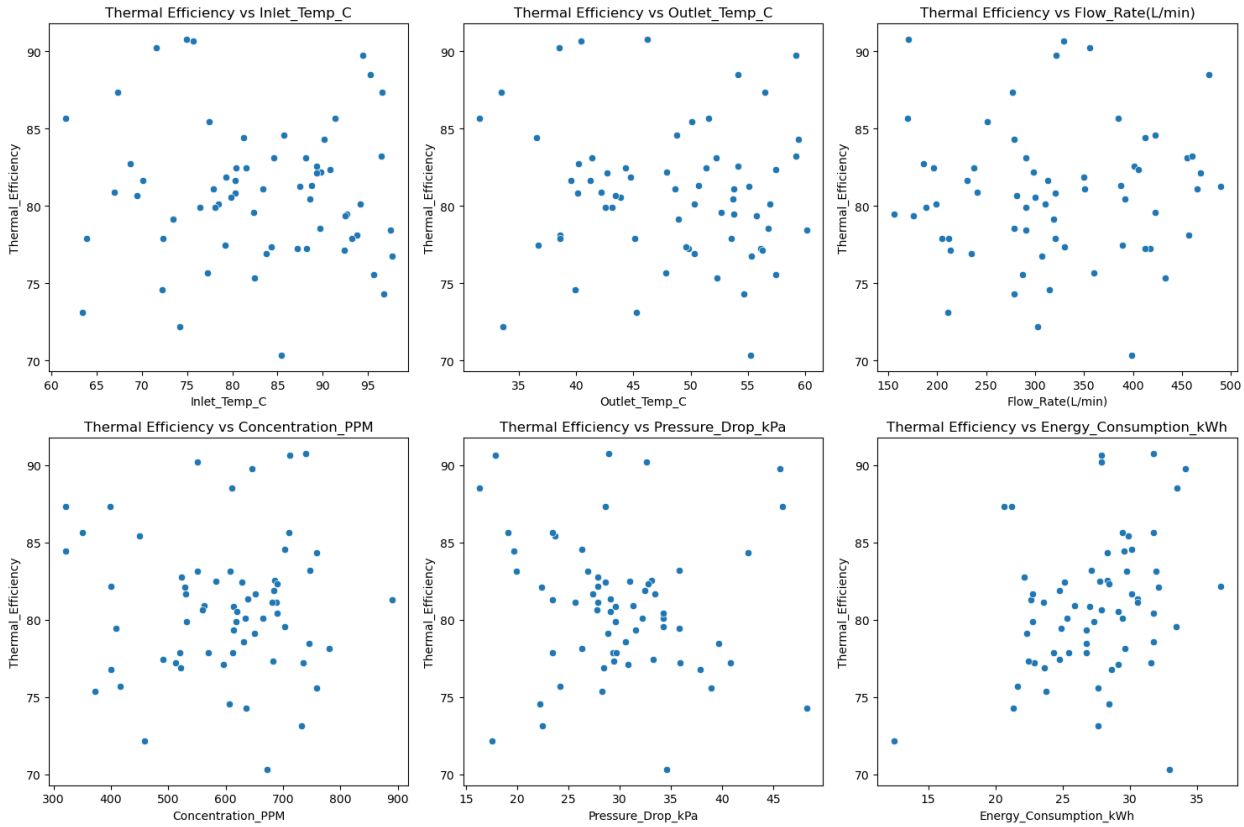

Q-Q Plot of Thermal_Efficiency
Ordered Values
Theoretical quantiles
90
85
80
75
70
−2
−1
0
1
2


Q-Q Plot of Pressure_Drop_kPa
Ordered Values
Theoretical quantiles
50
45
40
35
30
25
20
15
−2
−1
0
1
2


Q-Q Plot of Concentration_PPM
Ordered Values
Theoretical quantiles
1000
800
600
400
200
−2
−1
0
1
2

