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Model Prediction of The Optimum Production Rate Of An Industrial Lng Plant Using Linear Regression Analysis

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Abstract: - This paper demonstrates the applicability of a linear regression model to accurately determine the expected LNG production rate for a functional industrial LNG plant which uses the C3-MR liquefaction process. A total of 501 data points obtained at times of maximum plant LNG production rates were used for the regression analysis. The model showed a maximum deviation of 1.5375% and an average deviation of 0.4197% from the actual LNG production rate of the plant. The coefficient of determination of the model is 0.6033 with a standard error of 49.8T/D LNG. The model also indicated the strong dependence of LNG production rate on the MR gas turbine inlet air temperature (ambient air temperature) and cooling water supply temperature. The linear regression model obtained is peculiar to the plant considered in this study.

Keywords: - Linear regression, Liquefied Natural Gas, Coefficient of Determination, Standard Error

I. INTRODUCTION

The drive to monetize large stranded gas resources coupled with prudent utilization of gas resource and environmental considerations has led to the developments in Liquefied Natural Gas (LNG) due to the fact that the LNG occupies about 1/600th the volume of natural gas [1]. The historical developments of LNG technologies has been discussed by [2] and the different available LNG technologies by [3].

LNG plants are huge energy intensive process plants for the liquefaction of natural gas. The LNG plant considered in this study is a major LNG facility in Nigeria whose liquefaction process is based on the C3-MR liquefaction process and is shown in Figure1, Figure 2 and Figure 3 [4]. Figure 1 depicts the general overview of the C3-MR liquefaction process used in the plant while Figure 2 and Figure 3 describe the propane cycle and the mixed refrigerant cycle respectively.

Accurate prediction of the expected optimum LNG production rates of LNG plants is critical as it enables plant operators to maximize LNG production and efficiency by comparing actual LNG production rates with the expected value and making necessary adjustments if required to certain other parameters to bring actual production rates close to or above the expected value.

Regression analysis is a statistical technique for estimating the relationship between a dependent variable and one or more independent variables. This relationship is the regression model. In this paper, linear regression is employed to obtain the regression model that is fitted using the least square method to the plant LNG production rate. This model yields the expected LNG production rate of the LNG plant based on the cooling water supply temperature and the MR gas turbine inlet air temperature (Ambient air temperature).

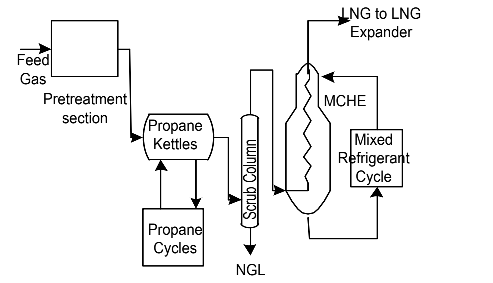

Figure 1 Schematic representation of LNG plant C3-MR liquefaction process

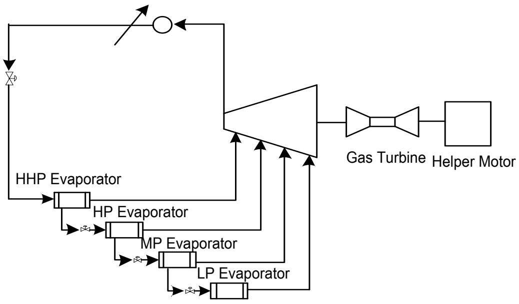

Figure 2 Schematic representation of propane cycle

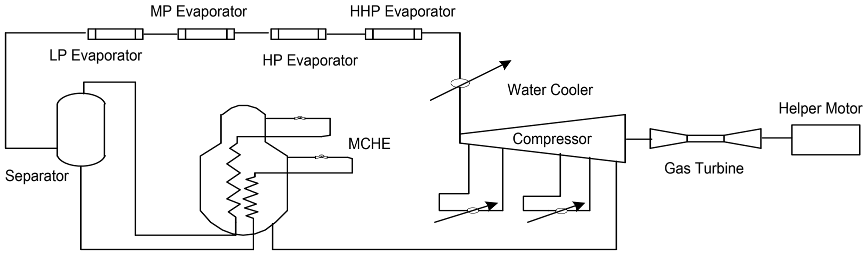

Figure 3 Schematic diagram of mixed refrigerant cycle

Dagde and Okonkwo, [4] developed, validated and simulated a thermodynamic model predicting the LNG production rate of a functional industrial LNG plant using exergy analysis. The model developed showed a maximum deviation of 3.06%. The thermodynamic efficiency of the plant was also calculated to be 45.1%. Previous literatures related to this research have been based on rigorous thermodynamic analysis, process simulation, design and optimization using thermodynamic models constructed in process simulation software. And these studies were limited to the calculation of thermodynamic efficiency, investigation of various approaches to improve thermodynamic efficiency and optimization to minimise energy consumption in various liquefaction processes ([5], [6], [7], [8], [9], [10], and [11]). Sutton [12] had used regression analysis on raw data to obtain second order fits for the pseudo critical properties of natural gas based on 264 different gas samples.

