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EXERGY EVALUATION OF THE VACUUM DISTILLATION UNIT OF THE PORT HARCOURT REFINERY

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ABSTRACT

The exergy analysis of the Vacuum Distillation Unit of the Port-Harcourt Refinery was carried out using Aspen-HYSYS 2006 Software for the characterization and simulation of the unit. From the study, the total energy lost in the unit was 99.423% with efficiency of 0.577%. This is an indication of high wastage of energy within the unit; therefore, there is the need to revamp the unit for optimum energy integration and utilization.
Keywords: *Energy utilization, exergy analysis, process revamp and improvement.*

INTRODUCTION

An important goal of process improvement in any industry is to tap as fully as possible all the likely secondary energy sources and to put them to industrial and domestic use, beneficial economically and ecologically (Kutepov et al., 1998). Inefficiencies in energy utilization and materials conversion manifests (or is evident) in pollution and increase energy cost. Improvement in process efficiency on account of reduction in the thermodynamic losses will have a positive impact in the reduction of energy cost of a process industry. Waste represents a great loss of resources in terms of both material and energy since high level of process emissions can be traced to inefficient production process. Specifically, when the process efficiency is reduced, more energy and materials are required to meet a specified production output. Similarly, more effluents are generated, with increased in the flue gas emissions; resulting in more cooling and increased usage of water treatment chemicals. Therefore, the solution that should meet the present day challenges; is the sustainability and incorporating schemes that reduce energy utilization, and control emissions on the first instance. This could be achieved by taking a holistic analysis of the exergy utilization of the process to discover energy utilization efficiency and factors that require improvement. In general, distillation process has been identified as a consumer of large amount of heat energy for separation of mixtures. Findings have shown that separation process to recover or purify products account for over 40% of the chemical process energy demand (Trambouze, 1995) Revamping of distillation system is not a new concept, but it is assuming greater importance today due to ever increasing energy cost and environment problems.

Therefore, industries are now finding innovative methods to maximize their returns from existing plants rather than investing in new facilities, thus the column revamping has become necessary (John , 1998). The potential economic gains achievable through revamp approach includes: increase system throughput, higher recovery of raw materials, better product yield, more efficient use of energy and operating personal. A lot of work has been done on exergy analysis of chemical processes. Rakesh and Herron, (1998), studied the use of intermediate re-boiler for the integration of the re-boiler and the condenser for efficient energy utilization.

Also, pre-fractionation can be used to reduce energy consumption in distillation without changing the utility temperature. Rivero *et al.,* (1995) presented new distillation column, adiabatic distillation, where two heat exchanger units were integrated in the column to replace the re-boiler and condenser. The exchangers were incorporated below and above feed point for heat supply and extraction. This arrangement minimizes entropy production in the system with energy losses of only about 56.6% as against 94.2% for the conventional distillation columns. Etim and James (2007), reported that pollution from process plant is an evidence of inefficiencies in raw material conversion and energy utilization by using energy analysis in the hydrofluoric acid akylation plant of the Warri Refinery. It is very clear that improvement in process efficiency on account of reduction in thermodynamic (i.e. energy) losses has a far reaching impact on the level of emissions released from a process industry. However, literature on the energy evaluation of the Vacuum Distillation Unit of the Port Harcourt Refinery is scarce. The purpose of this work is to carry out a second law thermodynamic (exergetic) analysis of the Vacuum Distillation Unit of the Port Harcourt Refinery to determine the efficiency of exergy utilization and the potential for the process improvement through revamp. The process flow sheet of the Vacuum Distillation Unit of the Port Harcourt Refinery and aspen-HYSYS 2006 model software were used for the analysis.

Exergy Analysis

For a closed and reversible system, Lothar, (1974) reported that

$$dH = dq + dW$$
(1)

Where, H is the enthalpy of the system, q and W are the heat and shaft work (or electrical energy), respectively, being absorbed. If the system exchanges heat with the surroundings at T_0, the change of entropy of the system is (Abdullahi and Adefila 2006).

$$dS \geq \frac{dq}{T_0}$$
(2)

equation (2) in equation (1) yields

$$dW = dH - T_0 dS$$
(3)

where the equality sign applies to reversible processes.

