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Design of a Vapor Recovery Unit for a Condensate Fractionation Plant to Minimize Hydrocarbon Vapor Loss

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Abstract

A condensate fractionation plant recycles vapors coming from the tank batteries and from the fractionation column by a vapor recovery unit (VRU). Otherwise, these valuable hydrocarbons would be lost through flaring or venting to the atmosphere. VRU is a multi-stage compressor, with intercooler and after cooler. The VRU must be designed such that it is not over-sized or under-sized. The project examined an existing plant of 4,000 barrels/day capacity and attempted to re-design the VRU for scenario where additional 6,000 barrels/day will be added to the plant capacity. The major obstacle in this task is to correctly estimate the total volume of vapor to be handled. There is no facility for direct measurements, so the amount of vapor must be estimated from correlations and by process simulation. The volume of the by-products from the fractionation column was estimated by using software, which simulated the whole fractionation process. With the help of tank data from the site, an analytical calculation was performed to compute the amount of tank vapor. A compressor for the VRU system was designed to handle the estimated total amount of hydrocarbon vapor. The benefit of using VRU from an environmental point of view was included in this work. New technologies to minimize tank vapor loss, such as construction of floating roof tanks, were also considered. The results obtained from the calculation and simulation steps reflect actual values from the plant with minor deviation, which gave confidence in this design process. The calculations indicate that, for the proposed capacity upgradation, the required VRU compressor should have 1.62 times greater capacity and 1.63 times greater horse power in case of fixed roof tanks. With floating roof, both the additional capacity and horsepower is negligible.

Keywords: Condensate fractionation, Vapor Recovery, Fractionation plant, Fractionation column, Tank battery, Condensate vapor loss.

1. Introduction

Condensate Fractionation is a distillation process where the heavy part of the raw material (condensate) is converted into diesel and the lighter parts are divided into Petrol (Motor Spirit/MS), Kerosene, Octane by utilizing different relative volatility (USA Patent No. 2134700, 1983) and stored in tanks. During distillation, off-gas is produced at the top of the column as a by-product and continuously flared into the environment which produces noise and thermal radiation as well as creates air pollution (Enam, 2015). Furthermore, in storage tanks (especially condensate and motor spirit tanks), a significant amount of hydrocarbon evaporates by venting to maintain the pressure in the tank, which is a waste of valuable fuel (Stricklin, 2020). A condensate fractionation plant (CFP) in Bangladesh, with 4,000 barrels per day (BPD) condensate handling capacity, produces fuels. A Vapor Recovery Unit (VRU) is used in this plant to recover the off-gas and tank vapors which are reused as utility gas. There is a plan to build an additional 6,000 BPD facility. Therefore, it is needed to scrutinize whether it can handle further hydrocarbon vapor generated in the new unit or whether a new VRU needs to be designed.

2. Methodology

Before designing the VRU compressor and associated system, off-gas volume and tank vapor loss volume for the new plant are needed. The analytical calculation to determine the off-gas volume from the column is complicated. But simulation software like steady-state process simulator AspenTM HYSYSv11 is a powerful approach and widely used in refinery industries before the installation of plants for modeling and also during operation stages for comparing with real-time process parameters. The distillation unit is one of the most complex unit operations that HYSYS simulates, where the Peng-Robinson fluid property package is used for modeling (Fares, 2020). The volume of vapor loss determination from the tanks requires a lot of variable data and assumptions which vary from plant to plant depending on locations and weather (Emission Factor Documentation for AP-42 Section 7.1, Organic Liquid Storage Tanks, 2006).

Finally, VRU compressor design will be conducted based on the total volume of hydrocarbon from tanks and process area. Theoretically, the isothermal compression process needs minimum compression work which is economically favorable. But in practice, this is not feasible. That is why, adiabatic/isentropic compression is followed by using multi-stages with intercoolers used between stages to make the process near to isothermal. VRU compressor's design parameters like the capacity, compression ratio, required horsepower and other parameters need to be taken into consideration during compressor design (Ikoku, 1992) (Kumar, 1987).

3. VRU Design for 6,000 BPD Capacity

3.1. Off Gas Estimation

Initial data (chemical and physical properties) of feed (condensate) was entered into the calculation window as oil manager in HYSYS to convert into a series of discrete hypothetical components to predict the remaining thermodynamic and transport properties. Once the characterization of the fluid is completed, the equipment and necessary data are added to the simulation environment to run the simulation (Aspen Technology, 2005). When the column converges and all other connections of equipment are fitted, the simulated result of the products' volume is achieved and shown in Table 1. The HYSYS Scheme for 6,000 BPD CFP is shown in Figure 1.