While Dagde and Okonkwo [4] focused on developing a predictive model based on thermodynamic analysis of an LNG plant, this paper demonstrates the applicability of a linear regression model to accurately predict the optimum expected production rate of a functional industrial LNG plant. The knowledge of the optimum expected LNG production rate from an LNG plant will assist plant operators in maximizing their LNG output since the actual plant LNG production rate can be compared to the expected value. Regression analysis of a particular plant data gives results that are peculiar to the plant due to different operational and environmental conditions. Therefore to obtain the regression model for the optimum LNG output of another LNG plant there is need for a regression analysis of the plant data during periods of optimum operations.

II. MATERIALS AND METHODS

The linear regression model describing the LNG production rate ($\dot{m}_{LNG}$) is of the form;

$$\dot{m}_{LNG} = A + BT_{a,MR} + CT_{cws} \qquad 1$$

where, *A*, *B* and *C* are constant coefficients, $T_{a,MR}$ is the MR turbine inlet air temperature (^{o}C), T_{cws} is the cooling water supply temperature. A, B and C are to be obtained by linear regression analysis.

A total of 501 data were obtained during the periods of maximum LNG plant production rates for the regression analysis. These periods represents the periods when the plant is operating most efficiently without any anomalous constraints. Although the data obtained includes LNG composition, MR helper motor power, MR turbine inlet air temperature, cooling water supply temperature, NGL extraction temperature, Feed gas pressure, LNG temperature and LNG production rate only the MR turbine inlet air temperature and the cooling water supply temperature as shown in Table 2 proved useful in obtaining the regression model.

The parameters in the regression model were selected after evaluation of the scatter diagrams of LNG production rate against different independent parameters for indication of reasonable correlation. Figure 4 and Figure 5 shows the scatter diagrams of LNG production rate against cooling water supply temperature and MR gas turbine inlet air temperature. Although the C3-MR liquefaction process used by the plant has both the propane cycle and the MR cycle with their dedicated gas turbine and helper motor, the MR cycle parameters were preferred because the MR cycle is limiting i.e the propane cycle has some excess capacity. The data was analysed and the constants A, B and C obtained using the regression tool in the analysis toolPak of Microsoft Excel Spreadsheet.

III. RESULTS AND DISCUSSION

Figure 4 and Figure 5 show the scatter diagram of the LNG production rate (T/D) against cooling water temperature (^oC) and MR inlet air temperature (^oC).

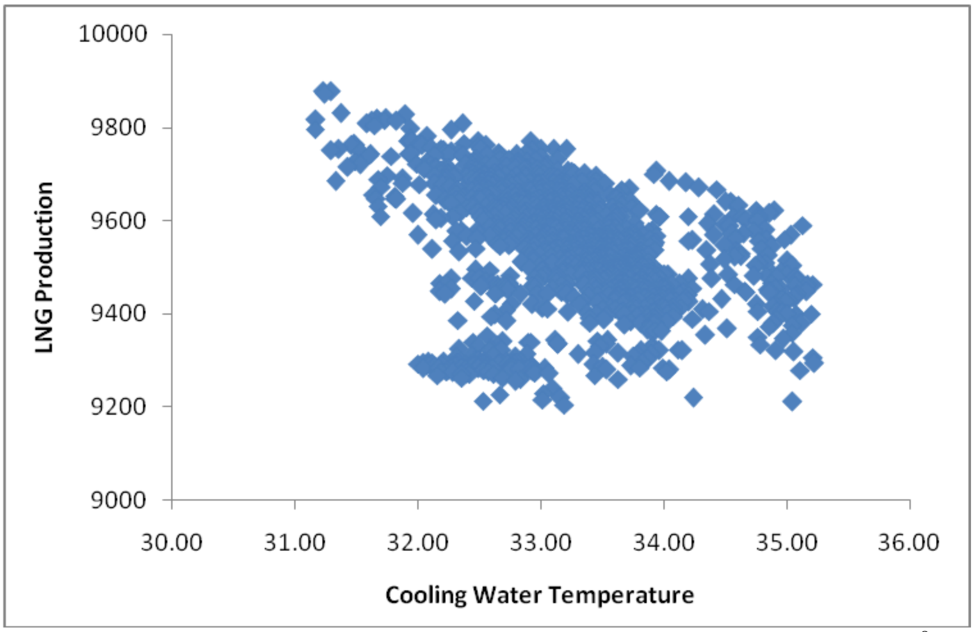

Figure 4: Scatter diagram of LNG production (T/D) to cooling water temperature (^oC)

