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SPECIAL FEATURES

Building a Better Competitive Positioning in the Downstream Industry – Crude Oil Refining Economy

Old Affinity Laws for Variable Speed Centrifugal Pumps

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Building a Better Competitive Positioning in the Downstream Industry – Crude Oil Refining Economy

Dr. Marcio Wagner da Silva

Introduction

As any industrial activity, the crude oil refining industry aims to get profits through the commercialization of derivatives of interest to society. In this sense, the downstream sector aims to add value to the crude oil through a series of chemical and physical processes aiming to obtain marketable crude oil derivatives with the lower environmental impact as possible.

Refiners profitability is directly proportional to his capacity to add value to the processed crude oil, aiming to maximize the production of high added value streams and derivatives. Equation 1 presents a simplified concept of the liquid refining margin.

$$Liquid\ Refining\ Margin = \sum_{i}^{n}(Di\ x\ Vi) - Pc - (Fc + Vc)$$

(1)

The first term in Equation 1 corresponds to the obtained revenue through the commercialization of the crude oil derivatives, represented by the sum of the product between the derivative market value and the volume or weight commercialized.

As aforementioned, the profitability or refining margin is directly proportional to the refinery capacity to add value to the processed crude slate, the maximization of higher added value derivatives lead to the maximization of the first term in the Equation 1.

Refining Configurations and Profitability

The maximization of high added value derivatives is directly related with the adopted refining scheme, Figure 1 presents a basic process flow diagram to a typical refinery operating with the "Topping" refining configuration, considered the simplest and with the lower complexity of the available refining schemes.

Nowadays, this refining scheme is less practicable once the purely physical processes difficultly achieve an economically attractive level of crude oil conversion, furthermore, the produced derivatives have high contaminants content, especially sulfur and nitrogen, making prohibitive his commercialization as final derivatives without infringing the current environmental regulations, in this case, the derivatives can be commercialized as

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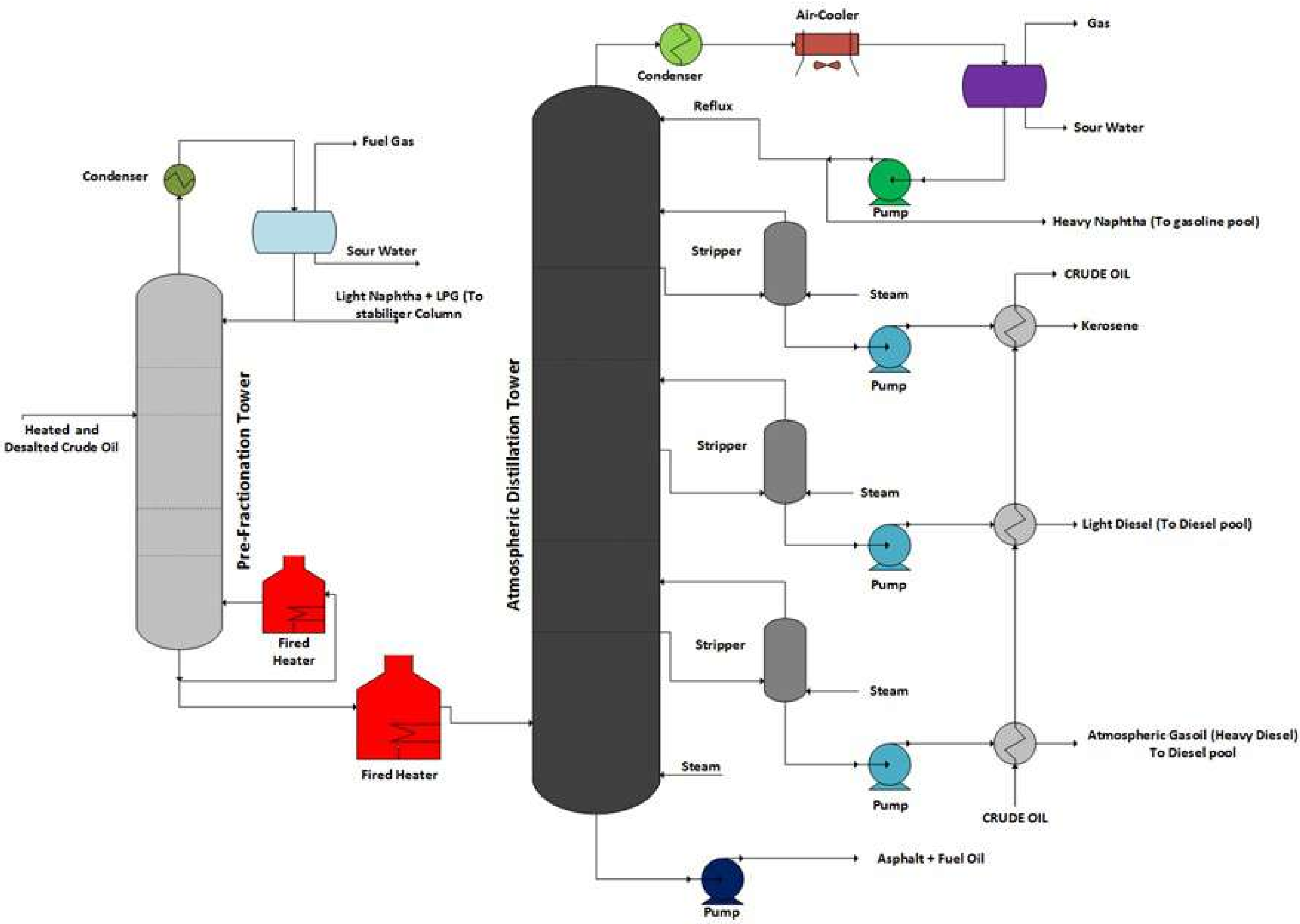