The amount of work of the shaft, $d\varepsilon$ which can be recovered by reversing a process characterized by dH and dS (Smith and Van Ness, 1975; Rivero et al.., 1995)

$$d\varepsilon = dH - T_0 dS$$
(4)

If H_0 and S_0 are the enthalpy and enthropy respectively of a closed system in equilibrium at T_o at a velocity V_o, when work can be obtained from it in the given surroundings, then

$$\varepsilon = (H - H_0) - T_0(S - S_0) + Q - Q_0 + \frac{1}{2}(V^2 - V_0^2)$$
(5)

is the maximum amount of work (shaft or electrical) which can become available from the system if it can exchange heat only with a heat reservoir at T_o. Q is specific potential energy. For zero potential and kinetic energy, exergy, ε is given as

$$\varepsilon = H - H_0 - T_0(S - S_0) \quad (6)$$

The exergy balance of a system is given by (Etim and James, 2007)

$$\sum \varepsilon_{in} - \sum \varepsilon_{out} = \textit{Exergy consumed or lost} \quad (7)$$

where $\sum \varepsilon_{in}$ is exergy input and $\sum \varepsilon_{out}$ is the exergy output.
The efficiency of exergy utilization, η is given by

$$\eta = \frac{\sum \varepsilon_{out}}{\sum \varepsilon_{in}} \quad (8)$$

The potential for revamp (or process improvement), ψ is given as

$$\psi = 1 - \eta$$

Characterization and Simulation of the VDU of the Port-Harcourt Refinery

The characterization and simulation of the VDU was based on data obtained from the plant and the process flow sheet. The aspen-HYSYS 2006 software was used in the characterization of the feed to the VDU and the simulation of the plant. The results of the characterization are presented in Appendix A. Results of the simulation is also presented in Table 1.

Table 1: Summary of Simulation Results and Exergy of Various Units of the VDU

Component of the VDU	Exergy Input KJ/hr	Exergy Output KJ/hr	Efficiency of Exergy Utilization %	Potential for Revamp %
Mixer	-1771551.04	-96123.08	5.80	94.20
E100	-3010790.80	-281489.28	9.30	90.70
E101	-2575561.20	-224274.16	8.70	91.30
E102	-2828282.80	-250039.10	8.80	91.20
Fired Heater	-139934647000.00	-11262970.00	9.90	90.10
Vacuum Column	-5.143×10^{11}	-3740835482.00	0.70	93.30
Component Splitter	-515830540.20	-28586612.30	5.54	94.46
TOTAL	-6.55×10^{11}	-3781536990.00	48.74	

TOTAL EXERGY ANALYSIS:

Total Input Exergy = -6.55×10^{11}
Total Output Exergy = -3781536990.00
Total Exergy Efficiency = 0.577%
Total Revamp Potential = 99.423%

Results and Discussion

From Appendix A, the characterization of the crude gave 59 distinct hypo components having a normal boiling point ranging from 505^{o}C-873^{o}C. This is an indication that about 59 products could be obtained by distillation of the feed in the temperature range. The result also showed that the feed was 771kmol/hr with an output of 596.8kmol/hr, as vacuum gas oil while 26.02 kmol/hr of sour water was obtained as product. Among other products formed are 0.4158kg/hr of LVGO and 0.7027kgmol/hr of HVGO. The result in Table 1 showed high wastages in exergy; having efficiencies ranging from 5.54% to 9.9%, indicating high revamp potential (i.e 94.46% to 90.1%). The vacuum distillation column has an exergy losses of 93.30% which is very close to the 94.2% reported in literature for conventional distillation columns (Lothar, 1978) The sum of the exergy efficiencies of the various units is not equal to the total exergy efficiency of the VDU, which is consistent with the works of Abdullahi and Adefila(2006). The useful work done on the system (i.e VDU) is 0.577% of the total work done on the unit, as such the remaining 99.923% of the work done is wasted; potential for revamp is 99.923%.

CONCLUSION

The exergetic analysis which is based on the second law of thermodynamics was carried out on the Vacuum Distillation Unit of the Port Harcourt refinery. The efficiency determined showed high wastages in energy utilization and high potential for a revamp of the unit. For optimum energy utilization, in a world of even increasing energy demands and cost, it is recommended that, if the Port Harcourt Refinery must be a global player in the energy market, a total revamp of their VDU.must be carried out.

Appendix A: Characterization of Crude Feed into the VDU of the Port Harcourt Refinery