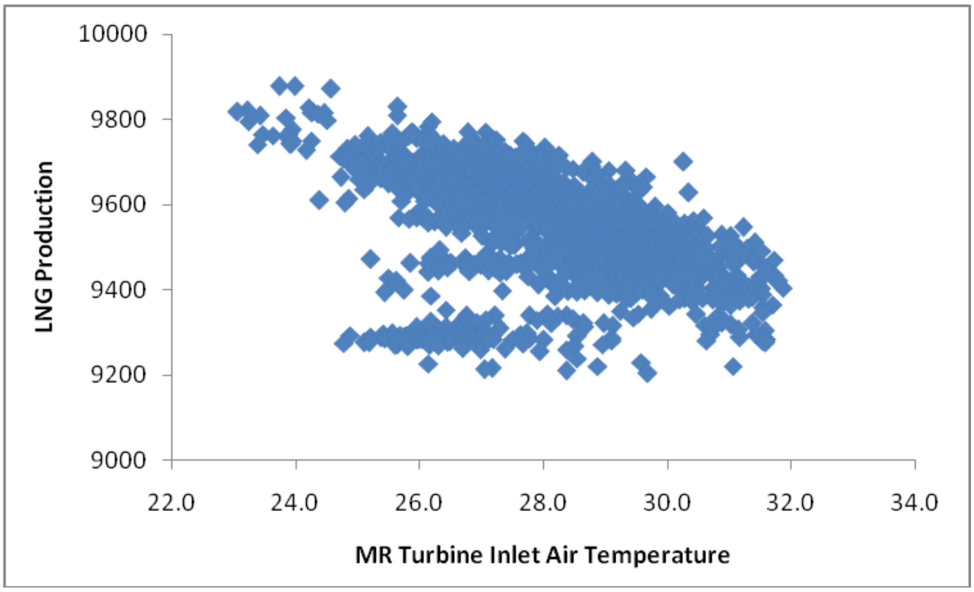

Figure 5: Scatter diagram of LNG production (T/D) against MR Turbine inlet air temperature (^oC)

Figure 4 and Figure 5 show a significant correlation of LNG production rate to cooling water temperature and MR turbine inlet air temperature. This indicates that at maximum LNG production rates, the LNG production depends significantly on these parameters.

From the data analysed, there is no significant correlation between the LNG production rate and the LNG temperature although LNG production rate depends strongly on LNG temperature [4]. There was also no significant correlation between the LNG production rate and the MR turbine helper motor power, the LNG production rate and the LNG composition, the LNG production rate and feed gas pressure and the LNG production rate and the NGL extraction temperature as suggested by Dagde and Okonkwo, [4]. These can be explained by the very low variation in the data for these parameters. They were essentially constant and therefore variations in LNG production rate did not depend on them. Optimisation of the LNG temperature and NGL extraction temperature of the plant had fixed the LNG temperature and NGL extraction temperature for the plant, MR helper motor power and feed gas pressure are at the maximum and the LNG composition does not vary significantly due to LNG specification.

The values of the constant coefficients A, B and C, its respective standard error and its lower and upper values at 95% confidence level obtained from linear regression analysis of the plant data is shown in Table 1.

Table 1: Coefficients and Standard error of coefficients in linear regression model

Coefficients	*Value*	*Standard Error*	*Lower 95%*	*Upper 95%*
A	11662.17	115.4272	11435.39	11888.96
B	-26.4672	2.008292	-30.413	-22.5214
C	-39.4378	4.399538	-48.0817	-30.7938

Substituting the values of the constant coefficients A, B and C into equation 1 yields,

$$\dot{m}_{LNG} = 11662.17 - 26.47T_{a,MR} - 39.44T_{cws} \qquad 2$$

Equation 2 is the linear regression model which predicts the optimum expected LNG production rate for the LNG plant considered in this study. The linear regression model indicates that LNG production rate is increased when the MR gas turbine inlet temperature is lower (lower ambient temperature) and when the cooling water supply temperature is lower in agreement with Dagde and Okonkwo, [4].