Figure 1 – Typical Process Configuration to a Refinery with "Topping" Refining Configuration

intermediate streams that have relatively low added value. The quantity of asphalt and fuel oil which are products with low added value and restricted market produced in a Topping refinery makes his operation uncompetitive economically. In this cases, the profitability is normally reached only under the processing of specific crude oils (lighter and with lower level of contaminants), that have high acquisition cost and restrict supply market, leading to a competitive loss.

The addition of higher capacity of treating and conversion, especially of bottom barrel streams makes the crude oil refining scheme more complex, however, raises the yield of high added value derivatives, contributing positively to improve the refining margin, according to Equation 1. Figure 2 shows a typical process flow scheme for a refinery operating under the Coking/Hydrocracking refining configuration. It's important to highlight that the raise of refinery complexity also tends to raise the operational costs.

In the Coking/Hydrocracking refining configuration, the production of fuel oil and asphalt is reduced to the minimum needed to meet the available market consumer, delayed coking and hydrocracking units raises the production of higher added value derivatives as naphtha, diesel, and kerosene that allow a significant improvement in the refiner profitability.

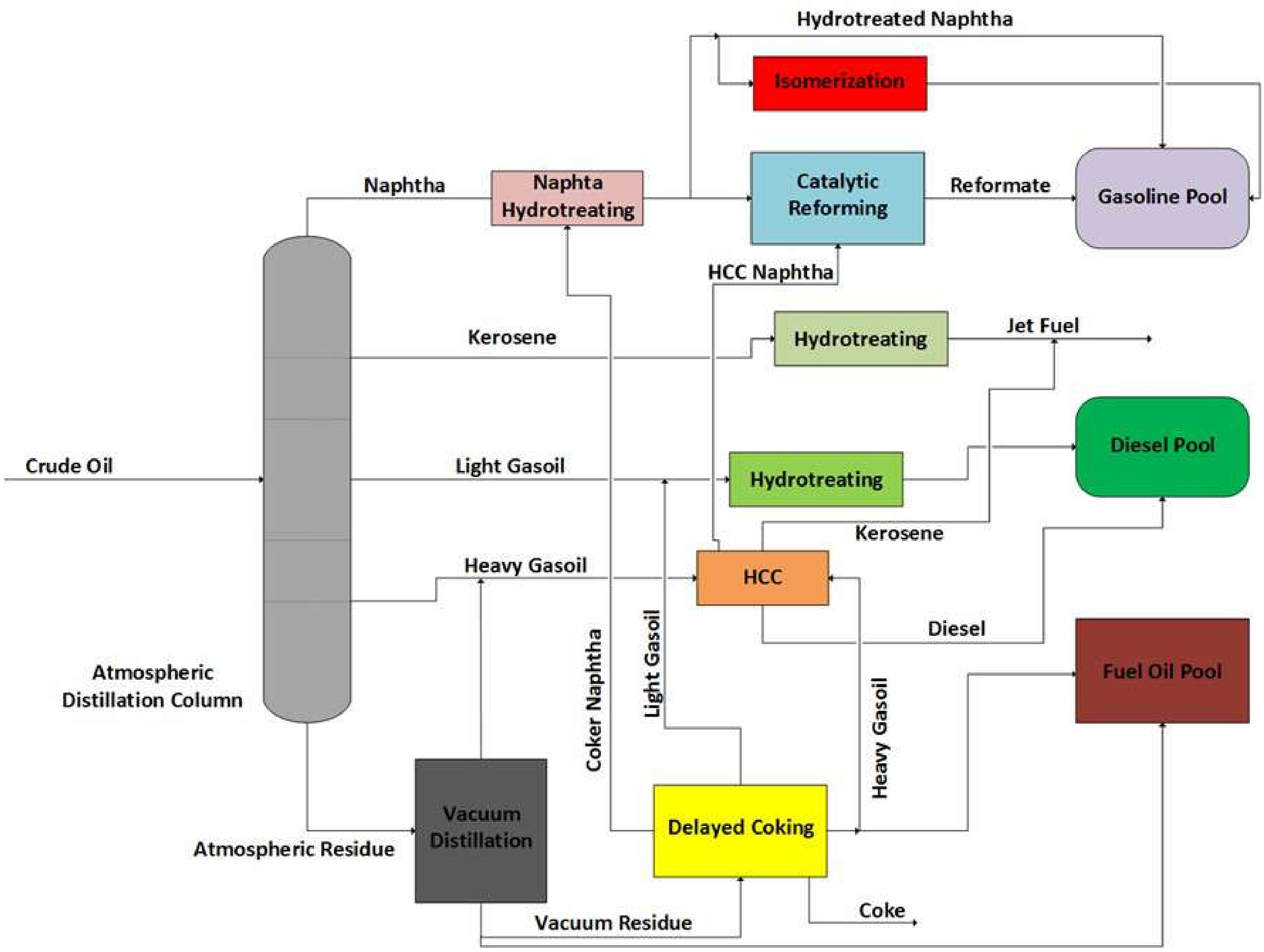

Figure 2 – Process Arrangement for a Typical Refinery Operating Under Coking/Hydrocracking Configuration

Strategies to Raise Refiners Profitability

Even in complex refineries, a common strategy to maximize the liquid refining margin is add to the high added value derivatives the maximum quantity of streams with low added value to compose the final derivative. However, it's necessary to meet some restrictions as presented in Figure 3.