Table 1: Simulated Volume of Products for 6,000 BPD Plant

Product Name	Mass Flow lb/hr	Percent
Motor Spirit	4.413×10^4	64.76 %
Kerosene	2.105×10^4	30.88 %
Diesel	2976	43.68 %
Off-Gas	22.02	0.32 %
Total	**6.815×10^4**	**100%**

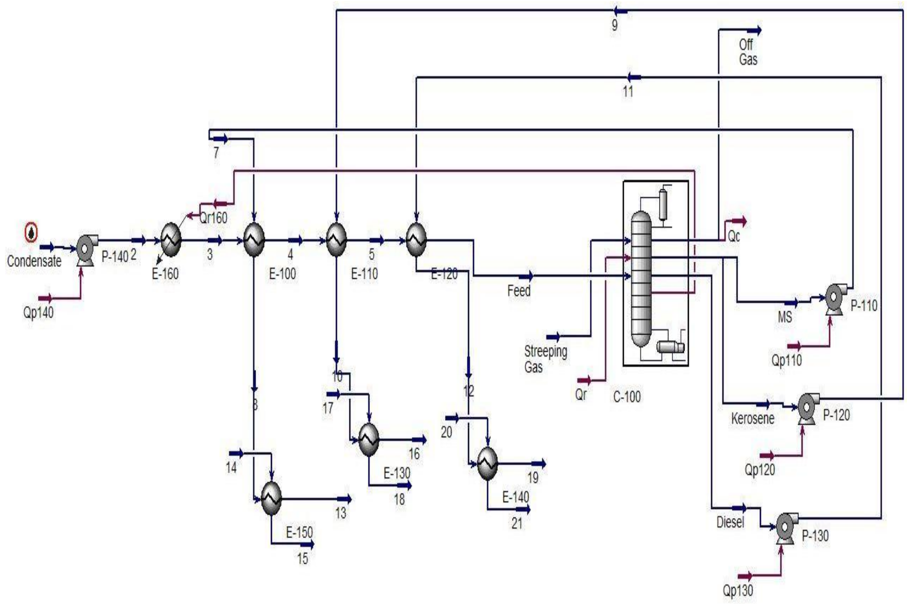

Figure 1: HYSYS Scheme for 4000 BPD Condensate Fractionation Plant

3.2. Tank Vapor Losses Calculation

In 4,000 BPD plant, the size and quantity of the storage tanks can provide the feed to process and store the products from the process for 38 days if the feed intake operation is interrupted. Based on that viewpoint, the storage tank for 6,000 BPD will be 17 in number for the same diameter and height as the existing 4,000 BPD plant with variable data, such as daily tank operation procedure, tank mechanical data, meteorological conditions etc. Among these 5 for condensate, 4 for MS, 7 for Kerosene and 1 for Octane storage. Vapor will be generated from condensate and MS tanks.

In the new unit, the tank can be either a fixed roof type or an internal floating roof type. Because it is observed that, there is a significant difference in vapor generation based on different types of tank construction. The fixed roof tanks are the least expensive yet generate the highest amount of vapor as there is no control system to reduce the vapor generation. On the other hand, floating roof tanks minimize vapor generation because the roof adjusts its height in accordance with the liquid level. That is why, the void space between the roof and liquid level is insignificant. Therefore, the tank vapor as well as the VRU capacity and other calculations are done for 2 (two) scenarios.

3.3. Compressor Design

The off-gas from the process and low-pressure vapor from tanks are entered in the VRU system common header. As tank vapor pressure is low, a booster fan is used to increase the pressure same as off-gas. The three streams (Off-gas, MS Vapor & Condensate Vapor) passed through a mixer to obtain the VRU Pre Inlet Vapor, which is then connected to a 2-phase separator as, a VRU Suction Scrubber for early liquid-gas separation (Figure 2). The gas from the scrubber as "VRU Com Inlet Vapor" then feeds to the VRU Compressor which is a reciprocating compressor. And the liquid goes to the condensate tank through a Close Drain Drum. With all the data, the overall calculation for the design of the 6,000 BPD plant VRU system has been made. The power requirement for the compressor is maximum as in the calculation, option to use a VFD was not included.

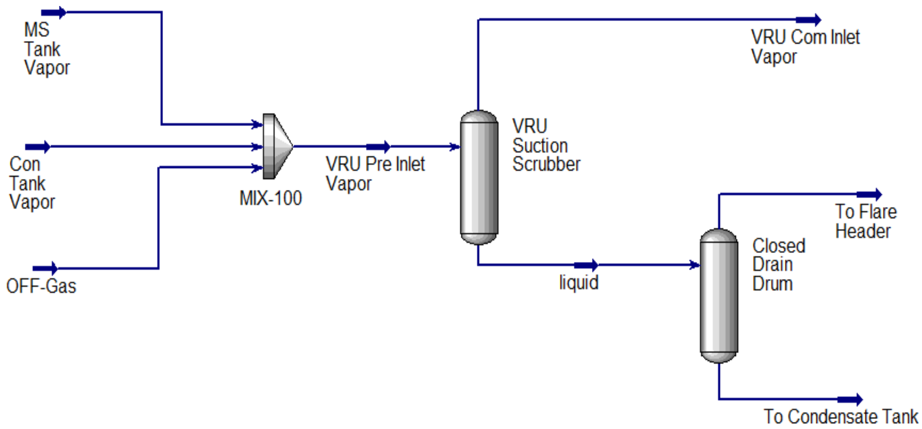

Figure 2: 60,000 BPD Plant VRU Compressor Inlet Scheme

4. Environmental Concerns

Gas flaring is a major environmental concern the world faces today as it generates a significant amount of greenhouse gases, especially CO2, contributing to the overall burden of global warming. Also flaring causes some local environmental problems, such as thermal and heat radiating, agricultural impact, etc. (Soltanieha, Zohrabianb, Gholipourc, & Eugenia, 2016). If there were no VRU system the amount of CO2 from flare would be 0.0549 metric tons/MSCF Flared gas (Greenhouse Gases Equivalencies Calculator, 2023).