Table 2 compares the plant data and the predictions of model [Eq. 2]. It may be seen from Table 2 that the predicted data agree reasonably well with the plant data.

Table2: Comparison of Plant data and Model Prediction

MR turbine inlet air Temperature (^{o}C)	Cooling Water Supply Temperature (^{o}C)	Plant LNG (T/D)	Predicted LNG (T/D)	% Deviation
23.73	31.23	9878	9802	0.7665
23.98	31.30	9877	9793	0.8494
23.22	31.67	9821	9799	0.2232
23.07	31.17	9817	9822	0.0499
23.24	31.17	9796	9818	0.2268
23.94	31.94	9775	9769	0.0602
23.47	31.48	9765	9800	0.3554
24.26	31.30	9750	9786	0.3687
24.84	32.48	9731	9724	0.0738
24.92	31.53	9720	9759	0.4026
25.55	32.53	9708	9703	0.0508
26.02	32.46	9694	9693	0.0060
28.02	31.88	9681	9663	0.1804
25.71	32.54	9668	9698	0.3095
27.04	32.94	9655	9647	0.0788
25.18	31.82	9647	9741	0.9706
27.40	33.39	9632	9620	0.1255
27.77	33.28	9611	9614	0.0367
26.51	32.58	9600	9676	0.7921
29.02	33.28	9587	9582	0.0519
28.25	33.76	9573	9583	0.1095
28.46	34.98	9559	9529	0.3106
29.55	33.93	9538	9542	0.0491
30.12	33.70	9511	9536	0.2651
27.96	33.82	9498	9588	0.9476

The maximum deviation of the model prediction from the plant LNG production is 1.5375% (150 T/D) and its average deviation is 0.4197% (40 T/D) for the entire data used in the regression analysis. This indicates that this linear regression model accurately predicts the expected optimum LNG production rate from the LNG plant. Therefore the expected LNG production rate for this LNG plant strongly depends on the ambient temperature and cooling water supply temperature. The deviations from the plant LNG production rates are due to the presence of other parameters not accounted for in the regression model.

Table 3 shows the results obtained from the linear regression analysis of the plant operating data. The coefficient of determination (R square) is 0.6033 with a standard error of 49.8T/D LNG. This indicates a good fit of the linear regression model to the plant LNG production rate as shown in Figure 6.

Table 3: Regression Results

Multiple R	0.7767
R Square	0.6033
Adjusted R Square	0.6017
Standard Error	49.8027
Observations	501

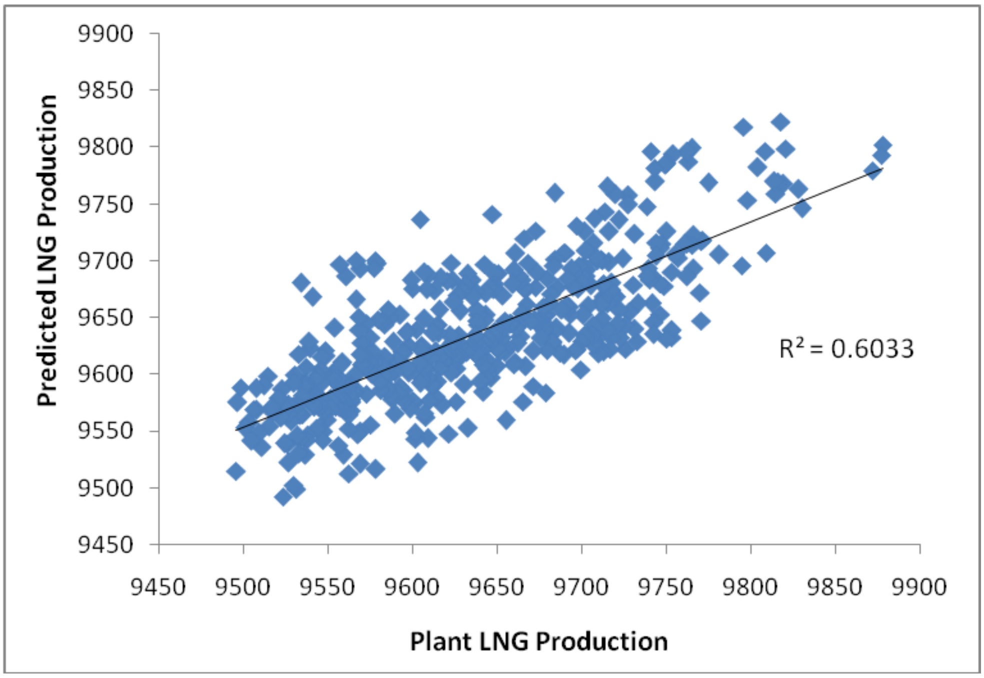

Figure 6. Graph of Predicted LNG production rate (T/D) to Plant LNG production rate (T/D)