The hydrocarbon mixture which will compose the final derivative needs to respect some restrictions as the available component stocks, market demand, the refining hardware limits, keep the prices attractiveness, and, mainly meet the quality and environmental regulations. The region limited by these restrictions is called "blending space" and, respected these restrictions, is possible to blend the low added value streams to compose the final derivatives.

In the Equation I, the term Pc corresponds to the acquisition cost of the crude oil, the refiners normally don't have control about the market and the acquisition cost of petroleum that is controlled by the geopolitical scenario and the international market. The cost reduction in the crude oil acquisition can be achieved through the processing of heavier crude oils which have relatively low cost, however, due to the lower distillates yield and higher contaminants content, the processing of heavier crude slates requires

Figure 3 – Schematic Representation of the "Blending Space" to Crude Oil Derivatives

refining configurations with higher conversion capacity raising the operational costs.

The fixed and variable costs, (Fc + Vc) in Equation 1, represents the operational costs of refiners. Figure 4 shows a simplified scheme to the profitability in the downstream industry, highlighting the refiners cost composition.

According to Equation 1 and Figure 4, an attractive strategy to maximize the refiners profitability is to reduce the operational costs. Energy consumption in the refining hardware is responsible by the major part of the variable costs, in this sense, an adequate energy management plan has a key role to allow that the refiners achieve higher economical results.

Another factor with great relevance in the refinery profitability is the equipment availability that is directly related to the maintenance management aiming to ensure market compliance and avoid production loss events due to equipment unavailability. Currently, the downstream industry has been looked to achieve a prescriptive model in the asset management in the sense of to anticipate to failures of critical equipment's, minimizing losses of production or market opportunities. Figure 5 introduces the evolutive pathway in the maintenance management highlighting the characteristics of the prescriptive model.

In real scenarios, it's necessary to take account seasonality factors in the demand by derivatives as well as regional peculiarities that can represent specific markets to refiners. The adoption of more complex refining schemes and with higher conversion capacity need be accomplished by a deep market study aiming to ensure a constant demand by higher added value derivatives once the capital cost is significantly higher as well as the operational costs, in other words, the revenue expected by

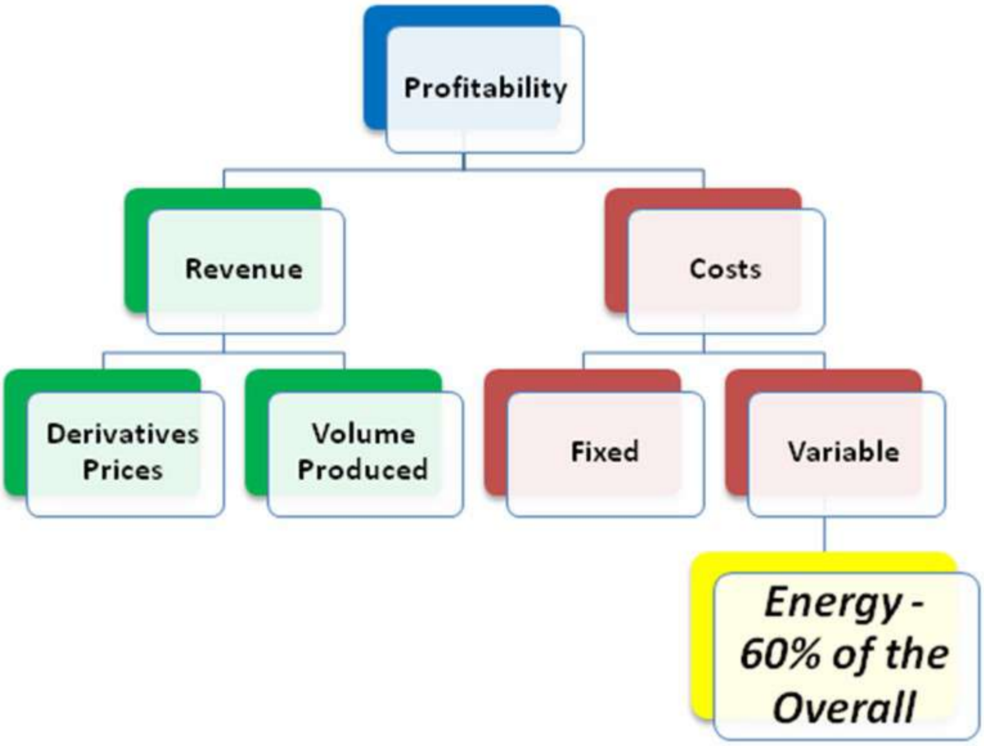

Figure 4 – Simplified Scheme to the Profitability in the Downstream Industry

the derivatives commercialization need to justify the raise in the operational costs and improve the refining margin, according to Equation 1.