Moreover, the venting of unburned hydrocarbons also releases other chemical compounds into the atmosphere, especially methane CH4 and may result in health risks to the local population as well as increase the greenhouse effect. Methane is 21 times more impactful as a greenhouse gas than CO2 over a 100-year timeline (Ngene, Tota- Maharaj, Eke, & Hills, 2016).

5. Results and Discussions

The volume of off-gas, tank vapor and VRU compressor parameters estimated above are summarized in Table 2.

It is seen that the off-gas quantity for the new unit is 1.5 times larger than the 4,000 BPD plant as predicted because preliminary data of feed is used from the existing plant. The simulation ran successfully with the same tray number (24 trays). For cost- effectiveness and efficiency, sieve trays are used for existing plant and also will be considered for future unit (Kolmetz & Dwijayanti, 2011). The vapor generated from the tank batteries varies significantly based on the types of tanks that will be constructed in an additional 6,000 BPD unit. If tanks are made as fixed roof type, same as the old unit, the volume of vapor will be roughly 1.62 times higher, whereas if floating roof type tanks are constructed the volume will be insignificant (99 times lesser) than the existing plant.

Table 2: Summary of Results

Description	4,000 BPD Plant (existing)	6,000 BPD Plant (Proposed)	
		Fixed Roof	Internal Floating Roof
Off-Gas Volume, MMSCFD	$2,062.76 \times 10^{-6}$	$3,094.14 \times 10^{-6}$	
Vapor Losses from Tank, MMSCFD	$136,945.00 \times 10^{-6}$	$222,950.61 \times 10^{-6}$	$1,382.55 \times 10^{-6}$
Capacity of VRU Compressor, m^3/hr	182	295.54	5.32
Compressor Stage	2		
Ideal Horsepower for Compression, hp	22.4	36.55	0.73
Break Horsepower for Compression, hp	28	45.69	0.91
Heat Removed by Intercooler, Btu/D	-	12.26×10^5	0.24×10^5
Heat Removed by Aftercooler, Btu/D	-	11.40×10^5	0.23×10^5
CO2 Emission, metric ton/year	62		
Amount of Heat Radiation by Flare, Btu/year	11.71×10^8		

The capacity of the compressor at present will not be able to handle the volume of gas for the proposed 6,000 BPD capacity. For a fixed roof tank, a 1.62 times higher capacity with 1.63 times higher horsepower (than the existing one) compressor is needed for compression work of the 6,000 BPD Plant. That means an additional 113.54 m^3/hr hydrocarbon will be required to be compressed by a new compressor along with the existing compressor. On the other hand, if an internal floating roof tank is installed, then only 6 m^3/hr additional capacity compressor needs to be added. Also, the horsepower requirement will be very negligible.

The quantity of CO_2 for the 6,000 BPD plant is equivalent to carbon sequestered by 1,025 tree seedlings grown for 10 years (EPA, 2023). Also, the flare would radiate 11.71 x 10^8 BTU heat per year.

6. Conclusions and Recommendations

Based on the existing operational process, the simulation software obtains the off-gas volume, and the tank vapor volume is calculated by analytical approach. After that, these two values are fed to the VRU compressor design calculation. A new compressor must be installed for either fixed roof type or internal floating roof type tanks. Vapor generation volume varies significantly for different tank construction methods, which has a substantial impact on the calculation of total VRU compressor capacity, horsepower requirement and other values. Tank vapor losses will be reduced by approximately 161 times in the internal floating roof type than in the fixed roof type. From a technical point of view, floating roof tanks will be preferable as a trivial amount of vapor will be generated. However, as the economic aspect is not the scope of this paper, a comparative study of VRU compressor construction cost based on tank types can be evaluated as future work. Moreover, the detailed calculation and effectiveness of using variable frequency drive (VFD) in the VRU compressor for production proficiencies and energy savings can be explored. From an economic point of view, a huge number of hydrocarbons would be wasted every year as a by-product if VRU is not installed. Last but not the least, VRU will provide a cleaner environment for on-site personnel and inhabitants near the vicinity.

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Nomenclature

BPD	Barrel Per Day
BTU/D	British Thermal Unit per Day
CFP	Condensate Fractionation Plant
EPA	Environment Protection Agency
hp	Horsepower
lb/hr	Pound per Hour
MMSCFD	Million Standard Cubic Feet Per Day