The linear regression model explains about 60% of the variation of the LNG output. The actual LNG production rate from the plant is within ± 98 T/D of the regression model prediction within a 95% confidence interval as calculated from the standard error. This also indicates that the model is accurate and reliable to calculate the expected LNG production from the plant.

IV. CONCLUSION

The statistical method, linear regression, was used to analyse 501 data points obtained from a functional industrial LNG plant during periods of maximum LNG production. A linear regression model which accurately predicts the expected LNG production rate from the plant was developed and validated. The maximum and average % deviation of the model prediction to the plant LNG production rate is 1.5375% and 0.4197% respectively. The model indicates that the expected LNG production rate from the plant depends strongly on the ambient air temperature (MR turbine inlet air temperature) and cooling water supply temperature. The coefficient of determination of the model was 0.6033 with a standard error of 49.8T/D LNG. The actual LNG production rate from the plant is within ± 98 T/D of the regression model prediction within a 95% confidence interval.

REFERENCES

[1] R. Khalilpour, I. A. Karimi, Evaluation of Utilization Alternatives for Standard Natural gas; *Energy*, 40, 2012, 317-328.

[2] P. Bosma, R.K. Nagelwort, Liquefaction Technology: Developments through History, *Proceedings of the First Annual Gas Processing Symposium*, Doha, Qatar, 2009, 1-13.

[3] T. Shukri, LNG Technology Selection, *Hydrocarbon Engineering*, 9, (February), 2004 71-74.

[4] K.K. Dagde, O. C. Okonkwo, Development of Predictive Thermodynamic Model for Liquefaction of Natural Gas using the C3-MR Refrigeration Process; *International Journal of Engineering and Technology,* 2(11), 2012, 1861-1871.

[5] G. Tsatsaronis, T. Morosuk, Advanced Exergetic Analysis of a Refrigeration System for Liquefaction of Natural gas; *International Journal of Energy and Environmental Engineering*, 1, (Fall), 2010, 1-17.

[6] V. Ravavarapu, J.H.Oakley, C.C. White, Thermodynamic Analysis of a Baseload LNG Plant; Proceeding of the Chemical 96: Excellence in Chemical Engineering: 24th Australian and New Zealand Chemical Engineering Conference and Exhibition: 1996, 143-148.

[7] M. Konoglu, Exergy Analysis of Multistage Cascade Refrigeration Cycle used for Natural Gas Liquefaction; *International Journal of Energy Research*, 26, 2002, 763-774.

[8] P. Rodgers, A. Mortazavi, E. Eveloy, S. Al-Hashimi, Y. Hwang, R. Radermacher, Enhancement of LNG Plant Propane Cycle through Waste Heat powered Absorption cooling, *Applied Thermal Engineering*, 48, 2012, 41-53.

[9] M. Wang, J. Zhang, Q. Xu, Optimal Design and Operation of a C3MR Refrigeration System for Natural Gas Liquefaction; *Computers and Chemical Engineering*, 39, 2012, 84-95.

[10] A. Alabdulkarem, A. Mortazavi, Y. Hwang, R. Radermacher, P. Rogers, Optimisation of Propane Pre-cooled Mixed Refrigerant LNG Plant; *Applied Thermal Engineering*, 31, 2011, 1091-1098.

[11] A. Aspelund, T. Gunderson, J. Myklebust, M. P. Nowak, A. Tomasgard, An Optimisation-Simulation Model for a Simple LNG Process; *Computers and Chemical Engineering*, 34, 2010, 1606-1617.

[12] R.P. Sutton, Compressibility Factor for High Molecular Weight Reservoir Gases; SPE 14265, *paper presented at the SPE Annual Technical Conference and Exhibition*, Las Vegas, NV, 1985.

NOMENCLETURE

T_{cws}	Cooling Water Supply Temperature
$\dot{m}_{LNG}$	LNG Production Rate
$T_{a,MR}$	MR Gas Turbine Inlet Air Temperature
C3-MR	Propane Pre-cooled Mixed Refrigerant
LNG	Liquefied Natural Gas
MR	Mixed Refrigerant