One of the most relevant issues in the current scenario of the downstream industry is the new regulation on Marine Fuel Oil (BUNKER), IMO 2020. The new regulation requires the reduction in the sulfur content in this derivative from the current 3,5 % (m.m) to 0,50 % (m.m), according to the adopted strategy, the compliance with IMO 2020 can impact in a significative way the profitability of some refiners.

In a first moment, some refiners can opt to process crude oils with low sulfur content, however, these crude oils have higher acquisition cost and, after the start of new regulation his cost should raise even more and his availability in the market tends to fall creating more pressure over the refining margins (term Pc in Equation 1). Another possible strategy is applying the noblest streams, normally directed to produce middle distillates, as dilutants tom produce the BUNKER with low sulfur content, this can lead to a scarcity of intermediate streams, raising the prices of these commodities. The market of high sulfur fuel oil tends to suffer a strong reduction, once the higher prices gap in relation to diesel should make his production poor economically attractive.

The implementation of deep conversion units to add value to bottom barrel streams can be an interesting alternative, however, the implementation of these units like residue fluid catalytic cracking, hydrocracking, and deep hydrotreating have high capital cost and long term of execution.


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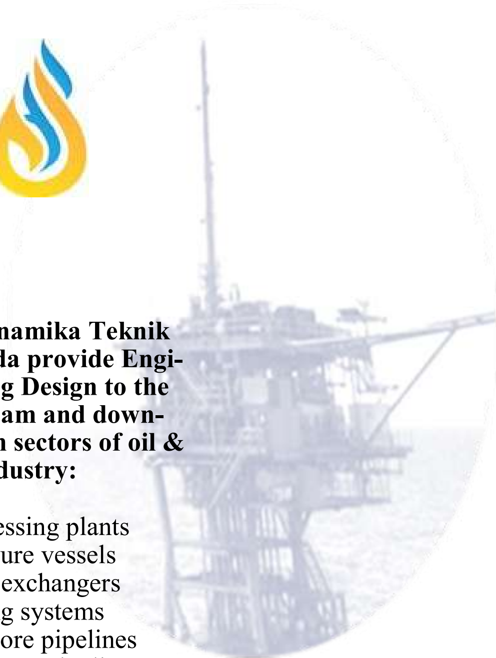

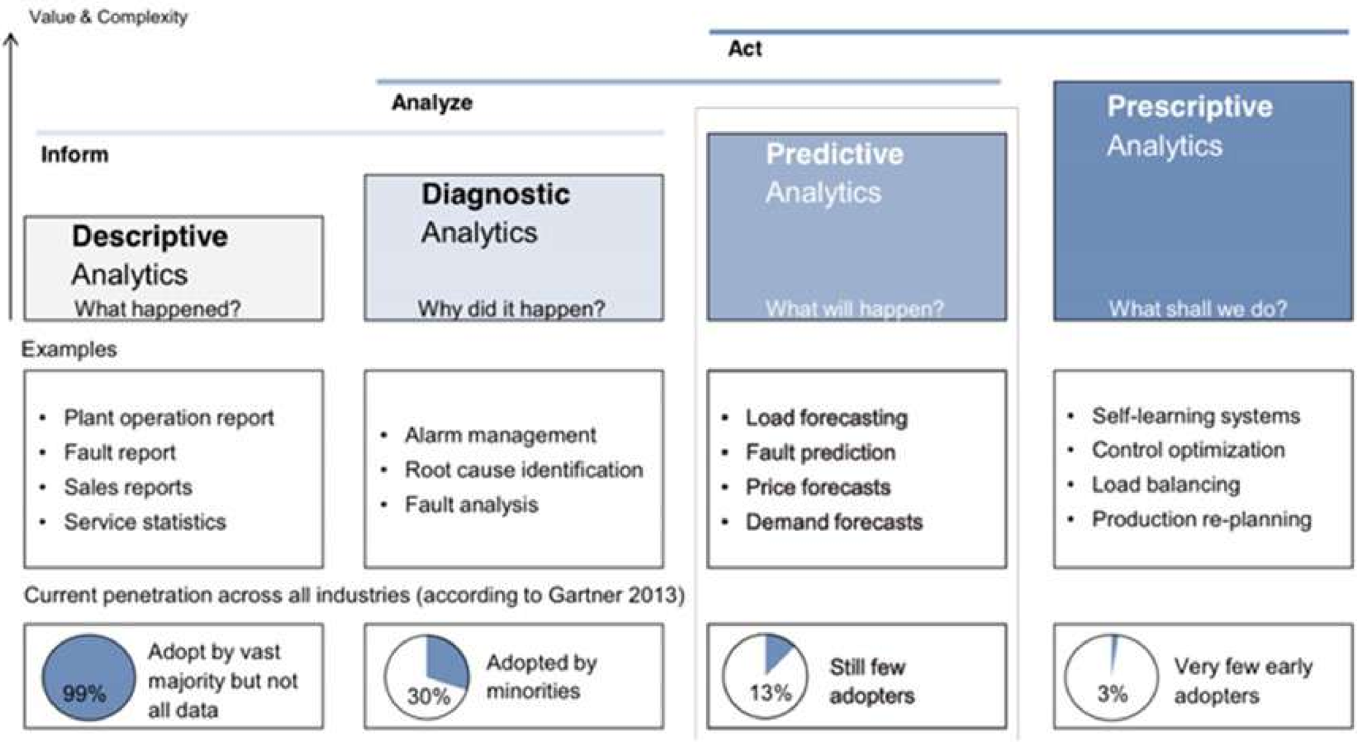

Figure 5 – Evolutive Pathway in the Asset Management (MindIT Company, 2018)

Conclusion

The current scenario of the downstream sector requires higher optimization of the refining hardware aiming to minimize the operational costs and add maximum value to the processed crude oil, in this sense, ensure the operational continuity through adequate maintenance management and reliability is fundamental to keep the financial health of refiners, mainly in highly competitive markets. The volatility in the prices of crude oil and derivatives are constant challenges to refiners and the decision making of capital investments, however, as discussed above there are available strategies to overcome the current and future challenges.