STREAMS	VACUUM FEED	VACUUM DISTILLATION COUMN			
		VACUUM GAS OIL	SOUR WATER	SLOP OIL	
				LVGO	HVGO
AMOUNT(kmol/hr)	771.0	596	26.02	0.4158	0.7027
COMPOSITION (moI%)					
H_2O	0.0000	0.0000	0.0000	0.0000	0.0000
NBP[0]505*	0.3465	0.4476	0.0002	0.0340	0.0000
NBP[0]519*	0.3394	0.4384	0.0003	0.0364	0.0000
NBP[0]534*	0.4028	0.5203	0.0004	0.0478	0.0000
NBP[0]549*	0.5529	0.7142	0.0007	0.0737	0.0000
NBP[0]563*	0.6671	0.8617	0.0011	0.0997	0.0000
NBP[0]577*	0.7680	0.9919	0.0016	0.1302	0.0000
NBP[0]594*	1.2582	1.6265	0.0036	0.2495	0.0000
NBP[0]606*	1.3399	1.7305	0.0049	0.3010	0.0000
NBP[0]621*	2.6511	3.4238	0.0131	0.7059	0.0000
NBP[0]635*	2.3981	3.0968	0.0640	0.7560	0.0000
NBP[0]650*	2.8483	3.6776	0.0269	1.0969	0.0000
NBP[0]664*	3.0747	3.9690	0.0415	1.4602	0.0000
NBP[0]679*	3.1691	4.0895	0.0640	1.9100	0.0000
NBP[0]693*	3.6067	4.6514	0.1128	2.8191	0.0000
NBP[0]716*	9.7659	12.5690	0.6555	11.9608	0.0000
NBP[0]739*	9.9403	12.7131	16619	20.5948	0.0000
NBP[0]770*	7.9603	9.7799	5.2656	35.2461	0.0000
NBP[0]797*	8.3366	8.2953	18.7244	0.0000	39.2121
NBP[0]824*	6.6198	2.7329	28.5554	0.0000	30.2566
NBP[0]851*	4.3341	0.2720	15.1212	0.0000	7.7814
NBP[0]877*	3.0196	0.0234	6.1982	0.0000	1.7247
NBP[0]906*	1.8911	0.0016	2.0021	0.0000	0.3483
NBP[0]950*	1.8441	0.0001	0.7535	0.0000	0.1094

NBP[1]494*	0.1014	0.1310	0.0001	0.0093	0.0000
NBP[1508*	0.1085	0.1402	0.0001	0.0108	0.0000
NBP[1]522*	0.1218	0.1573	0.0001	0.0134	0.0000
NBP[1]537*	0.1385	0.1790	0.0002	0.0168	0.0000
NBP[1]551*	0.1717	0.2218	0.0002	0.0233	0.0000
NBP[1]565*	0.2262	0.2922	0.0004	0.0345	0.0000
NBP[1]581*	0.4067	0.5254	0.0009	0.0711	0.0000
NBP[1]592*	0.5257	0.6790	0.0015	0.1024	0.0000
NBP[1]608*	0.8625	1.1139	0.0033	0.1980	0.0000
NBP[1]622*	0.7357	0.9501	0.0037	0.1982	0.0000
NBP[1]636*	08525	1.1009	0.0059	0.2734	0.0000
NBP[1]650*	0.8642	1.1158	0.0083	0.3353	0.0000
NBP[1]665*	0.8921	1.1516	0.0123	0.4287	0.0000
NBP[1]679*	0.9872	1.2739	0.0202	0.5998	0.0000
NBP[1]693*	1.1842	1.5271	0.0372	0.9279	0.0000
NBP[1]715*	2.9093	3.7448	0.1892	3.4981	0.0000
NBP[1]741*	2.4828	3.1723	0.4500	5.3848	0.0000
NBP[1]769*	2.3722	2.9192	1.5271	10.352	0.0000
NBP[1]796*	2.1813	2.1948	4.7631	0.0000	10.151
NBP[1]824*	1.7060	0.7091	7.3525	0.0000	7.8171
NBP[1]852*	1.1673	0.0691	4.0200	0.0000	2.0298
NBP[1]878*	0.7954	0.0059	1.6106	0.0000	0.4425
NBP[1]906*	0.5214	0.0004	0.5510	0.0000	0.0958
NBP[1]951*	0.5512	0.0000	0.2172	0.0000	0.0315
NBP[2]626*	0.0000	0.0000	0.0000	0.0000	0.0000
NBP[2]640*	0.0000	0.0000	0.0000	0.0000	0.0000
NBP[2]653*	0.0000	0.0000	0.0000	0.0000	0.0000
NBP[2]667*	0.0000	0.0000	0.0000	0.0000	0.0000
NBP[2]681*	0.0000	0.0000	0.0000	0.0000	0.0000
NBP[2]694*	0.0000	0.0000	0.0000	0.0000	0.0000
NBP[2]718*	0.0000	0.0000	0.0000	0.0000	0.0000
NBP[2]745*	0.0000	0.0000	0.0000	0.0000	0.0000
NBP[2]778*	0.0000	0.0000	0.0000	0.0000	0.0000
NBP[2]808*	0.0000	0.0000	0.0000	0.0000	0.0000
NBP[2]839*	0.0000	0.0000	0.0000	0.0000	0.0000
NBP[2]873*	0.0000	0.0000	0.0000	0.0000	0.0000
TEMPERATURE ^{O}C	407	488.3	629.7	540.4	571.4

NOMENCLATURE

VDU	Vacuum Distillation Unit
Atm-res	Atmospheric Residue
Longres	Long residue
Vac feed	Vacuum feed
Vac gas	Vacuum gas
VR	Vacuum residue
So	Slop Oil
LVGO	Light Vacuum gas oil
HVGO	Heavy Vacuum Gas Oil
VRO	Vacuum residue Oil

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