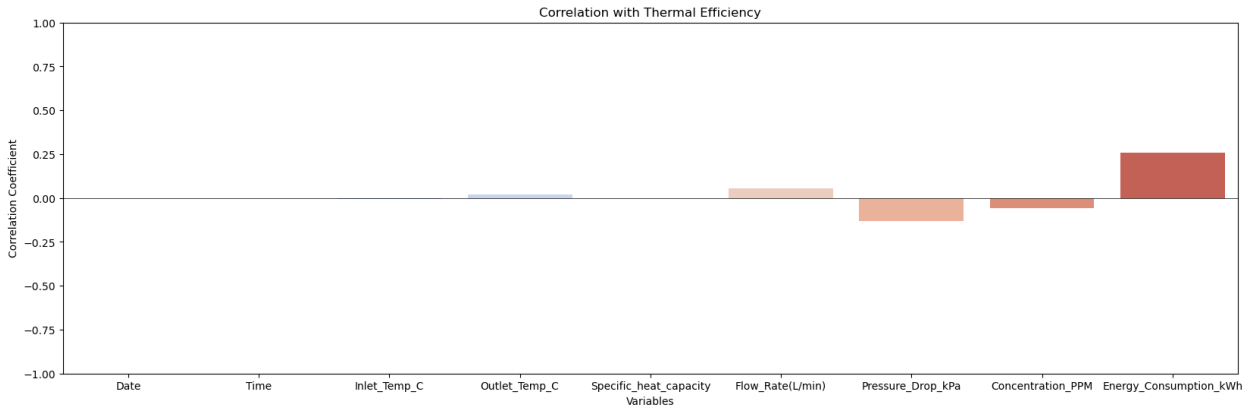



```
# scatter plot is done to determine whether the parameters shows
positive correlation,negative correlation or no relation )
features = ['Inlet_Temp_C', 'Outlet_Temp_C', 'Flow_Rate(L/min)',
'Concentration_PPM', 'Pressure_Drop_kPa','Energy_Consumption_kWh']

plt.figure(figsize=(15, 10))

for i, feature in enumerate(features):
    plt.subplot(2, 3, i+1)
    sns.scatterplot(x=df_no_outliers[feature],
y=df_no_outliers['Thermal_Efficiency'])
    plt.title(f'Thermal Efficiency vs {feature}')
    plt.xlabel(feature)
    plt.ylabel('Thermal_Efficiency')

plt.tight_layout()
plt.show()
```




```
#assignning the old name to the new data frame
df = df_no_outliers

#Positive Bars: Variables with positive bars are positively correlated
with Thermal_Efficiency. As these variables increase,
Thermal_Efficiency tends to increase.
#Negative Bars: Variables with negative bars are negatively correlated
with Thermal_Efficiency. As these variables increase,
Thermal_Efficiency tends to decrease.
#Height of Bars: The height (or depth) of each bar indicates the
strength of the correlation.

corr_matrix = df.corr()

# Extract correlations with Thermal Efficiency
thermal_efficiency_corr =
corr_matrix['Thermal_Efficiency'].drop('Thermal_Efficiency')

# Create a bar plot for visualizing the correlations
plt.figure(figsize=(20, 6))
sns.barplot(x=thermal_efficiency_corr.index,
y=thermal_efficiency_corr.values, palette='coolwarm')
plt.title('Correlation with Thermal Efficiency')
plt.xlabel('Variables')
plt.ylabel('Correlation Coefficient')
```

```
plt.ylim(-1, 1)
plt.axhline(0, color='black', linewidth=0.5)
plt.show()
```



observation from the above finding

Positive Correlations:

1.Energy Consumption (0.25): **The positive correlation suggests that as energy consumption increases, thermal efficiency tends to increase slightly**. 2.Flow Rate (0.10): **The positive correlation with thermal efficiency is very weak. This suggests that changes in flow rate have a minimal effect on thermal efficiency**. Negative Correlations: 1.Pressure Drop: **A higher pressure drop might suggest increased resistance in the system, which could decrease thermal efficiency**. 2.Concentration PPM: **Increased concentration might affect the thermal properties of the slurry, potentially reducing efficiency**.

Statistical Analysis

```
#Hypothesis testing
#Null Hypothesis (H₀)
#There is no significant difference in thermal efficiency between
different levels of pressure drop.
#Alternative Hypothesis (H₁)
#There is a significant difference in thermal efficiency between
different levels of pressure drop.

threshold = df['Pressure_Drop_kPa'].median()
group1 = df[df['Pressure_Drop_kPa'] <= threshold]
['Thermal_Efficiency']
group2 = df[df['Pressure_Drop_kPa'] > threshold]['Thermal_Efficiency']

# Perform T-Test
t_stat, p_value = ttest_ind(group1, group2)
```

```
print(f"T-statistic: {t_stat:.4f}")
print(f"P-value: {p_value:.4f}")
```

```
T-statistic: 1.2727
P-value: 0.2076
```

observation from the above finding

p value >0.05 we failed to reject null hypothesis

```
#Null Hypothesis (H₀)
#There is no significant difference in thermal efficiency related to
energy consumption
#Alternative Hypothesis (H₁)
#There is a significant difference in thermal efficiency related to
energy consumption.

threshold = df['Energy_Consumption_kWh'].median()
group1 = df[df['Energy_Consumption_kWh'] <= threshold]
['Thermal_Efficiency']
group2 = df[df['Energy_Consumption_kWh'] > threshold]
['Thermal_Efficiency']

# Perform T-Test
t_stat, p_value = ttest_ind(group1, group2)
print(f"T-statistic: {t_stat:.4f}")
print(f"P-value: {p_value:.4f}")
```

```
T-statistic: -2.4956
P-value: 0.0151
```

observation from the above finding

p value < 0.05 we reject the null hypothesis