About the Author

Dr. Marcio Wagner da Silva is Process Engineer and Project Manager focusing on Crude Oil Refining Industry based in São José dos Campos, Brazil. Bachelor in Chemical Engineering from University of Maringa (UEM), Brazil and PhD. in Chemical Engineering from University of Campinas (UNICAMP), Brazil. Has extensive experience in research, design and construction to oil and gas industry including developing and coordinating projects to operational improvements and debottlenecking to bottom barrel units, moreover Dr. Marcio Wagner have MBA in Project Management from Federal University of Rio de Janeiro (UFRJ) and is certified in Business from Getulio Vargas Foundation (FGV).

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Old Affinity Laws for Variable Speed Centrifugal Pumps

Jayanthi Vijay Sarathy, M.E, CEng

The world is becoming more conscious of greenhouse gases (GHG) & it's estimated that nearly 10% of the electricity usage is from operating pumps ranging from domestic pumps, sewerage pumps, air conditioning and in every other industrial application. The mechanical aspect of centrifugal pumps have changed fairly little in the last 5 decades, but what has brought a vast change in pump performance is the control system based on a variable frequency drive (VFD).

A centrifugal pump consists of an impeller in a casing that raises the fluid's head for a given speed & discharges liquid at a desired pressure. For applications that require attending to a variable flow scenario, a flow control valve is installed at the pump discharge that throttles fluid pressure to achieve the desired flow. But such methods cause a loss of energy that was initially used to raise the fluid's pressure in the pump.

With the advent of variable speed drives consisting of a pressure sensor & piece of circuitry that alters the frequency of the electric current, the pump's speed parameter can be altered to achieve the required flow & also avoid throttling using a flow control valve. VFD's although tend to cause a temperature rise in the circuitry, sometimes require ventilation systems being incorporated for cooling purposes.

Advantages of Variable Frequency Drives

1. VFD's when newly fitted or retrofitted to rotating machinery such as pumps are referred to as variable speed drives (VSD). For applications where the duty is expected to be constant without much variation in process conditions, a fixed speed drive (FSD) should be more cost effective. But VSD's are mostly suitable for pumping applications where the pump duty is not expected to be constant.
2. Noise & Vibrations are reduced when running at lower speeds.
3. Consumers that use only a small portion of rated flow during varying loads would have the pump running at full load speed corresponding to full load power. In such situations, VFD's help alter the speed to consume less power during operation.
4. VFD's reduce the risk of a motor burnout during start-up from excessive in-rush current & increases the longevity of the equipment.

When VFD's Are Not Advantageous

1. VFD's are not to compensate for an improperly selected pump.
2. In systems with high resistance like boiler feed water (BFW) pumps where the pump has to generate high starting torque to overcome the static head, VFD's do not offer much in terms of providing high start-up torque.
3. Performance curves that cause the operating point to fall off the Q vs. H curves cause the operating point to operate closer to the stall region at lower speeds which can cause cavitation. In such situations, a new pump with a discharge throttle valve is required to push the operating point into the operating envelope which defeats the purpose of retrofitting with a VSD.
4. At lower speeds, though noise & vibrations are reduced, chances exist for structural resonance that can compromise the integrity of the bearing house and support structures.

Selection Process - New Pumps

1. For new pumps its common to oversize the pump but this is not recommended as it adds higher initial cost & higher life cycle costs.
2. When selecting a rotodynamic pump in combination with a VSD for a system with some static head, a pump should be chosen such that the maximum flow rate is slightly to the right-hand side of the best efficiency point (BEP). The exception is for a constant flow regulated system, in which case the recommendation is to select a pump that operates to the left hand side of BEP at maximum pressure. This approach optimizes pump operating efficiency.

3. Some operating profiles may be satisfied best by installing multiple pumps, which could be fixed or variable speed. On/off control can be used to vary flow rate for systems in which intermittent flow is acceptable.

Selection Process - Retrofit Pumps

1. Often a contingency of 20% - 25% on the required system head is added. Therefore retrofitting with VSD's could match pump systems to actual system requirements more accurately to save considerable amounts of energy.

1. When adding a VSD to an existing electric AC motor, the electrical characteristics of the motor & the frequency converter must match. Variable frequency drives work on the principle of altering the frequency of the incoming current using a frequency converter that produces a change in the synchronous speed of the motor for a given number of poles. Therefore frequency converters that give smaller levels of harmonic current distortion is to be chosen to avoid over heating the motor windings and avoid the risk of premature failure.

Performance Curves for VSD Retrofit

Centrifugal Pumps that run on a fixed speed are characterized by a single Q vs. H curve. In the event of a retrofit with a VFD, the pump can operate at various other speeds & correspondingly would have their respective Q vs. H curves.

To estimate the Q vs. H curves at other speeds, Fan Laws a.k.a Affinity Laws can be used. Affinity Laws are used under the premise that

1. Liquids are largely incompressible and their density [r] remains fairly constant.
2. Frictional losses due to impeller & casing construction as well as bearing losses exist at lower speeds but are considered to be lower than the losses experienced at 100% speed.

As per Affinity Laws, Pump speed [N] is related to the Pump Flow [Q], Pump Head [H] & Pump Hydraulic Power [P] as,

$$Q = k_1 N \tag{1}$$

$$H = k_2 N^2 \tag{2}$$

$$P = k_3 N^3 \tag{3}$$

Where k_1, k_2, k_3 are constants.

Once the constants k_1, k_2, k_3 are estimated for the rated curve [100% speed], the Q vs. H curves can be estimated for other speeds, i.e., 90%, 80%, 70%, 60%, 50%, 40%, 30%. It is to be noted that the pump efficiency for a given flow range and for various speeds would be fairly constant and these are referred to as Constant Efficiency [h] lines.

To demonstrate the use of Affinity Laws to derive Q vs. H curves for various speeds, a case study is shown. A motor driven centrifugal pump operating at 50 Hz, delivers water from 5 bara suction pressure to 10 bara discharge pressure. The process parameters & performance curves are as follows,

Table 1. Pump Process Parameters

Parameter	Value
Service	Water
Operating Capacity	372 m³/h
Pump Head	52.4 m
Rotational Speed	1493 rpm
Suction Flange Pressure	5.0 bara
Discharge Flange Pressure	10.0 bara
Liquid Density	973.6 kg/m³

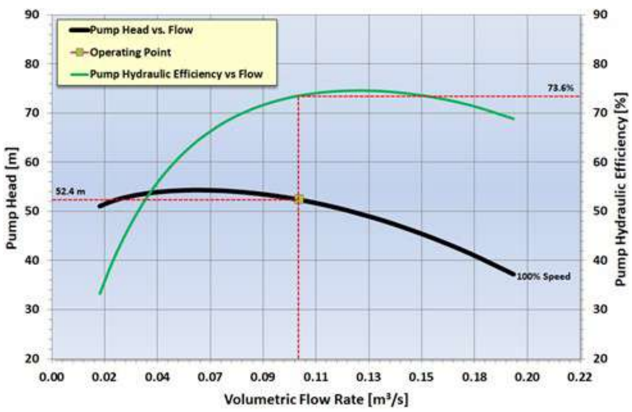

Figure 1. Pump Performance Curves

Pump speeds chosen for retrofitting are,

Table 2. Electric Motor Speeds

Speed [%]	Speed [rpm]
100	1493
90	1344
80	1194
70	1045
60	896

Design Methodology

As described previously, fan constants k_1, k_2, k_3 are estimated for each volumetric flow rate (Q) & corresponding head (H) for 100% speed. Using these k values, Q vs. H curves is calculated for various speeds [Table 2].

$$k_{1,100\%} = \frac{Q}{1493} \tag{4}$$

$$k_{2,100\%} = \frac{H}{1493^2} \tag{5}$$

$$k_{3,100\%} = \frac{P}{1493^3} \tag{6}$$

The hydraulic efficiency is estimated as,

$$\eta = \frac{Q \times \rho \times H}{P} \tag{7}$$

Tabulating the Q vs. H values for the 100% speed case, the values of k_1, k_2 & k_3 are,

Table 3. Fan Law Constants for 100% Speed

Q	H	P	$K_{1,100\%}$	$K_{2,100\%}$	$K_{3,100\%}$
[m³/s]	[m]	[kW]	[m³/s/rpm]	[m/rpm²]	[kW/rpm³]
0.024	51.1	34.9	1.60E-05	2.29E-05	1.05E-08
0.039	53.3	40.5	2.61E-05	2.39E-05	1.22E-08
0.049	54.0	45.0	3.29E-05	2.42E-05	1.35E-08
0.067	54.3	53.7	4.50E-05	2.44E-05	1.61E-08
0.085	53.9	62.4	5.68E-05	2.42E-05	1.88E-08
0.090	53.7	64.9	6.02E-05	2.41E-05	1.95E-08
0.095	53.4	67.4	6.36E-05	2.40E-05	2.03E-08
0.100	53.1	69.9	6.70E-05	2.38E-05	2.10E-08
0.105	52.7	72.3	7.04E-05	2.37E-05	2.17E-08
0.110	52.4	74.6	7.36E-05	2.35E-05	2.24E-08
0.120	51.3	79.5	8.07E-05	2.30E-05	2.39E-08
0.131	50.1	84.1	8.79E-05	2.25E-05	2.53E-08
0.152	47.1	92.4	1.02E-04	2.11E-05	2.78E-08
0.202	37.2	104.1	1.35E-04	1.67E-05	3.13E-08

Using 100% speed k_1, k_2, k_3 values, Q, H, P, h for other speeds shown in Table 2, are,

$$Q_{90\%} = k_{1,100\%} \times N_{90\%} \tag{8}$$

$$H_{90\%} = k_{2,100\%} \times N_{90\%}^2 \tag{9}$$

$$P_{90\%} = k_{3,100\%} \times N_{90\%}^3 \tag{10}$$

$$\eta_{90\%} = \frac{Q_{90\%} \times \rho \times [H_{90\%}/102.04]}{P_{90\%}} \tag{11}$$

$$Q_{80\%} = k_{1,100\%} \times N_{80\%} \tag{12}$$

$$H_{80\%} = k_{2,100\%} \times N_{80\%}^2 \tag{13}$$

$$P_{80\%} = k_{3,100\%} \times N_{80\%}^3 \tag{14}$$

$$\eta_{80\%} = \frac{Q_{80\%} \times \rho \times [H_{80\%}/102.04]}{P_{80\%}} \tag{15}$$

$$Q_{70\%} = k_{1,100\%} \times N_{70\%} \tag{16}$$

$$H_{70\%} = k_{2,100\%} \times N_{70\%}^2 \tag{17}$$

$$P_{70\%} = k_{3,100\%} \times N_{70\%}^3 \tag{18}$$

$$\eta_{70\%} = \frac{Q_{70\%} \times \rho \times [H_{70\%}/102.04]}{P_{70\%}} \tag{19}$$

$$Q_{60\%} = k_{1,100\%} \times N_{60\%} \tag{20}$$

$$H_{60\%} = k_{2,100\%} \times N_{60\%}^2 \tag{21}$$

$$P_{60\%} = k_{3,100\%} \times N_{60\%}^3 \tag{22}$$

$$\eta_{60\%} = \frac{Q_{60\%} \times \rho \times [H_{60\%}/102.04]}{P_{60\%}} \tag{23}$$

With the above set of calculations made, for each calculated values of *Q, H, P, h* for speeds of 90%, 80%, 70%, 60%, the pump performance curves at constant efficiency are as follows,

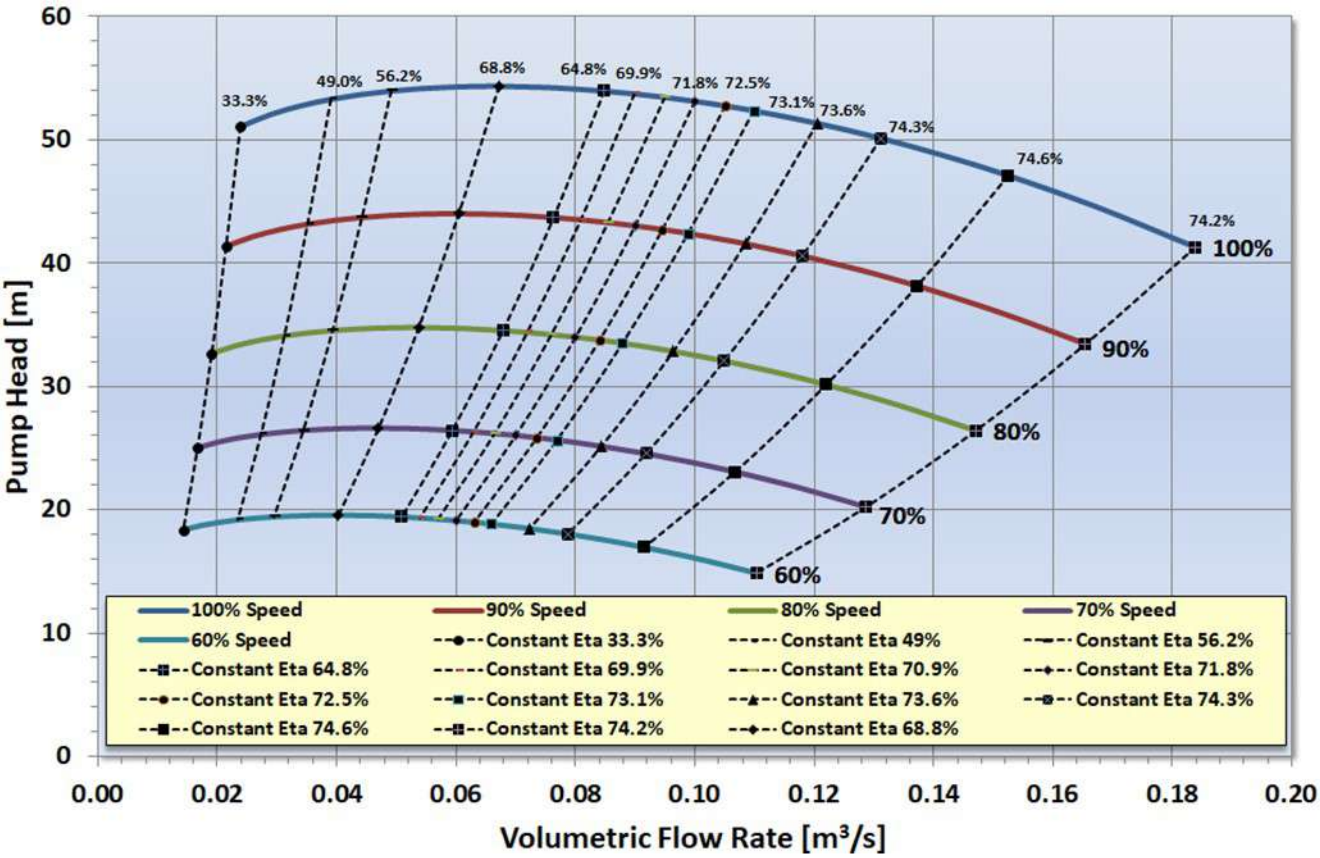

Figure 2. Performance Curves at Constant Efficiency for Various Speeds

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Vijay Sarathy holds a Master's Degree in Chemical Engineering from Birla Institute of Technology & Science (BITS), Pilani, India and is a Chartered Engineer from the Institution of Chemical Engineers, UK. His expertise over 12 years of professional experience covers Front End Engineering, Process Dynamic Simulation and Subsea/Onshore pipeline flow assurance in the Oil and Gas industry. Vijay has worked as an Upstream Process Engineer with major conglomerates of General Electric, ENI Saipem and Shell.

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As we approach the year's end, remember that accurate recording and reporting is imperative. It is also a good tool to use in determining injury trends or even tracking repeaters in your company that continue to get hurt.

There's confusion among employers over which forms should be used and how to record and/or report injuries and illness and those that should be submitted to OSHA or other reporting agencies such as the BLS (Bureau of Labor Statistics). I will explain some things to consider to help those tasked with filling out and maintaining OSHA 300 Injury and Illness logs and I will clarify what should be recorded as an injury or illness, as well as how to account correctly for lost time or limited duty job transfer days.

—Recording and Reporting are different. Know the difference.

—Recording is creating a maintaining an injury log of injuries that have gone above the level of first aid ONLY. Know what injuries and illnesses are recordable.

—Reporting is notifying OSHA or other government agency upon request of your log numbers or it could include reporting to OSHA a workplace death, multiple employee injuries, hospital admissions of one or more employees, an amputation or other serious injury or illness requiring hospitalization.

—This OSHA website provides detailed information and clarity on these issues. https://www.osha.gov/recordkeeping/entryfaq.html

—Build good employees work relationships and transparency regarding injury claims.

—Employees need to understand the importance of being transparent with their employer to properly management an injury claim and track days lost and other log data.

—How to record days and injury cases bases on the case type.

—Count ALL days of the week and weekend lost since the injury occurred, (NOT just business days) when recording days lost or days transferred. The day of injury does not count.

—You "cap" the total days away or transferred recorded and STOP counting at 180 calendar days. So, that means that you stop count days once reaching the max days of injuries and/illnesses resulting in more than 180 total calendar days away, day restricted or total of both in cases where both occur.

—A Recordable Case is classified as a "Death", "Days Away", "Job Transfer" or "Other". You can ONLY pick one case type on the 300 log and it must change as the injury case status gets worse. For example if a "Light Duty Case/Transfer Case" changes to "Days Away" resulting in lost time, the check box on your OSHA 300 log must be moved from "Job Transfer Case" to "Days Away". You can only select one and it must be the most sever outcome of the case.

Describe the Case			Select Type of Case with an X				Enter the # of Days		Select Type of Injury with an X					
			MARK ONLY ONE CASE TYPE below using an X based on the most serious outcome of the injury or illness case:				Enter the # of Days Away or Job Transfer or Restriction		Mark with an X the "Injury Type" Choose ONE type of illness:					
(D) Date of injury or onset of illness (mo./day)	(E) Where the event occured (e.g. Loading dock north end)	(F) Describe injury or illness, parts of body affected, and object/substance that directly injured or made person ill (e.g. Second degree burns on right forearm from acetylene torch)	Enter ONLY one X for each case				Enter Number of Days		(M)					
			Death	Days away from work	Job transfer or restriction	Other record-able cases	Enter the # of Days Away from Work	Enter the # of Days of Job Transfer or Restriction	Injury	Skin Disorder	Respiratory Condition	Poisoning	Hearing Loss	All other illnesses
			(G)	(H)	(I)	(J)	(K)	(L)	(1)	(2)	(3)	(4)	(5)	(6)
09/23	Warhouse 7	EE hurt lower back lifting a wooden pallet		X			14	11	X					

<u>You can ONLY pick one Case Type!</u>

—What recordable? (Primarily importance is "YOU" knowing what's recordable).

—Plan and simple! ONLY record injuries that go ABOVE a level of first aid and/or those that require prescription drug treatment or OTC (over the counter) drug treatment, prescribed by a physician at a prescription strength. Testing and immunizations DO NOT count as recordable.

—Here is the OSHA Basic Requirement: §1904.7(a) You must consider an injury or illness to meet the general recording criteria, and therefore to be recordable, if it results in any of the following: death, days away from work, restricted work or transfer to another job, medical treatment beyond first aid, or loss of consciousness. You must also consider a case to meet the general recording criteria if it involves a significant injury or illness diagnosed by a physician or other licensed health care professional, even if it does not result in death, days away from work, restricted work or job transfer, medical treatment beyond first aid, or loss of consciousness.

—Size matters - If your company had ten (10) or fewer employees at all times during the last calendar year, you do not need to keep OSHA injury and illness records, unless OSHA or the BLS informs you in writing that you must keep records for a given year for data statistics purposes.

—Remember that the unnecessary recording of a first aid cases on an OSHA log is not being proactive, it is a practice that raises big red flags at OSHA and may generate an inspection visit at your company.

For more information on OSHA recording and reporting, go to this OSHA web page for help. https://www.osha.gov/laws-regs/regulations/standardnumber/1904

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